3.3.1 Number of research papers published per teacher in the Journals notified on UGC CARE list during the last five years

	Title of paper	Name of the author/s	Department of the teacher	Name of journal	Calendar Year of publication	ISSN number	Link to the recognition in UGC enlistment of the Journal /Digital Object			
							Link to website of the Journal	Link to article / paper / abstract of the article	Is it listed in UGC Care list	
1	Analyzing Role of Construction and Demolition Waste in GFRG & EPS Paneling Rapid Walling Technology	"Prajakta Dalal-Kulkarni Dr. Vasudha Gokhale"	M. Arch EA	International Journal of Archhitecture, Engineering and Construction	2019	ISSN 1911-110X [print] and ISSN 1911-1118 [online])	https://ijaec.rpress.co.in/index.php/ijaec	http://dx.doi.org/http://dx.doi.org/10.7492/IJAEC.2019.024	yes	doi error- discontinuied from oct 2023, proof attached when it waslisted in UGC
2	Assessment of Building Envelope material for Embodied Energy to reduce Global Warming and	Kulkarni Sayali, Karve Sujata, Kulkarni Prajakta	M. Arch EA	International Journal of Research and Analytical Reviews	2019	E-ISSN 2348-1269	https://ijrar.org/	http://ijrar.org/viewfull.php?&p_id=IJRAR19J3257	yes	Discontinued , proof attached when it was listed in UGC
3	Analysis of Fire hazard in healthcare Buildings through Media Elicitation	Meera Shirolkar, Vasudha Gokhale	B Arch	Disaster Advances	2020	ISSN: 0974-262X E-ISSN: 2278-4543	https://worldresearchersassociations.com/disaster.aspx	https://worldresearchersassociations.com/Archives/DA/Vol(13)2020/July2020.aspx	yes, CARE list II, scopus	
4	Integral Elements of Residential Liveable Environments: Private Gardens	Aarti Verma, Abhijit Natu	B Arch	International Journal of Archhitecture, Engineering and Construction	2020	"ISSN 1911-110X [print] ISSN 1911-1118 [online]"	https://ijaec.rpress.co.in/index.php/ijaec	http://dx.doi.org/10.7492/IJAEC.2020.005	yes	doi error- discontinuied from oct 2023, proof attached when it was listed in ugc
5	Decision Making Model of Residential Redevelopment: A Multi-Disciplinary Perspective	Vaishali Anagal, Abhijit Natu	B Arch	International Journal of Archhitecture, Engineering and Construction	2020	"iSSN 1911-110X [print] ISSN 1911-1118 [online]"	https://ijaec.rpress.co.in/index.php/ijaec	http://dx.doi.org/10.7492/IJAEC.2020.036	yes	doi error- discontinuied from oct 2023, proof attached when it was listed in ugc
6	Investigation on the Feasibility of Steel Construction Technology for Indian Residential Buildings	Poorva Kulkarni Vasudha Gokhale	B Arch	International Journal of Archhitecture, Engineering and Construction	2020	"iSSN 1911-110X [print] ISSN 1911-1118 [online]"	https://ijaec.rpress.co.in/index.php/ijaec	http://dx.doi.org/10.7492/IJAEC.2020.033	yes	doi error- discontinuied from oct 2023, proof attached when it was listed in ugc
7	Analytical Study of Construction Waste Generation and Management for Residential Building - A Case study of Pune City	Dharati Sote-Wankhade, Vasudha Gokhale	B Arch	"International Journal of Architecture, Engineering and Construction, Vol. 09 (01) "	2020	"iSSN 1911-110X [print] ISSN 1911-1118 [online]"	https://ijaec.rpress.co.in/index.php/ijaec	http://dx.doi.org/http://dx.doi.org/10.7492/IJAEC.2020.009	yes	doi error- discontinuied from oct 2023, proof attached when it was listed in ugc
8	Proposed SMA Tension Sling Damper for Passive Seismic Control of Building	Sujata Mehta, Dr. Sharad Purohit	B Arch	Electronic Journal of Structural Engineering	2020	1443-9255	https://ejsei.com/EJSE/index	https://ejsei.com/EJSE/article/view/235	yes	link not opening
9	Fire Hazards in Healthcare Buildings: Investigating role of Health Care Providers (Vol 8 Issue 29)	Shirolkar Meera , Gokhale Vasudha	B Arch	Shodh Sarita -UGC-CARE	2021	ISSN 2348-2397	http://seresearchfoundation.in/	https://ugccare.unipune.ac.in/Apps1/User/WebA/SearchList	yes	discontinuied from april 2021, after p,aper was published, , proof attached when it was listed in ugc

3.3.1 Number of research papers published per teacher in the Journals notified on UGC CARE list during the last five years

	Title of paper	Name of the author/s	Department of the teacher	Name of journal	Calendar Year of publication	ISSN number	Link to the recognition in UGC enlistment of the Journal /Digital Object			
							Link to website of the Journal	Link to article / paper / abstract of the article	Is it listed in UGC Care list	
10	Passive Seismic Protection of Shear Building Using Shape Memory Alloy-Based Tension Sling Damper	Sujata Mehta, Dr. Sharad Purohit	B. Arch	IUP Journal of Structural Engineering	2021	0974-6528	https://iupindia.in/Structural_Engineering.asp	https://www.iupindia.in/0121/Structural%20Engineering/Passive_Seismic.asp	yes	
11	Seismic response control of modal building using shape memory alloy tension sling damper	Sujata Mehta, Dr. Sharad Purohit	B Arch	International Journal of Structural Engineering, Inderscience publishers, UK	2021	ISSN online 1758-7336 ISSN print 1758-7328	https://www.inderscience.com/jhome.php?jcode=ijstructe	http://dx.doi.org/10.1504/IJSTRUCTE.2022.123749	yes	UGC care II list, science citation index
12	Exploring The Impact And Trajectories Of Commercial Gentrification	Dr. Vasudha Ashutosh Gokhale*Shruti Joshi**Dr. Deepa Joshi ***	B Arch	Shodh Sarita Vol 8 Issue 29 UGC-CARE	2021	2348-2397	http://seresearchfoundation.in/		yes	discontinuied from april 2021, after paper was published ,proof attached when it was listed in ugc
13	Study of perception of parents and their children about	Dhruv Chandwania, Abhijit Natu	B Arch	EARLY CHILD DEVELOPMENT AND CARE	2021	Print ISSN: 0300-4430 Online ISSN: 1476-8275	https://www.tandfonline.com/journals/gecd20	https://doi.org/10.1080/03004430.2021.2004134	yes	
14	Vernacular Building Materials	Pradnya Patki , Neha Joshi	B Arch	Shodh Sarita	2021	ISSN - 2229-3620 Print only	http://seresearchfoundation.in/		yes	
15	Exploration of Interrelationship between Music and Architecture	Dr. Sanjeevani Pendse and Dr Vasudha Gokhale	B Arch	Sangeet Galaxy	2022	e-Journal [ISSN: 2319-9695]	https://sangeetgalaxy.co.in/	https://sangeetgalaxy.co.in/paper/exploration-of-interrelation-between-music-and-architecture/	yes	
16	The Dynamics Of Aesthetical Expression In Music And Architecture	Dr. Sanjeevani Pendse and Dr Vasudha Gokhale	B Arch	Swar Sindhu	2022	ISSN 2320–7175	http://swarsindhu.pratibha-spandan.org	https://swarsindhu.pratibha-spandan.org/wp-content/uploads/v10i01a01.pdf	yes	
17	Legibility a product of obligatory processes in parametric architectural design : A study of implications of associative modeling on design thinking in parametric architectural design	Dhanashree Sardeshpande and Dr Vasudha Gokhale	M.Arch (DA)	International Journal of Architectural Computing	2022	eISSN: 20483988 | ISSN: 14780771	https://journals.sagepub.com/home/JAC	https://doi.org/10.1177/14780771221139911	yes	
18	Examining the relationship between self-reflection and academic achievement in problem-based learning	Chetan Sahasrabudhe	B Arch	Journal of Engineering Education Transformations	2022	Print ISSN: 2349 - 2473 Online ISSN: 2394 - 1707	https://journaleet.in/about	https://dx.doi.org/10.16920/jeet/2022/v36is1/22171	yes	
19	Invesigating Imapct of COVID-19 on Architectural Education from Student's Perspective	Vasudha Gokhale & Madhura Vaze	B Arch	International Journal of Archhitecture, Engineering and Construction	2022	"iSSN 1911-110X [print] ISSN 1911-1118 [online]"	https://ijaec.rpress.co.in/index.php/ijaec	http://dx.doi.org/10.7492/IJAEC.2021.013	yes	

3.3.1 Number of research papers published per teacher in the Journals notified on UGC CARE list during the last five years

	Title of paper	Name of the author/s	Department of the teacher	Name of journal	Calendar Year of publication	ISSN number	Link to the recognition in UGC enlistment of the Journal /Digital Object			
							Link to website of the Journal	Link to article / paper / abstract of the article	Is it listed in UGC Care list	
20	Post Occupancy Evaluation of Indoor Air Quality in Green Rated Commercial Interiors	Karve Sujata, Nachane Rucha	M.Arch (EA)	Current World Environment	2023	0973-4929	http://www.cwejournal.org/	http://dx.doi.org/10.12944/CWE.18.1.27	yes	discontinuied from oct 2023,, proof attached when it was listed in ugc
21	Investigating the Relationship Between Street Design and Urban Vitality Through 'Smart-City Initiative' Case of Pune, Maharashtra, India	Aghera, I. E., and Anagal, V.	B.Arch	ShodhKosh: Journal of Visual and Performing Arts	2023	ISSN (Online): 2582-7472	https://www.granthaalayahpublication.org/Arts-Journal/index.php/ShodhKosh	https://www.granthaalayahpublication.org/Arts-Journal/ShodhKosh/article/view/711/741	yes	Discontinued from July 2023,, proof attached when it was listed in ugc
22	Investigating the Challenges Between Designs to the Reality of Digitally Fabricated Structures	Parange, S. M., and Anagal, Vaishali	B.Arch	ShodhKosh: Journal of Visual and Performing Arts	2023	ISSN (Online): 2582-7473	https://www.granthaalayahpublication.org/Arts-Journal/index.php/ShodhKosh	file:///C:/Users/cheta/Downloads/_10_ShodhKosh_M206.pdf	yes	Discontinued from July 2023,, proof attached when it was listed in ugc
23	Identifying factors shaping architecture of residential redevelopment - application of factor analysis model in architectural research,	Anagal, V., & Natu, A. (2023). 90(2) (2023), 161-188.	B.Arch	Advances and Applications in Statistics	2023	ISSN: 0972-3617	https://pphmjopenaccess.com/index.php/aas	http://dx.doi.org/10.17654/0972361723068	yes	
24	Understanding the Impact and Necessity of Building Information Modelling (BIM) Tools for Efficient Design and Construction	Sathe, M., and Anagal, Vaishali	B.Arch	International Journal of Technology Engineering Arts Mathematics Science, Special Issue 1, August 2023	2023	ISSN: 2583-1224	https://aissmsioitresearch.com/journal-topic/	https://aissmsioitresearch.com/special-issue/	yes	
25	Landslide Vulnerability of Urban slums:Case of Warje Slum, Pune, Maharashtra	Gokhale Vasudha1* and Joshi Deepa2	B. Arch	Disaster Advances	2023	ISSN: 0974-262X E-ISSN: 2278-4543	https://www.scopus.com/sourceid/19700175287	https://doi.org/10.25303/1603da044051	yes	
26	Women's contested mobility and equity in Indian urban environment: case of public toilets in Pune,Maharashtra	Vasudha A. Gokhale, Deepa Joshi & Anjali Acharya	b Arch	Cities and Health	2023	ISSN 2374-8834	https://www.tandfonline.com/action/doSearch?target=default&ContribRaw=Gokhale,%20Vasudha%20A	https://www.tandfonline.com/journals/rcah20	yes	

2018-19	2
2019-20	6
2020-21	6
2021-22	5
2022-23	7
Total	**26**

ugccare.unipune.ac.in/Apps1/User/WebA/SearchList

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**International Journal of Architecture, Engineering and Construction**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	Action
1	International Journal of Architecture, Engineering and Construction	International Association for Sustainable Development and Management	1911-110X	1911-1118	View

Showing 1 to 1 of 1 entries

Previous 1 Next

International Journal of
Architecture, Engineering and Construction

HOME | ABOUT | LOG IN | REGISTER | NEWS AND EVENTS | SEARCH | CURRENT ISSUE | ALL ISSUES | AEC FORUM

Home > **International Journal of Architecture, Engineering and Construction**

International Journal of Architecture, Engineering and Construction (ISSN 1911-110X [print] and ISSN 1911-1118 [online]), IJAEC, is published by the International Association for Sustainable Development and Management (IASDM) and North China University of Water Resources and Electric Power. IJAEC is a scholarly peer-refereed journal that promotes scientific, technical and managerial advances in the three intertwined disciplines of the built environment: Architecture, Engineering and Construction. IJAEC publishes original research papers, state-of-the-art review papers, novel industrial applications and insightful case studies in a broad scope of topics related to the three disciplines.

IJAEC also provides an AEC Forum, an interactive platform for international business organizations, public agencies, civil societies and academia to disseminate and exchange information, and to discuss on various issues in architecture, engineering and construction. Bookmark this Page

Editor-in-Chief
Xueqing Zhang, PhD, *Hong Kong University of Science and Technology, HKSAR, China*

Honorary Editor
Hojjat Adeli, PhD, *Ohio State University, United States of America*

Editor for Architecture
Ewelina Wozniak-Szpakiewicz, PhD, *Cracow University of Technology, Poland*

Editor for Engineering
Shunbo Zhao, PhD, *North China University of Water Resources and Electric Power, China*

Editor for Construction
Onishi Masamitsu, PhD, *Kyoto University, Japan*

USER

Username

Password

Remember me

Log In

JOURNAL INFO

- Editorial Board
- Editorial Office
- Production and Distribution
- Contact Us

BEST PAPER AWARD

- Best Paper Award

THEMATIC ISSUES

- Call for Thematic Issues

READERS

- Make a Search
- View Contents
- Recommend to a Friend/Library

AUTHORS

- Submit an Article
- Guide for Authors
- Ethical Guidelines
- Copyright Transfer Agreement

International Journal of
Architecture, Engineering and Construction

Vol 8, No 4 (2019)

Table of Contents

Research Paper

International Journal of Architecture, Engineering and Construction
Vol 8, No 4, December 2019, 13-22

Analyzing Role of Construction and Demolition Waste in GFRG & EPS Paneling Rapid Walling Technology

Prajakta Dalal-Kulkarni*, Tania Gour and Vasudha Gokhale

MKSSS's Dr. B. N. College of Architecture, SPP University, Pune, India

Abstract: India construction sector contribute to the generation of a huge amount of construction and demolition (C&D) waste where its inadequate management is creating an environmental hazard. The use of recycled, instead of virgin materials in construction is aimed to ease landfill pressures as well as to reduce demand of extraction of natural resources. In such application is it important to ensure that the material produced with the use of recycled material should be able to meet prescribed technical specifications as well as it must be environment friendly and cost effective. This research examines physical and environmental performance of GFRG & EPS panels made with recycled construction waste. The physical parameters that included compressive strength, density, water absorption, fire resistance, and thermal conductivity were tested in an experimental setup. The test samples were made with various concrete mixes, where a part of the aggregates was substituted by different proportion of recycled material. Environmental indicators included embodied energy (EE) and greenhouse gas (GHG) emissions which were tested for a residential unit which was modelled using Revit software. As per test results partial incorporation of C&D waste in GFRG and EPS panels was found satisfactory in terms of physical strength as well as it showed a reduction in cost, EE and GHG emissions. The optimum limit of incorporation of C&D waste in GFRG and EPS panels was found to be 25-30%. This study provided the optimum proportion for replacement of virgin material in GFRG and EPS panels which will help in production of such panel having desirable structural and environmental performance. The study stressed the large scale reuse of C&D waste as it is cost effective and helps Indian building industry to achieve the recycling goals, conserve natural resources, preserve valuable landfill space and protect the environment as a whole.

Keywords: Constructions and demolition waste, rapid walling technologies, embodied energy, GHG emissions, mass housing

DOI: http://dx.doi.org/10.7492/IJAEC.2019.024

1 INTRODUCTION

Large scale building activities are coupled with the generation of walloping amount of construction and demolition (C&D) waste have an adverse effect on the environment in the form of Pollution which can be severe and long term (Mah et al. 2018). Management of waste on construction sites is very important because of construction waste's negative effect as it has been considered to be a major source of environmental pollution and result in land depletion and deterioration, energy consumption, noise pollution, and dust and gas emission (Dajadian and Koch 2014). Given the contribution of C&D waste in environmental deterioration, it is becoming a critical issue in urban solid waste management (Gayakwad and Sasane 2015).

Construction is an essential part of any country's infrastructure and industrial development. There are mainly three segments in the construction industry viz infrastructure, industrial and real estate sector. The Indian construction sector is expecting a huge growth particularly in the real estate sector which includes residential and commercial construction. In India more than 377 million people are living in 7,935 towns/cities which is about 31.2% total population of the country (Joshi and Ahmed 2016) And It is estimated that 700–900 million square meters of space will be built every year in India up to 2030 under residential and commercial sector, which is almost equal to Chicago city (Ellen MacArthur Foundation 2016). The gargantuan growth in the residential sector experienced in last few decades is encouraged by the Govt. of India's various initiatives such as "Smart Cities", Housing for all, and Pradhan Mantri Awas Yojana (PMAY) (Dmg Events India 2015). The increase in construction and redevelopment projects across India and the consequent generation of a huge amount of C&D waste is adversely affecting the environment. Union Ministry of Urban Development (MoUD) states that 12–14.7 metric ton (MT) of C&D waste production annually is estimated in India (Gupta and Rk 2018). It has been found that most of the C&D waste is dumped illegally into common open areas or landfills posing threat to the environment in terms of air, water and land pollution (Dajadian and Koch 2014; Bansal et al. 2016). The research established the main constituent of C& D waste are concrete and masonry (Gayak-

*Corresponding author. Email: ar.prajaktad@gmail.com

wad and Sasane 2015). The construction industry despite being one of the major generators of waste have not yet followed environmentally friendly practices for waste management in India and landfill is followed as a convenient and cost-effective solution (Kaliannan et al. 2018). To reduce C&D waste generation It is important to follow waste management strategies at various stages of project from planning to completion (Chanki and Pitroda 2018). Integrated solid waste management (ISWM) follows a three-tiered approach referred as the 3R approach aimed at optimizing the management of solid waste (CPHEEO-Part I 2016). The 3R here refers to reduce, reuse, and recycle, which are waste management strategies for maximum possible utilization of waste before it is sent to disposal (Miranda et al. 2017; Ng et al. 2018). It has been stated that the environmental impact of recycling is less than the impact of traditional waste disposal methods like land filling in addition to economic benefits (Samiha 2013; Ferronato and Torretta 2019).

2 IMPACT OF C&D WASTE ON ENVIRONMENT

Though C&D waste emissions are considered short term it is observed that they are consistent source throughout the year contributing about Particulate matter (PM) 10 and PM 2.5 emissions which are dangerous for human health. The research established that 56% of PM 10 and 38% of PM 2.5 emissions are generated because of road dust from C&D waste and found to be the most important source of pollution in urban areas (Sharma and Dikshit 2016; Bhandari and Mehra 2017; Gupta and Rk 2018). Haphazardly disposed of C&D waste contributes to water pollution as the mixing of C&D waste with water sources increases the concentration of iron, manganese, hardness, alkalinity, conductivity, and chemical oxygen demand. Unlined landfills result in leachate which may result in the contamination of groundwater (Ponnada and P 2015; Kumar et al. 2017). Chemicals such as paints, solvents, oils, etc. which become part of C&D waste can cause land and water pollution (Gupta and Rk 2018). Thus it is utmost important to focus on the issue of C&D waste & its handling as far as climate change mitigation measures and commitment towards sustainable development goals is concerned (BMTPC 2018).

3 CONSTRUCTION AND DEMOLITION WASTE SCENARIO IN INDIA

"Construction and demolition waste includes all the materials that are generated as a waste either during the construction or repair or re-modelling or demolition (including deconstruction and decommissioning) of any civil structure" (BMTPC 2018). The main composition of C&D waste in India consists of Cement concrete, bricks, and sand & gravel (IL&FS Ecosmart Limited 2013; Mullick 2015; BMTPC 2018). New construction and renovation activities generate 40–50 kN/m^2 of C&D waste approximately however in destruction activities the amount of waste generated is much higher ranging between 300 to 500 kg/m^2 (CPCB 2017; Ministry of Housing and Urban Affairs 2018). Though there is no organized database available on C&D waste generation in India; It is roughly estimated that around 100 million tons of C&D waste is generated annually in the country (BMTPC 2018; Gupta and Rk 2018). A very small part of this generated C&D waste is recycled and reused while remaining C&D waste end up in the landfills which is an area of concern. A common practice of dumping of C&D waste illegally along the roads, into municipal bins, open lands, water bodies, swamplands, rivers, etc. is observed in India which reduces the opportunity of recycling and reuse of this waste (Gupta and Rk 2018; Ministry of Housing and Urban Affairs 2018). Research states that reuse of waste can also be economically beneficial (Agarwal et al. 2015).

Realizing the importance of C&D waste handling issue various initiatives has been taken up by the government of India and state governments. These include C&D Waste Management Rules-2016 to promote utilization of C&D waste & products (CPCB 2017), MoUD's notification on June 28, 2012, to Establish C&D waste recycling plants in cities more than one million population, Swachh Bharat Mission (Ministry of Housing and Urban Affairs 2017), incorporation of codes regarding use of recycled material such as IS:383 by Bureau of Indian Standards (BIS) (PWD 2018) and Inclusion of guidelines for reuse of recycled aggregate in construction in National Building Code (NBC) of India 2005: Part 11.

4 THE INDIAN CONSTRUCTION INDUSTRY AS A GROWTH DRIVER FOR C&D WASTE

The Indian construction sector is the second largest industry in terms of scale after agriculture which contributes 7.74 percent to the GDP (BMTPC 2018). Population growth, increased urbanization, and industrialization have made construction industry to boost remarkably in India. It is estimated that the urban areas in India will experience huge growth by 404 million people between 2014–2050. As a result vast demand for buildings is expected to be generated. As per KPMG's report, an increase in housing requirement in India is at the rate of 2.5–3 million homes per annum (KPMG 2017). In 2012 the total housing shortage in India was 68.53 million units. Due to this housing shortage, there is a huge demand for construction material and mainly for the affordable housing sector in India (Bocquier 2014; Seminarsonly 2017). As per Mckinsey's report, during the 2005-2030 building construction sector in India will be growing at a rate of 6.6% per annum (McKinsey & Company 2009).

Understanding the need for affordable housing government of India announced the agenda of "Housing for all by 2022". PMAY was launched in 2015 under Urban Housing Mission which will fulfil over 20 million urban housing requirement by 2022 (KPMG 2017). Under this scheme the construction of 157,100 residential units are completed in the year 2017 while 2.4 million housing units are approved to be built under affordable housing category. To fulfil "Housing for all by 2022" mission Indian government has allotted INR 0.23 trillion to PMAY in the union budget of 2017-2018 (KPMG 2017).

The above statistics demonstrate enormous growth in the Indian construction sector which will lead to a huge demand for construction materials. It is projected that with a large number of construction activities the Indian construction sector is likely to face scarcity of natural resources like aggregates and river sand. It has been projected that there will be 55,000 million m^3 shortage of aggregates in housing sector while 750 million m^3 in infrastructure sector (Vasam et al. 2018). Further, It is estimated that in new construction nearly 15% of construction material end up as a waste during construction process thus adding to the amount of C&D waste generated in the country annually in huge quantity (Lee et al. 2013). This phenomenon indicated to recycle waste material and use it in construction activities in order to bridge the gap of material demand and supply and reduce the load on virgin materials.

5 ALTERNATIVE BUILDING TECHNOLOGY

Realizing rising demand of housing sector and need of faster, reliable and eco-friendly construction technologies to fulfil this demand, government of India initiated use of alternate building technologies which are functionally and environmentally sound (BMTPC 2017). Building Material and Technology Promotion Council (BMTPC) suggested various alternative building technologies which are rapid, affordable and green to meet Housing for all targets. Rapid construction, simple-easy to adopt technology and sustainability are the main benefits of these alternative technologies (Madala et al. 2019). The main barrier realized was cost of these alternate technologies. But researches proved that if constructed at a larger scale the cost is comparable with conventional construction cost. These technologies additionally prove advantageous over conventional construction techniques on various parameters like low maintenance, durability, thermal performance, acoustical properties, hazard resistance, low waste generation, low embodied energy and life cycle cost, etc. The provision of incorporation of alternate technologies for faster construction is also updated in recently published National Building Code 2016 under various sections like Part-5 Building Materials; Part-6 Structural Design: Section 7 Prefabrication and Systems Building and Mixed/Composite Construction, 7A Prefabricated Concrete, 7B Systems Building and Mixed/Composite Construction; and Part-7 Construction Management, Practices And Safety (BMTPC 2017).

Following are the examples of alternative technologies suggested by BMTPC for mass housing (BMTPC 2016):

1. Technology Profile of Monolithic Concrete Construction System using plastic Aluminium Formwork
2. Technology Profile of Monolithic Concrete Construction System using Aluminium Formwork
3. Technology Profile of Expanded Polystyrene (EPS) Core Panel System
4. Technology Profile of Industrialized 3-S System using Cellular Lightweight Concrete Slabs & Precast Columns
5. Factory-made Fast Track modular Building System-Instacon
6. Glass Fibre Reinforced Gypsum Panel System (GFRG)
7. Formwork for Monolithic Construction.
8. Advanced Building System-Emmedue

In the present research potential of using recycled material is examined in Glass Fiber Reinforced Gypsum Panel System (GFRG) and Expanded Polystyrene Core Panel System (EPS) technology both of which are currently in larger use for mass housing schemes in India. It is aimed to find the extent of utilization of C&D waste in GFRG and EPS panel in order to promote large scale use of recycled material which is recognized as one of the most promising strategies of sustainable waste management.

6 METHODOLOGY

As stated earlier, the study focuses on GFRG & EPS panel technologies mentioned under PMAY as suggested construction technologies for affordable mass housing. These two technologies are examined for physical, environmental and economic aspects. The methodology adopted for examining physical and environmental aspects is graphically presented in the following Figure 1 and discussed in detailed in the following section 7.

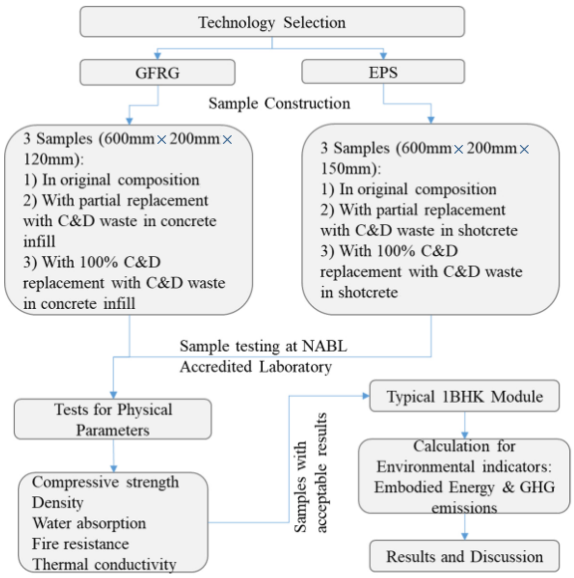


Figure 1. Methodology of the study

7 PREPARATION OF SAMPLES

In the first step sample of panels were prepared using GFRG & EPS in their original composition. This is followed by preparation of the second sample replacing concrete based component in both GFRG and EPS panel partially with C&D waste where the recycled material used is recycled aggregate and sand. The third sample is prepared by replacing concrete based component in GFRG and EPS panel with 100% recycled material.

For partial replacement 25–30% materials is replaced which is the range prescribed for structural members for replacement of secondary materials with natural building materials in IS:383 code.

It is found important to analyze the physical properties of the material as the performance of material depends on its physical properties which are to be optimized to reduce material's environmental impact. The physical properties of the samples were tested in the laboratory having National Accreditation Board for Testing and Calibration Laboratories (NABL) accreditation. The strength and performance of the samples were tested for physical parameters that included compressive strength, density, water absorption, fire resistance, and thermal conductivity. The samples having acceptable results under Physical parameter tests were further tested for environmental indicators such as embodied energy (EE) and greenhouse gas (GHG) emissions.

The EE and GHG emissions were selected as environmental indicators; the reason being both EE and GHG emissions due to construction operations are a large contributor to annual global emissions. They are estimated at 5% to 10% of the entire energy consumption in developed countries and 10% to 30% in developing countries (Olivier et al. 2016). Use of recycled secondary materials is found one of the suitable mitigation options for the construction sector aimed at the reduction of GHG emissions.

A typical 1 BHK residential module comprising of a living room, one-bed room, and a kitchen was used to analyze the impact of environmental indicators of GFRG and EPS samples is shown in Figure 2. The unit was modelled using Revit software as it can generate material quantities and 3 dimensional (3D) view of the structure. GFRG and EPS panels were applied as a walling material for a unit alternately and EE and GHG emissions were calculated for walling material for both. The calculations for EE and GHG emissions were performed based on the material quantities obtained from the software and EE and global warming potential baseline values obtained from the India Construction Materials Database developed by International finance corporation (IFC) (IFC 2017).

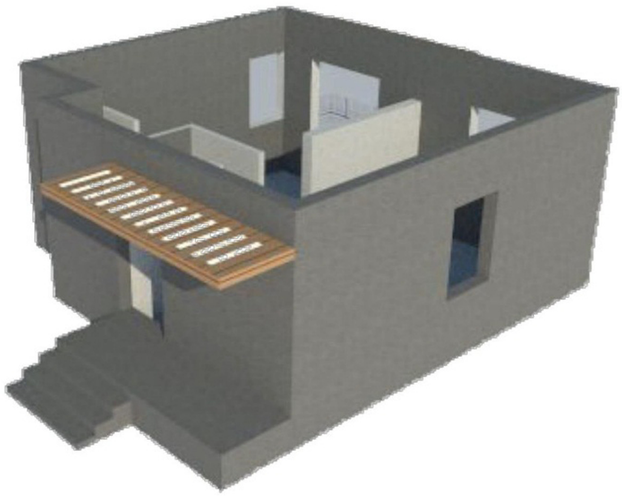


Figure 2. Typical 1 BHK module used to analyze the impact of environmental indicators

The GFRG and EPS panel quantity required for 1 BHK module:

1. GFRG Panel:

   Total wall area of 1 BHK = 117.45 m^2

   Panel size of GFRG = 12 m × 3 m × 0.124 m

   Total no. of panels = 3.5

2. EPS Panel:

   Total wall area of 1 BHK = 117.45 m^2

   Panel size of EPS = 1.2 m × 3 m × 0.150 m

   Total no. of panels = 33

8 GLASS FIBRE REINFORCED GYPSUM PANEL SYSTEM (GFRG)

GFRG Panel is a building panel product made-up of calcined gypsum plaster, reinforced with glass fibers and concrete infill. These panels are normally manufactured to a thickness of 124mm under controlled conditions to a length of 12 m and height of 3m. These panels contain cavities that may be unfilled, partially filled or fully filled with reinforced concrete as per structural requirement. Research established that GFRG panel can also be used as in-fills (non-load bearing walls) in combination with RCC framed columns and beams (conventional framed construction) where there is no any restriction on a number of stories (IIT Madras and BMTPC 2012).

8.1 Physical Parameters Test

Three samples of GFRG Panels measuring 600mm × 200mm × 120mm were prepared for laboratory testing. The panel composition considered for the study purpose is mentioned in the Figure 3.

The panels were tested for uni-axial Compressive strength; Density, Fire Resistance and Thermal Conductivity. The result of the tests are presented in Table 1.

The Uni-axial Compressive strength of the panel with partial replacement was found 161 kN/m^2 which is adequate while in panel with full replacement it was found less than the required value. Density remained constant in case of panel with partial replacement while it was substantially reduced in the panel made out of 100% recycled material. Water absorption was found satisfactory in both the samples while fire resistance was found less in case of panel with 100% replacement of virgin material. The overall results indicated the suitability of panel made with partial replacement of virgin material while panel made with full replacement was found deficient to satisfy the physical characteristics as per prescribed standards.

8.2 Environmental Indicators: Embodied Energy and GHG Emissions

EE and GHG emissions of the residential unit are calculated for GFRG panel wall with original composition and with partial replacement (70:30 ratio) of recycled material. The detailed calculations are mentioned in Table 2. A sample with 100% replacement of recycled raw materials does not fulfil all required physical parameters, thus it was not considered for environmental indicator calculations. EE and GHG emissions calculated for both the GFRG core panel samples based on India Construction Materials Database by IFC (IFC 2017) as shown in Table 2.

The results for EE & GHG emission comparison for GFRG panel wall with original composition and with partial replacement (70:30 ratio) of recycled material are shown in Figures 4 and 5 respectively. The results indicated 24.64% reduction in EE and 14.98% reduction in GHG emissions of coarse aggregate when natural aggregate was replaced with recycled aggregate. In case of fine aggregate 23.32% reduction in EE and 19.99% reduction in GHG emissions observed. However for the total quantity of concrete infill comparatively less reduction in both EE and GHG emissions i.e. 2.16% and 0.63%

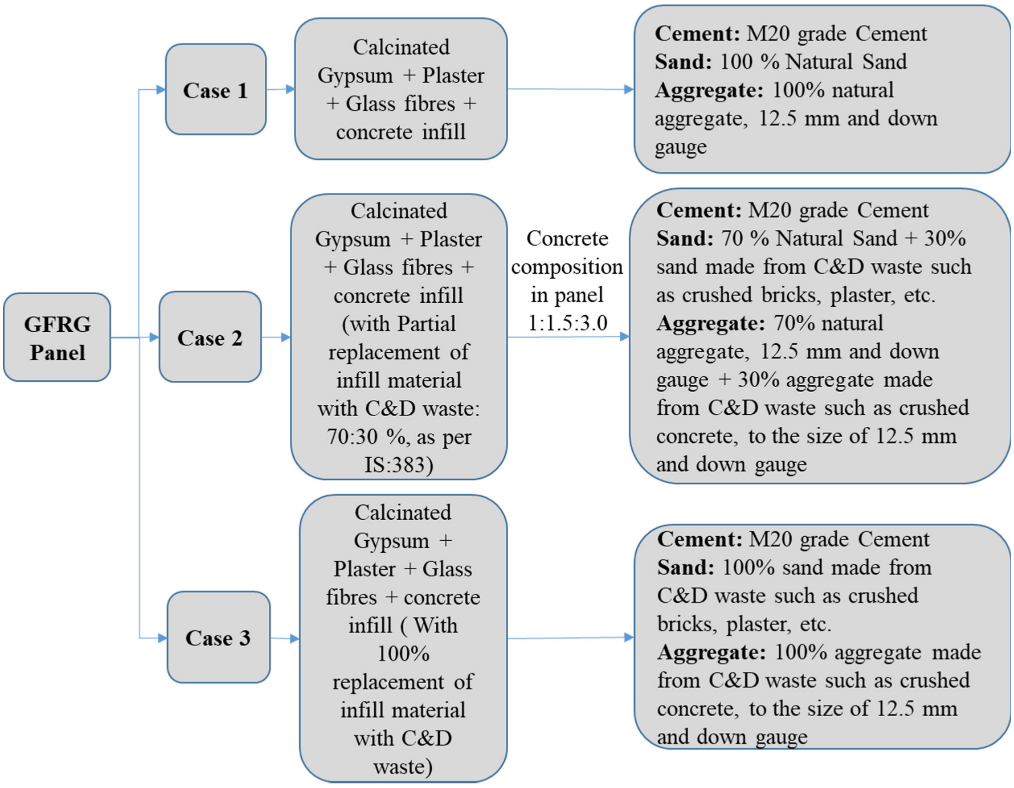


Figure 3. Details of GFRG panel samples with different concrete compositions

Table 1. GFRG panel properties

Physical properties	Permissible values as per BMTPC	Properties after partial (70:30) replacement of recycled C&D waste as per IS code	Properties after full (100%) replacement of recycled C&D waste
Uni-axial compressive strength	160 kN/m^2 (Minimum)	165 kN/m^2	126 kN/m^2
Density	2550 kg/m^3 (minimum As per IFC material database)	2550 kg/m^3	2400 kg/m^3
Water absorption	Maximum 5% by weight after immersion in water for one day	3.8% by weight after immersion in water for one day	4.5% by weight after immersion in water for one day
Fire resistance	4 hour rating withstood 700-1000°C	4 hour rating withstood 900°C	4 hour rating withstood 450°C
Thermal conductivity	0.617 W/m·K (As per IS 3346:1980)	0.597 W/m·K	0.62 W/m·K

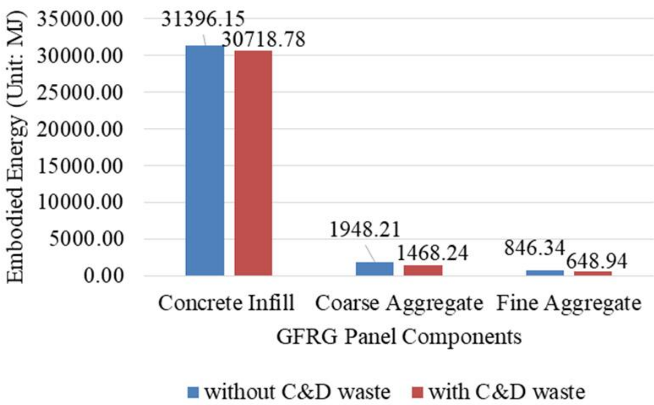


Figure 4. Embodied energy (EE) for GFRG panel

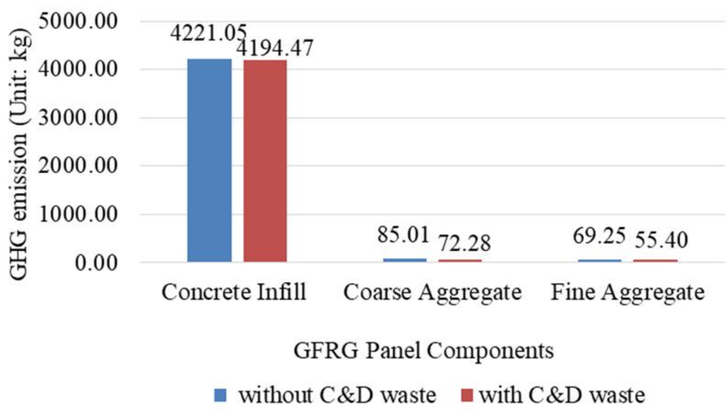


Figure 5. GHG emissions for GFRG panel

Table 2. Embodied energy and GHG emission calculation for GFRG panel samples

	Material	Quantity (m^3)	Quantity (kg)	Embodied energy (MJ/kg)	GHG emissions (kg CO_2eq/kg)	Embodied energy (MJ)	GHG emissions (kg)
GFRG panel (Original composition)							
GFRG	4.46		5088.96	3.3	2.9	16793.57	14757.98
Concrete infill	Cement	3.10	4469	6.4	0.91	28601.60	4066.79
	Coarse aggregate	9.32	17711	0.11	0.0048	1948.21	85.01
	Fine aggregate	5.12	7694	0.11	0.009	846.34	69.25
	Total for (Concrete infill)					31396.15	4221.05
	Total					48189.72	18979.03
GFRG panel (with 70:30 C&D waste incorporation)							
GFRG	4.46		5088.96	3.3	2.9000	16793.57	14757.98
Concrete infill	Cement	3.1	4469	6.4	0.9100	28601.60	4066.79
	Coarse aggregate (70% natural)	6.52	12388.00	0.11	0.0048	1362.68	59.46
	Coarse aggregate (30% recycled)	2.82	3770.00	0.03	0.0034	105.56	12.82
	Fine aggregate (70% natural)	3.58	5370.00	0.11	0.0090	590.70	48.33
	Fine aggregate (30% recycled)	1.53	2080.00	0.03	0.0034	58.24	7.07
	Total (for concrete infill with C & D waste)					30718.78	4194.47
	Total					47512.35	18952.46

was observed. The results for the entire GFRG panel shows 1.40% reduction in overall EE and 0.14% reduction in overall GHG emissions of GFRG panel after incorporating C&D waste.

9 EXPANDED POLYSTYRENE CORE PANEL SYSTEM (EPS)

EPS panel consists of expanded polystyrene sheet of minimum 60mm thick sandwiched between 3D welded wire space frames made of high strength galvanized wire. These Panels are finished using minimum of 30 mm thick Shotcrete on-site (CBRI 2017).

9.1 Physical Parameters Test

For the laboratory testing purpose, three samples of GFRG Panels measuring 600 mm × 200 mm × 150 mm were prepared. The panel composition considered for the study purpose is mentioned in Figure 6.

The panels were tested for Compressive strength; Density, Fire Resistance and Thermal Conductivity. The results of the test indicating EPS panel Properties after performing experiments in laboratory are presented in Table 3.

The physical parameters density, fire resistance and thermal conductivity of EPS panel with partial (25%) replacement of C&D waste were observed within acceptable limits while water absorption was found slightly more. However for sample with 100% replacement of recycled raw materials the physical parameters density and thermal conductivity was found not in accordance with desired values marginally while for fire resistance and water absorption the difference between values obtained with the prescribed ones was substantial.

9.2 Environmental Indicators: Embodied Energy and GHG Emissions

EE and GHG emissions of the residential unit are calculated for EPS panel wall with original composition and with partial replacement (75:25 ratio) of recycled material, refer Table 4. As sample with 100% replacement of recycled raw materials does not fulfil all required physical parameters, it was not considered for environmental indicator calculations.

The EE & GHG emission for EPS panel wall with original composition and with partial replacement (75:25 ratio) of recycled material are compared. Effect on EE emissions are shown in Figure 7. The results indicated reduction in EE emissions by 20.62% in case of coarse aggregate 19.43% in case of fine Aggregate While it was just 1.5% for shotcrete. Reduction in GHG emissions was found slightly less as compared to EE emissions as shown in Figure 8. It has been found that GHG emissions were reduced by 12.65% in case of coarse aggregate, by 16.66% in case of fine Aggregate while for shotcrete it was observed reduced by 0.75%. The results for the entire EPS panel walling shows 0.95% Reduction in EE and 0.43% reduction in overall GHG emissions after incorporating C&D waste.

10 ECONOMIC PARAMETER: COMPARISON AND ANALYSIS

Considering the financial feasibility as one of the important aspects that affect use of any technology and material the two materials are further analyzed in terms of cost. Comparison of cost for two different walling materials (GFRG and EPS) with and without incorporation of recycled materials has been done for the residential unit under investigation. The result of comparative analysis is shown in Figure 9.

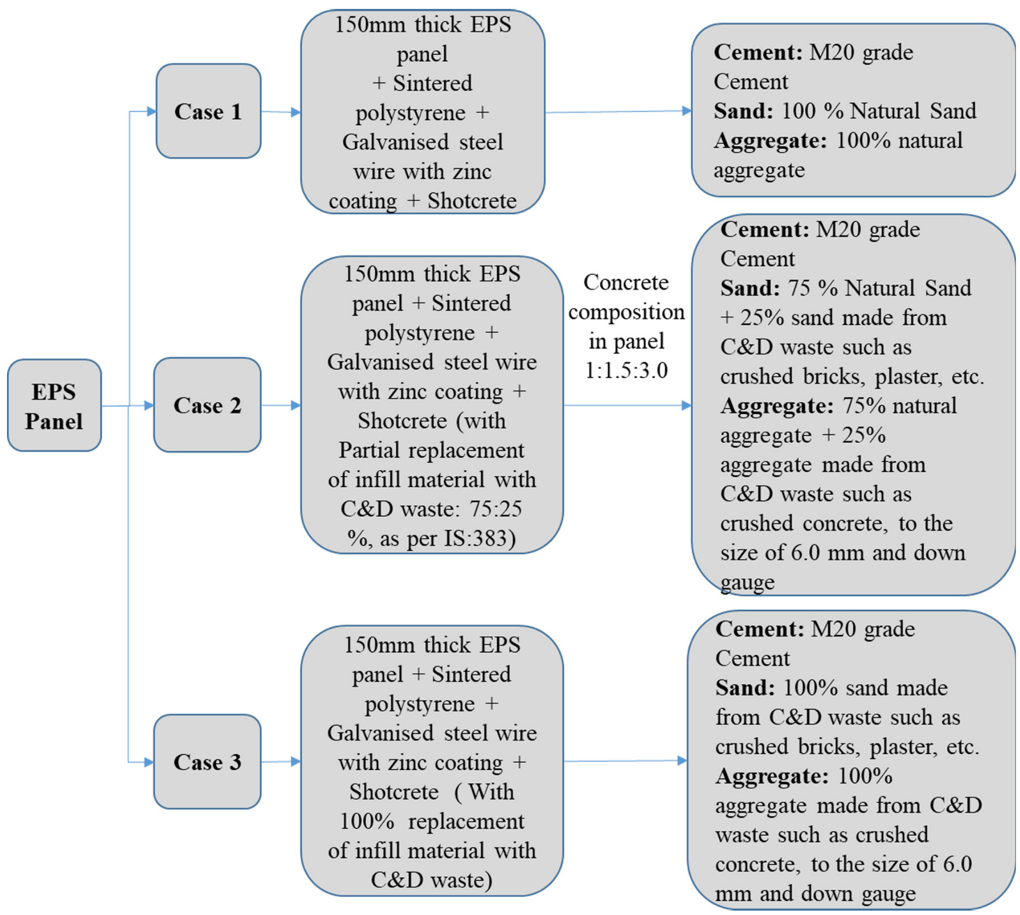


Figure 6. Details of EPS panel samples with different concrete compositions

Table 3. EPS panel properties

Physical properties	Permissible values as per BMTPC	Properties after partial (70:30) replacement of recycled C&D waste as per IS code	Properties after full (100%) replacement of recycled C&D waste
Compressive strength	20 MPa (Minimum)	20.4 MPa	16.8 MPa
Density	20 kg/m^3 (Minimum As per IFC material database)	20 kg/m^3	21 kg/m^3
Water absorption	Maximum 2.3% after immersion in water for 7 days	2.4% after immersion in water for 7 days	4.2% after immersion in water for 7 days
Fire resistance	With 40 mm of shotcrete applied to both sides, can withstand the temp. of upto 163°C (Minimum)	165°C	108°C
Thermal conductivity	0.34 W/m·K	0.32 W/m·K	0.34 W/m·K

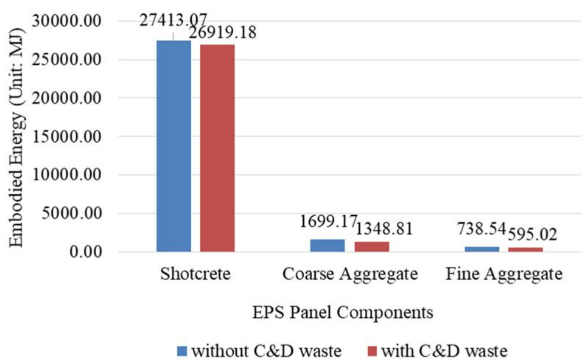


Figure 7. Embodied energy (EE) for EPS panel

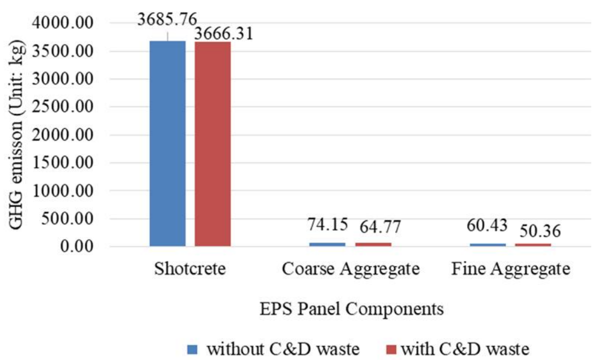


Figure 8. GHG emissions for EPS panel

Table 4. Embodied energy and GHG emission calculation for EPS panel samples

Material		Quantity (m^3)	Quantity (kg)	Embodied energy (MJ/kg)	GHG emissions (kg CO_2eq/kg)	Total embodied energy (MJ)	Total GHG (kg)
EPS panel (Original composition)							
EPS		8.31	291.06	85.0	2.9	24740.10	844.07
Steel			348.00	30.0	2.6	10440.00	904.80
Shotcrete (40mm both sides)	Cement	2.71	3902.40	6.4	0.91	24975.36	3551.18
	Coarse aggregate	8.13	15447.00	0.11	0.0048	1699.17	74.15
	Fine aggregate	4.47	6714.00	0.11	0.009	738.54	60.43
Total for (shotcrete)						27413.07	3685.76
Total						52153.17	4529.83
EPS panel (with 75:25 C&D waste incorporation)							
EPS		8.31	291.06	85.0	2.9	24740.10	844.07
Steel			348.00	30.0	2.6	10440.00	904.80
Shotcrete (40mm both sides)	Cement	2.71	3902.40	6.4	0.91	24975.36	3551.18
	Coarse aggregate (75% Natural)	6.09	11571.00	0.1100	0.0048	1272.81	55.54
	Coarse aggregate (25% recycled)	2.03	2714.11	0.0280	0.0034	76.00	9.23
	Fine aggregate (75% Natural)	3.35	5025.00	0.1100	0.0090	552.75	45.23
	Fine aggregate (25% recycled)	1.11	1509.60	0.0280	0.0034	42.27	5.13
Total (for shotcrete with C & D waste)						26919.18	3666.31
Total						51659.28	4510.38

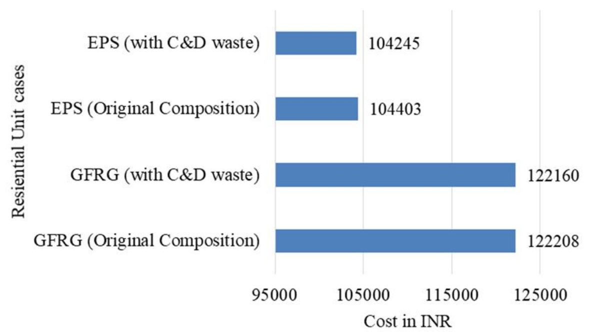


Figure 9. Residential unit cost for GFRG & EPS panels with & without C&D waste

It has been found that cost of GFRG panel was reduced by 48.0 INR/m^2 while substantial reduction of 158.0 INR/m^2 was observed in EPS panel with incorporation of C&D waste.

11 RESULTS

The physical parameter test results demonstrated that 100% replacement of recycled raw materials in GFRG and EPS panels result in lesser density and fire resistance which is not found suitable for construction of residential units. The optimum limit of incorporation of C&D waste in GFRG and EPS panels was found to be 25–30%. The research established that GFRG panels which are filled with concrete possess required strength for its use as a load-bearing structural element. The panels were found structurally strong for the construction of a shear wall which is capable of resisting lateral loads imposed due to earthquake and wind. Marginal savings in EE and GHG emissions were observed after incorporation of C&D waste in both GFRG and EPS panels. The cost reduction observed in the construction of 1 BHK module using GFRG and EPS panels with C&D waste incorporation was 0.50 INR/m^2 and 1.35 INR/m^2 respectively. Though nominal savings in cost, EE and GHG emissions are obtained for 1 BHK module constructed using GFRG and EPS panels with C&D waste, when scaled up for multiple housing units under mass housing scheme the quantum of savings achieved will be huge.

12 CONCLUSION

Ever-growing constructional activities and subsequent generation of waste are envisaged as a potential environmental threat. Recycling of constructional waste is established as one of the best options to check the disposal of materials in landfills. This study addresses the issue of C&D waste generation and establishes its reuse as a beneficial solution. In this research, the physical properties, embodied energy and GHG emissions of GFRG and EPS panels were compared with GFRG and EPS panels produced using C&D waste. The results were examined for possibility of C&D waste reuse in these panels.

As per results obtained the panel with 30% use of recycled material satisfied the prescribed requirements for physical parameters uni-axial compressive strength, density, water absorption, fire resistance and thermal conductivity. The study confirmed that 25–30% C&D waste can be successfully incorporated in the concrete component of GFRG and EPS panel which will also provide environmental benefits like significant reduction in embodied energy of materials, GHG emissions and low construction cost if used at a larger scale like multiple housing units under mass housing scheme. Considering the failure of panels made with 100% recycled materials in light of structural requirements as per test results it has been suggested that the use of recycled material should not be more than 30%.

Given the requirement of 26.5 million affordable housing units in India, Government of India is promoting use of alternative rapid construction technologies GFRG and EPS panel technology is one of them. The GFRG & EPS walling technologies are already established as rapid, structurally sound and economically viable technologies. It has been established that this technology could be successfully used with the use of recycled constructional waste without adversely affecting structural performance as well is it is proved to be cost effective. This work presented a viable technology in the context of construction material recycling which is supposed to provide a useful reference for future applications. The results obtained will encourage the use of recycled material in construction. This research recommend and emphasizes the use of C&D waste in such technologies to achieve additional economic and environmental advantages to the society as it will not only help in reducing Embodied energy, carbon emissions and cost of construction but also save landfill space which itself will conserve the environment.

REFERENCES

Agarwal, R., Chaudhary, M., and Singh, J. (2015). Waste management initiatives in India for human well-being. *European Scientific Journal*, 7881,1857–7881.

Bansal, A., Mishra, G., and Bishnoi, S. (2016). Recycling and reuse of construction and demolition waste for sustainable development. *7th International Conference on Sustainable Build Environment 2016*, Kandy, Srilanka.

Bhandari, L., and Mehra, C.S. (2017). *Fixing Delhi's Pollution*. Indicus Foundation, New Delhi, India.

BMTPC (2016). *Compendium of Green Technologies in Mass Housing Projects for "Composite" Climatic Zones of India-Covering Regions of Punjab, Haryana, Delhi-NCR*. Building Materials & Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation Government of India, New Delhi, India.

BMTPC (2017). *Compendium Technologies for Mass Housing Emerging Technologies*. Building Materials & Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation Government of India, New Delhi, India.

BMTPC (2018). *Utilization of Recycled Produce of Construction & Demolition Waste A Ready Reckoner*. Building Materials & Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation Government of India, New Delhi, India.

Bocquier, P. (2014). *World Urbanization Prospects: The 2014 Revision, Highlights*. United Nations, Department of Economic and Social Affairs, Population Division, New York, United States. https://doi.org/10.4054/DemRes.2005.12.9.

CBRI (2017). *Manual for Expanded Polystyrene (EPS) Core Panel System and Its Field Application*. Central Building Research Institute, Roorki, India.

CPCB (2017). *Guidelines on Environmental Management of Construction & Demolition (C & D) Wastes*. Central Pollution Control Board, New Delhi, India.

Chanki, N.M., and Pitroda, J. (2018). A critical literature review on construction waste management. *International Journal of Advance Engineering and Research Development*, 5(3), 434–439.

CPCB (2017). *Guidelines on Environmental Management of C&D Waste Management in India (CPCB's Draft February 2017)*. Central Pollution Control Board, New Delhi, India.

CPHEEO-Part I (2016). *Swachh Bharat Mission-Municipal Solid Waste Management Manual Part I: An Overview*. Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, New Delhi, India.

Dajadian, S., and Koch, D.C. (2014). Waste management models and their applications on construction sites. *International Journal of Construction Engineering & Management*, 3(3), 91–98. https://doi.org/10.5923/j.ijcem.20140303.02.

Dmg Events India (2015). *Construction Market in India*. Dmg Events India, Mumbai, India.

Ellen MacArthur Foundation (2016). *Circular Economy in India: Rethinking Growth for Long-Term Prosperity*. Ellen MacArthur Foundation, Isle of Wight, United Kingdom.

Ferronato, N., and Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health*, 16(6), 1060. https://doi.org/10.3390/ijerph16061060.

Gayakwad, H.P., and Sasane, N.B. (2015). Construction and demolition waste management in India. *International Research Journal of Engineering and Technology (IRJET)*, 2(3), 712–715.

Gupta, S., and Rk, M. (2018). The impact of C&D waste on Indian environment: A critical review. *Civil Engineering Research Journal*, 5(2), 555658. https://doi.org/10.19080/CERJ.2018.05.555658.

IFC (2017). *India Construction Materials Database of Embodied Energy and Global Environmental Indicators for Materials Warming Potential-METHODOLOGY REPORT*. International Finance Corporation, Washington, D.C., United States.

IIT Madras and BMTPC (2012). *GFRG/RAPIDWALL Building Structural Design Manual*. Building Materials & Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation Government of India, New Delhi, India.

IL&FS Ecosmart Limited (2013). Chapter 12: Solid waste management, CDP Delhi. Department of Urban Development, Delhi, India.

Joshi, R., and Ahmed, S. (2016). Status and challenges of municipal solid waste management in India: A review. *Cogent Environmental Science. Cogent*, 2(1), 1–18. https://doi.org/10.1080/23311843.2016.1139434.

Kaliannan, S., Nagapan, S., Abdullah, A.H., Sohu, S., and Jhatial, A.A. (2018). Determining root cause of construction waste generation: A global context. *Civil Engineering Journal*, 4(11), 2539–2547. https://doi.org/10.28991/cej-03091179.

KPMG (2017). *Indian Real Estate: Unfolding the New Era of Growth*. Klynveld Peat Marwick Goerdeler, India.

Kumar, S., Smith, S.R., Fowler, G., Velis, C., Kumar, S.J., Arya, S., Rena, Kumar, R., and Cheeseman, C. (2017). Challenges and opportunities associated with waste management in India. *Royal Society Open Science*, 4(3), 1–11. https://doi.org/10.1098/rsos.160764.

Lee, C.F., Rahman, I.A., Asmi, A., Nagapan, S., and Khalid, K.I. (2013). Classification and quantification of construction waste at housing project site. *International Journal of*

Zero Waste Generation, 1(1), 1–4.

Madala, S.C., Asadi, S.S., and Chandra, D.S. (2019). Critical study of the technological interventions on the evaluation of affordable housing to be implemented under PMAY. *International Journal of Recent Technology and Engineering,* 6, 270–277.

Mah, C.M., Fujiwara, T., and Ho, C.S. (2018). Environmental impacts of construction and demolition waste management alternatives. *Chemical Engineering Transactions*, 63, 343–348. https://doi.org/10.3303/CET1863058.

McKinsey & Company (2009). *Environmental and Energy Sustainability: An Approach for India*. McKinsey & Company, Inc., Mumbai, India.

Ministry of Housing and Urban Affairs (2017). *Swachh Bharat Mission (Urban)*. Ministry of Housing and Urban Affairs Government of India, New Delhi, India.

Ministry of Housing and Urban Affairs (2018). *Strategy for Promoting Processing of Construction and Demolition (C&D) Waste and Utilization of Recycled Products*. Ministry of Housing and Urban Affairs Government of India, New Delhi, India.

Miranda, R., Tike, C., and Vadake, K. (2017). Study of construction and demolition waste management in India. *International Journal of Scientific Engineering and Science*, 1(11), 50–52.

Mullick, A.K. (2015). Recycled concrete aggregate from C&D wastes. *The Masterbuilder*, (August), 56–65.

Ng, L.S., Tan, L.W., and Seow, T.W. (2018). Constraints to 3R construction waste reduction among contractors in Penang. *IOP Conference Series: Earth and Environmental Science*, 140, 012103. https://doi.org/10.1088/1755-1315/140/1/012103.

Olivier, J., Janssens-Maenhout, G., Muntean, M., and Peters, J. (2016). Trends in global CO_2 emissions: 2016. PBL Netherlands Environmental Assessment Agency & European Commission's Joint Research Centre (JRC), Hague, Netherlands.

Ponnada, M.R., and P, K. (2015). Construction and demolition waste management: A review. *International Journal of Advanced Science and Technology*, 84, 19–46. https://doi.org/10.14257/ijast.2015.84.03.

PWD (2018). Use of recycled products from C&D waste circular. Office of the Director, Government of NCT of Delhi, New Delhi, India.

Samiha, B. (2013). The importance of the 3R principle of municipal solid waste management for achieving sustainable development. *Mediterranean Journal of Social Sciences*. 4(3), 129–136. https://doi.org/10.5901/mjss.2013.v4n3p129.

Seminarsonly (2017). Manufacturing of GFRG panel concrete shuttering. Available at: https://www.seminarsonly.com/Civil_Engineering/affordable-rapid-mass-housing.php (accessed on 2019/01).

Sharma, M., and Dikshit, O. (2016). Comprehensive study on air pollution and greenhouse gases (GHGs) in Delhi. Indian Institute of Technology, Kanpur, India.

Vasam, S., Jagannadha Rao, K., and Seshagiri Rao, M.V. (2018). Experimental investigation on utilization of RCA in low, medium and high strength self-compacting concrete. *IOP Conference Series: Materials Science and Engineering*, 431(10), 0–9. https://doi.org/10.1088/1757-899X/431/10/102001.

Welcome to UGC, New Delhi, Ind × IJRAR(ISSN 2348 –1269, Print ISS ×

https://www.ugc.ac.in/journallist/subjectwisejurnallist.aspx?tid=MjM0ODEyNjk=&&did=U2VhcmNoIGJ5IElTU04=

Apps | unauthorized | Conference - Googl... | hard copy.xlsx - Go... | urgent publication... | IJRAR Paper Submis... | HDFC Bank: Person...

UGC Approved List of Journals

You searched for **23481269**

|| Home ||

Total Journals : 1

Show 25 entries Search:

View	Sl.No.	Journal No	Title	Publisher	ISSN	E-ISSN
View	1	43602	International Journal of Research and Analytical Reviews	International Journal of Research and Analytical Reviews	23495138	23481269

Showing 1 to 1 of 1 entries Previous 1 Next

Activate Windows
Go to Settings to activate Windows.

https://www.ugc.ac.in/faq.aspx

Type here to search

10:03 PM
6/15/2019

Welcome to UGC, New Delhi, Ind × | UGC Journal Full Details × | +

https://www.ugc.ac.in/journallist/ugc_admin_journal_report.aspx?eid=NDM2MDI=

Apps | unauthorized | Conference - Googl... | hard copy.xlsx - Go... | urgent publication... | IJRAR Paper Submis... | HDFC Bank: Person...

UGC Journal Details

Name of the Journal :	International Journal of Research and Analytical Reviews
ISSN Number :	23495138
e-ISSN Number :	23481269
Source:	UNIV
Subject:	Multidisciplinary
Publisher:	International Journal of Research and Analytical Reviews
Country of Publication:	India
Broad Subject Category:	Multidisciplinary

Print

Activate Windows
Go to Settings to activate Windows.

Type here to search

10:04 PM
6/15/2019

ASSESSMENT OF BUILDING ENVELOPE MATERIAL FOR EMBODIED ENERGY TO REDUCE GLOBAL WARMING AND OZONE DEPLETION POTENTIAL

[1]Sayali P. Kulkarni, [2] Dr. Sujata Karve, [3]Ar. Prajakta Kulkarni
[1]M. arch Student, [2]Head of Department (guide/coordinator), [3]Prof.(guide/coordinator)
[1] Department of Environmental Architecture,
[1] Dr. Bhanuben Nanavati college of Architecture, Pune, India

Abstract: Global warming and ozone layer depletion are the highlighted issues of sustainable development, more than one third of global greenhouse gas emission is occurring due to building sector and they are also responsible for largest source of these emissions. The building industry plays an important role in the energy consumption of the nation, includes both embodied energy and operational energy. There has been more attention given to operational energy reduction over assessment of embodied energy in building envelope material. In residential buildings the use of embodied energy is accounted for up to 40% of life – cycle energy has been formulated from the resent research. The purpose of this paper is to identify and analyze appropriate wall assemblies for embodied energy which reflects in reduction of global warming and ozone depletion potential. The methodology adopted for the study includes comparison of different wall assemblies for embodied carbon from building material. Tally®, a software Plug in the Revit is used to quantify the embodied carbon impact of building materials and provides number of environmental impact measurements including Global warming potential, ozone depletion potential and embodied carbon of building enclosures and finish material. The results delivered that the building envelope made up of cavity wall performed better in all the environmental impact measurements.

***Index Terms* - Embodied energy, Building envelope material, Wall assemblies, Tally®, Global warming potential, Ozone depletion potential**

I. Introduction

Today the building industry is responsible for almost 40% of primary energy use and 24% of carbon dioxide emission in India. To reduce the energy consumption and greenhouse gas emissions which is having the adverse environmental impact numerous studies have been conducted. Every year in India nearly 2 million residential buildings are built. Majorly conventional materials like clay brick and cement are used to build the building. Large quantity of raw material is used in building industry which is responsible for high energy consumption.

Energy consumed during the life-cycle of the building consist of embodied energy, operational energy and demolition energy. Embodied energy in the building material has been studied to contemplate the relationship between building material, construction processes, and their environmental impacts. Embodied energy is of two forms Initial embodied energy and recurring embodied energy. The energy used to produce the building is known as initial embodied energy of a building on the other hand the energy used in maintaining and repairing of the building over its effective life is known as recurring embodied energy. The energy use in producing and transporting the building materials and components, and energy use for different processes during the production and demolition of the building included to form a total energy demand. The energy use in keeping the indoor environment within the desired range is known as operational energy while the energy use for the destruction and disposal processes at the end of the life span of the building is demolition energy.

The ability to preserve certain process or state over a long period in future is in the broader senses resembles sustainability. For sustainability the use of material that are readily available in nature which would not require production is to be considered. On the other hand, manufactured materials are produced with great expense of energy and therefore their sustainability requires careful analysis and evaluation for both production and use. Use of minimum natural resources and low environmental impact construction of buildings, leads to sustainable future.

The main objective of this study is to assessment of the embodied energy of building envelope, finish material and compare the different wall assemblies on the bases of Global warming and ozone depletion potential. The scope area of the study is to focus on only embodied energy of material, operational and demolition energy are not taken into consideration. Further the analysis is done based on global warming and ozone depletion potential of environmental impact measurements. The study limits to Indian context when taken into consideration the transportation criteria. Proposed wall assembles are designed to meet the recommended heat transfer coefficient to be almost constant so as to not impose any change in operational energy.

II. Embodied Energy and carbon emissions

Embodied energy is the energy consumed by all of the processes related with the production of a building, from the addition of natural resources to product delivery, involving mining, manufacturing of materials and equipment, transport and administrative functions (Turker, 2000)

(Lindsay Rasmussen, Alison G.Kwok, 2017) compares the embodied energy and the carbon emission of a multifamily, affordable passive house building and a similar building of standard construction – the stellar apartment. Revit, zero tool and tally are used to calculate and compare the environmental impact of the material and operation in the building. Alternative wall assemblies were examined to evaluate the feasibility of achieving zero carbon building. (Lindsay Rasmussen, Alison G.Kwok, 2017) mainly focused on relationship between the embodied carbon of material and operational carbon emission of the building designed to passive house standards. Material choices plays more significant role because if the embodied carbon of the building material exceeds the operational energy savings, the effort to achieve a high-performance building becomes futile. Method and approach taken are Building description of dwelling unit – The operational energy consumption data will be used in the following calculations. Carbon emission from operational energy considering different wall section - Operation energy consumption is calculated. The data is run through Architecture 2030's Zero tool or Edge tool - To estimate and compare the operational greenhouse gas emission. Embodied carbon from building material for different wall sections – Tally, a software Plug in in Revit – use to quantify the embodied carbon impact of building materials – provides number of environmental impact measurements, this analysis will focus on Global warming Potential. Payback time analysis – using tally and zero tool Key GWP contributor-using Tally. Wall assembly comparison - Global warming potential -embodied carbon of building enclosures and finish material, ozone depletion potential. (Lindsay Rasmussen, Alison G.Kwok, 2017)concluded that one feasible pathway to design zero carbon building, is by using passive house standards to reduce operational carbon emission and focusing on using low embodied carbon material is further reduce total carbon emission.

(Qarout, 2017) assess the embodied energy and carbon emissions of structural building materials and determine environmental savings associated with construction and shifting the focus to the reduction of building operational energy makes embodied energy a significant part of a building's life cycle. (Qarout, 2017) focused on the assessment of the embodied energy of the structural materials and photovoltaic system of a high-performance building. Embodied energy for conventional Buildings represents between 2% - 38% of the energy use over their lifetime periods. These increases to 9% - 46% for high-performance buildings and 100% for zero carbon ones, making embodied Energy a significant part of the total life cycle energy of a building (Qarout, 2017). Embodied energy is a means to quantify the invested energy of a material. It is the basic unit of measure in a life cycle assessment. Natural materials like timber and cut stone tend to be lower in embodied energy because they require fewer manufacturing processes. The more processed materials like metals will generally have higher embodied energy.
The following are factors to consider when looking for materials and with low embodied energy:
• The distance needed to transport materials; local sourcing results in lower embodied energy.
• Quantity of used raw material.
• Intricacy of manufacturing process. (The more complex the process, the more energy intensive)
• Recycling potential.
• Renewable materials are desirable.
• Efficient building design; where the use of energy and materials is lowered (Qarout, 2017)Operational energy can be reduced through building performance optimization, whereas embodied energy can only be reduced if low energy intensive materials and products are selected at the initial stages of the design process.

2.1 Low-Carbon Materials

(Ali Akbarnezhad,Jianzhuang Xiao, 2017) expressed that the designer is obliged to select from limited options depending up on their performance against technical requirements. Embodied carbon of material may differ depending on factors like the type of the raw material constituents, the location of material quarries and mode of transport needed, carbon concentrated of extraction and processing operations, carbon concentrated of applicable construction methods to install the materials, carbon concentrated of recycling and reuse operations, and distance to disposal sites accepting the resulting waste

2.2 Material Minimization

(Ali Akbarnezhad,Jianzhuang Xiao, 2017) proposed that the quantity of the material used in the building structure is directly proportional to total embodied carbon of a structure. Hence, he suggested, comparing the alternative materials should be performed by accounting the total embodied carbon, which is the product of the unit embodied carbon rate and the total quantity of the material used Therefore, minimizing the waste generated during production and construction can be encounter a potential strategy for reducing the embodied carbon of structures**.** (Ali Akbarnezhad,Jianzhuang Xiao, 2017) showed through a case study that minimizing the trim loss in cutting reinforcing steel rebars appeared in a decrease of about 7.7% and 49.6% in the total amount of material used and generated waste, respectively

2.3 Local Sourcing of Materials and Components

(Ali Akbarnezhad,Jianzhuang Xiao, 2017) stated the essential factors affecting the transport emission of materials, including the number of trips, the mode of transport and travel distance requirements, should be acquired in selecting materials for low-carbon buildings. However, he also noted that the final decision on choice of material and supplier should be made by considering for other important economic, social and environmental factors affected by the selection of the material supplier

2.4 Construction Optimization Strategies

(Ali Akbarnezhad,Jianzhuang Xiao, 2017)also proposed that the carbon emissions of the construction phase can be decreased through number of approaches including optimizing the construction operations to minimise the idle time of equipment, selection of best equipment for a construction operation, optimizing the operation of equipment, and reducing the on-site transport involving both horizontal and vertical transport. Apart from this, he found out minimizing the on-site transport on a construction

site through develop the layout of construction facilities on a construction site, which has been majorly investigated earlier as a potential cost reduction strategy, is ultimately to result in considerable carbon emission reductions.
As presented in some LCA studies, embodied energy can represent approximately 10-20% of the life cycle energy of a conventional building (Dixit, 2010) Operational energy plays a dominant role in building life cycle energy, ranging from 80% to 90% in conventional buildings and 40-60% in low-energy buildings (Karimpour, 2014). Considerable research has been conducted into the improvement of operational energy performance and the reduction of associated environmental impacts. A review of previous studies indicates that the operational energy and associated emissions performance of dwellings are dependent on many factors including the shape and orientation of buildings, thermal properties of construction materials, surrounding environment, climate and the behaviour of occupants (Bin Huang , Ke Xing , Stephen Pullen , 2015)
Building and construction is responsible for up to 30% of annual global greenhouse gas (GHG) emissions, mostly reported in carbon equivalent unit. Carbon emissions are incurred in all stages of a building's life cycle and are generally differentiate into operating carbon and embodied carbon, each making varying contributions to the life cycle carbon depending on the building's characteristics (Ali Akbarnezhad,Jianzhuang Xiao, 2017)

III. Building Envelope material

(Silvia Vilčeková, 2015) Analyzed that the residential stock is the largest segment of the construction, A total of 64% of residential building floor area is related with private family houses and 36% with apartments. He also accounts that the amount of embodied energy (EE) of a residential building is predicted at 20%–40% of operational energy over its usable life. Many a times this differs depending on context due to the type of primary energy resources used, technological advancements, and the methods used for inventory analysis. (Silvia Vilčeková, 2015) also proposed that the proper choice of materials for the building envelope plays the vital role and can have various effects on energy consumption and associated emissions over the different phases of a building's life cycle. He put forward that EE can be reduced by applying alternative infill materials, especially insulation in wall system and cumulative energy saved over a 50-year life cycle by this material substitution is around 20%. The best way to reduce overall intensity of environmental loads is done by integrating in design phase of building. Material selection has an important impact on the total energy balance and the GHG emissions of buildings. (Silvia Vilčeková, 2015) The energy corresponding with the construction and maintenance as well the embodied energy in the building material accounts for large share in life cycle

(B.V. Venkatarama Reddy*, 2001) mentioned that considerable amount of energy is spent in the manufacturing processes and transportation of various building materials and conservation of energy becomes important in the context of limiting of greenhouse gases emission into the atmosphere and decrease costs of materials. Author focused around some issues pertaining to embodied energy in buildings particularly in the Indian context. Author presents a detailed account of embodied energy in alternative building materials and procedures and correlation of embodied energy in buildings built with conventional and the new building methods. Author considered for the analysis, five types of building blocks viz. stone, burnt clay brick, soil–cement block, hollow concrete block and steam cured mud block -
1. Burnt clay bricks consume maximum amount of energy among the alternatives, whereas Stone blocks do not consume any thermal energy
2. Soil–cement block with 6% cement is the most energy efficient block consuming only 23.5% of burnt clay brick energy.
3. Soil–cement block and hollow concrete block with 7–8% cement have embodied energy values, i.e. around 30% of the burnt clay brick energy.
4. About 60% of burnt clay brick energy is consumed by steam cured mud blocks. This can be credit to huge percentage of lime and fuel utilise for steaming operations. Energy required in transportation of building materials- Thermal energy used for natural sand production is nil, but it desires about 175 MJ of diesel energy/m3 for transporting it about 100 km distance. Crushed aggregate consumes around 20 MJ/m3 while its production and an additional 400–800% more during transportation for distances of 50–100 km (B.V. Venkatarama Reddy*, 2001).
He estimated that energy spent during transportation of bricks is about 4–8% of its energy in construction, for distances of 50–100 km.

IV. Methodology

The methodology used for this research is primarily based on Tally®, a software plugin for Revit, will be used to quantify the embodied carbon impacts of the building material. The analysis will examine alternative material choices, comparing six wall assemblies to see how lower embodied carbon material impacts the GHG emissions. Tally® also provide number of environmental impact measurements, this analysis will majorly focus on the Global warming potential (GWP) and Ozone Depletion potential (ODP). Note That the Tally provided averages of transportation and construction emissions because of two reasons: firstly, to not make it site specific and to make the result more universally acceptable and secondly it is impossible to track down exact material used in the construction of building. Some secondary environmental impacts like Acidification, Eutrophication and Smog analysis are also taken into consideration to make appropriate choice of wall assembly from six options. Three kind of wall assemblies is addressed i.e. simple wall, thermal insulation wall and cavity wall and each one of them have two options. The selection of material is based on the R -value of the total assembly and the area of wall is restricted to 16sqm.

4.1 Calculation Methodology

The results represent the analysis of the building component i.e. wall. This may be utilised to compare the relative environmental impacts associated with building components or for comparative study with one or more wall sections for appropriate choice. It also helps in quantifying the building component and help in defining the objective of study.

4.1.1 Life Cycle stage – this describes the scope and System boundaries utilised to define each stage of life cycle of the building from collection of raw material to its disposal. Tally includes full life cycle impact under Environmental Product Declarations.

PRODUCT	CONSTRUCTI	USE	END- OF- LIFE	MODULE D
A1. Extraction **A2. Transport to factory** **A3. Manufacturing**	**A4. Transport (to site)** ***A5. Construction installation***	B1. Use **B2. Maintenance** **B3. Repair** **B4. Replacement** **B5. Refurbishment** ***B6. Operational Energy*** B7. Operational water	C1. Demolition **C2. Transport (to disposal)** **C3. Water processing** **C4. Disposal**	**D. Benefits and loads beyond the system boundary from:** **1. Reuse** **2. Recycling** **3. Energy recovery**

Life cycle stages as defined by EN15978. Processes included in Tally modelling scope are shown in bold. Italics indicates optional process.

4.1.2 Environmental Impact categories

A representation scheme translates all emissions and fuel use associated with the reference flow into quantities of categorized environmental impact. As on regional ecosystem conditions and the location in which they occur, the degree that the emissions will result in environmental harm depends so the results are reported as impact potentials. The following impact variables needed for analysis is reported according to the TRACI 2.1 characterization scheme, the environmental impact model formulated by the US EPA to quantify environmental impact risk related with emissions to the environment in the United States.

4.1.3 Global Warming Potential (GWP) kg CO_2eq - A parameters of greenhouse gas emissions, such as carbon dioxide and methane. These emissions are the main reason of an increase in the absorption of radiation emitted by the earth, rise in the natural greenhouse effect. This may, in return, are responsible for adverse impacts on ecosystem health, human health, and material welfare

4.1.4 Ozone Depletion Potential (ODP) kg CFC-11eq - A parameter of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone tends to higher levels of UVB ultraviolet rays reaching the earth's surface with adverse effects on humans and plants. As these impacts leads to be very small, ODP impacts can be hard to calculate and are responsible to a larger margin of error than the other impact categories.

4.1.5 Acidification Potential (AP) kg SO_2eq - A parameter of emissions that cause acidifying effects to the environment. The acidification potential is a meter of a molecule's capacity to rise the hydrogen ion (H^+) concentration in the presence of water, thus reducing the pH value. Potential effects contain fish mortality, forest decline, and the deterioration of building materials.

4.1.6 Eutrophication Potential (EP) kg Neq - A Parameter of the impacts of excessively high levels of macronutrients, the most vital of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an unacceptable shift in species composition and upraised biomass production in both aquatic and terrestrial ecosystems.

4.1.7 Smog Formation Potential (SFP) kg O_3eq - A parameter of ground level ozone, caused by various chemical reactions within nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in sunlight. Human health impact can result in a various respiratory issue, involving rise in symptoms of bronchitis, asthma, and emphysema

V. Results and Analysis

5.1 Wall Assembly Comparison

This analysis compares six wall assembles pf equal R- value to Quantify and understand the opportunities for reducing embodied carbon in the buildings. Each Wall assembly is designed to have same R- value so as to keep operational performance constant.

5.1.1 Wall No. 1

This wall assembly consist three layers out of which two are finishes layer and one masonry layer. Finishes layer one is formed of 10mm thick Portland cement Stucco with exterior acrylic latex paint and the other one is formed of 10mm thick Portland cement Stucco with interior acrylic latex paint. Masonry layer is made up of 230 thk brick, generic. [fig 1]

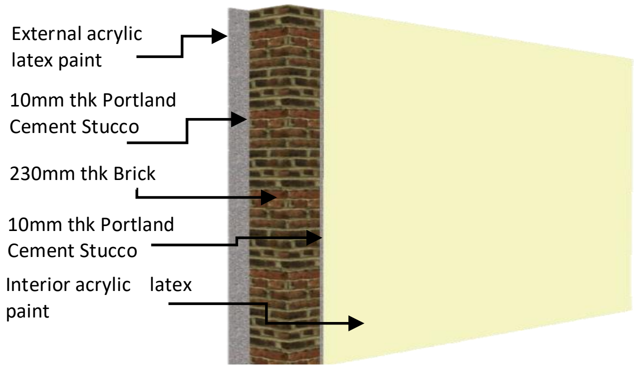
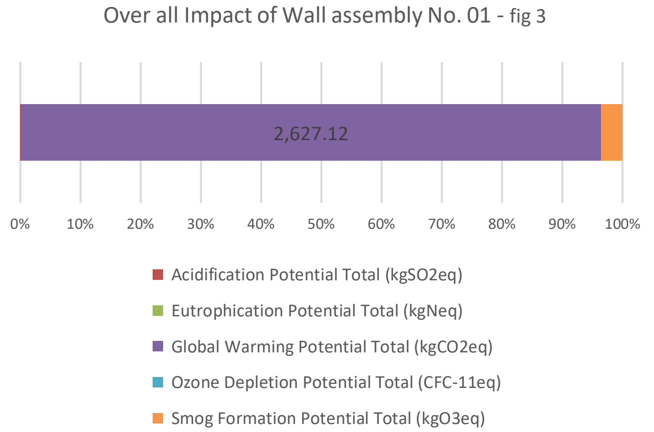
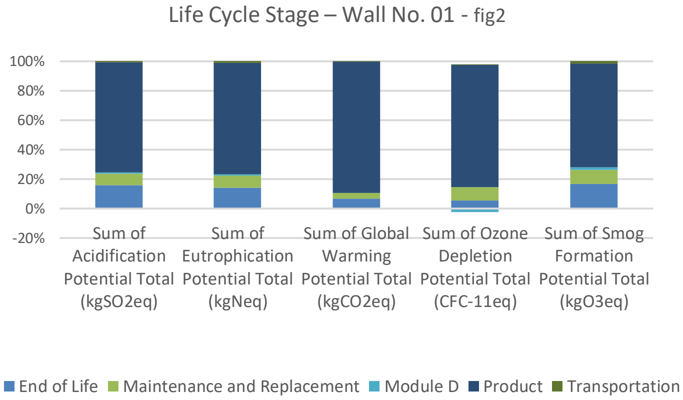
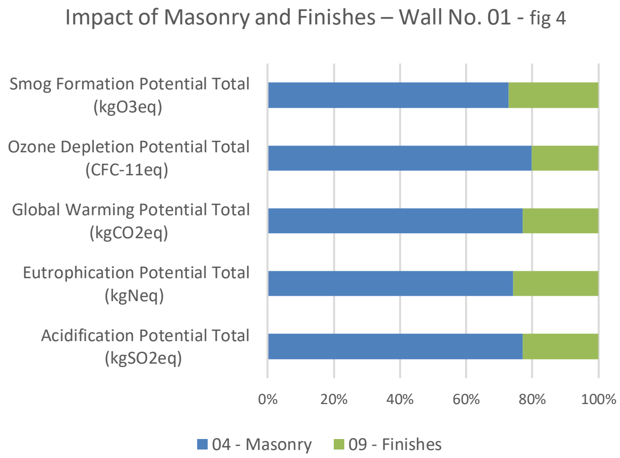
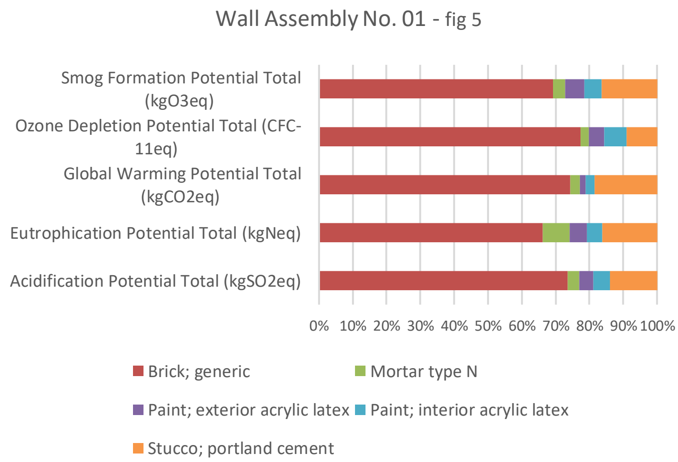


Fig 1. Wall assembly No. 1





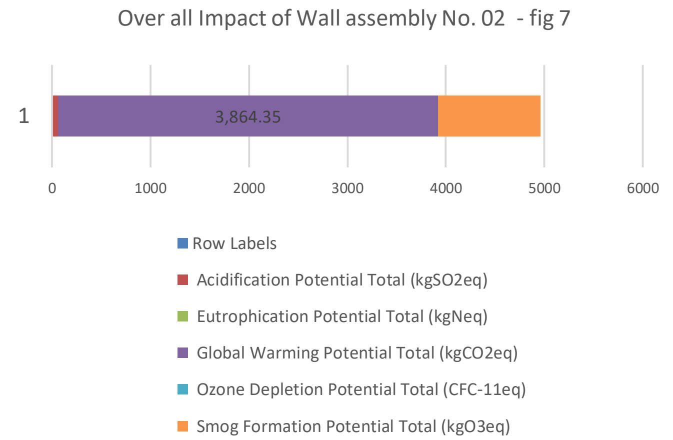




The global warming potential of Wall no. 01 is 2627.12 kgCO2e i.e. the embodied carbon obtained for the 16 sqm wall assembly. The major contributor GWP is masonry about 2027.35 kgCO2e, more precise the embodied carbon of generic brick as a walling material is 1951.19 kgCO2e being a reason for rise in GWP. The ODP of this assemble is 5.66e-10 and generic brick is only responsible for the increase in other environmental factors like smog formation, acidification and eutrophication potential.

5.1.2 Wall no. 02

This is simple wall assembly consist one masonry layers. Masonry layer is made up of 300 thick lime stone wall with 10mm S type mortar. [fig 6]



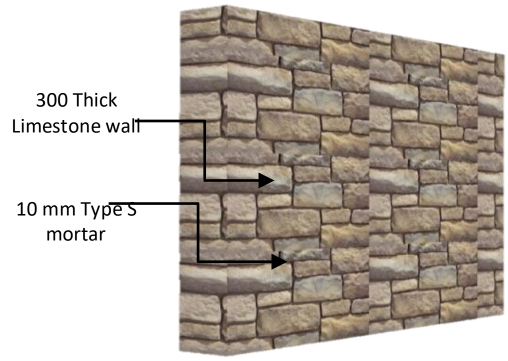
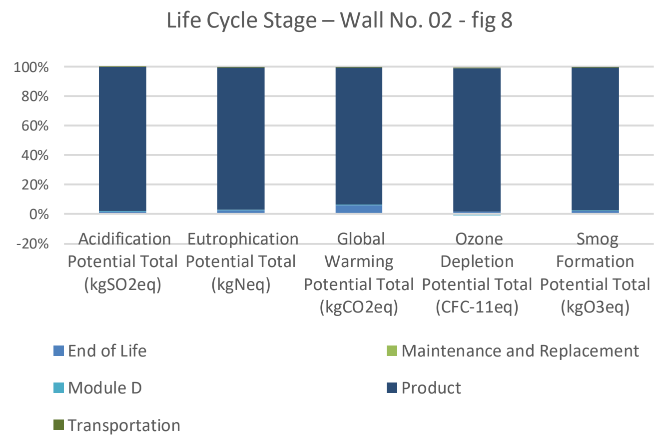
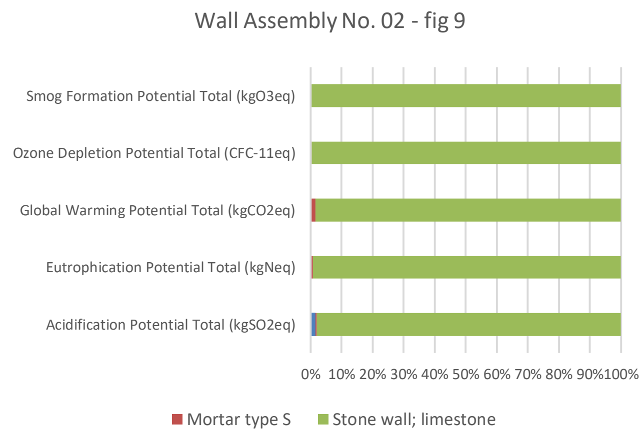


Fig. 6- Wall Assembly No. 02





The global warming potential of Wall no. 02 is 3864.35 kgCO2e i.e. the embodied carbon obtained for the 16 sqm wall assembly. The major contributor GWP is masonry about 3864.35 kgCO2e, more precise the embodied carbon of limestone as a walling material is 3799.91 kgCO2e being a reason for rise in GWP. The ODP of this assemble is 2.46e-09 and limestone is only responsible for the increase in other environmental factors like smog formation, acidification and eutrophication potential.

5.1.3 Wall no. 03

This one is thermal insulation wall assembly consist 5 layers out of which three are finishes layer, one masonry layer and one thermal insulation layer. Finishes layer one is formed of 10mm thick Portland cement Stucco with exterior acrylic latex paint, second layer is of 10mm thk absorbent plaster and the other one is formed of 10mm thick Portland cement Stucco with interior acrylic latex paint. Masonry layer is made up of 150 thk brick, generic. Thermal insulation layer is of 20mm thk mineral wool board [fig 10]

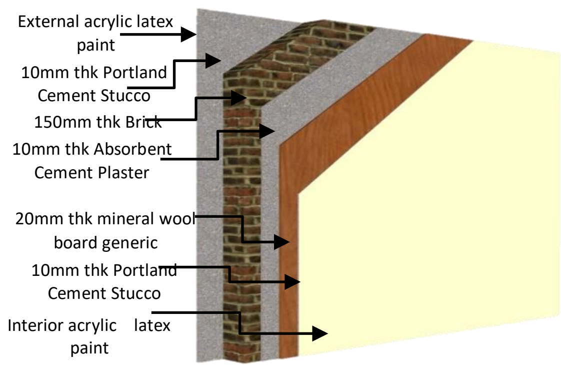
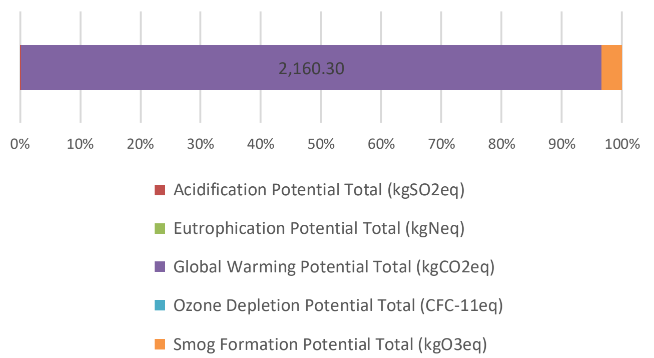
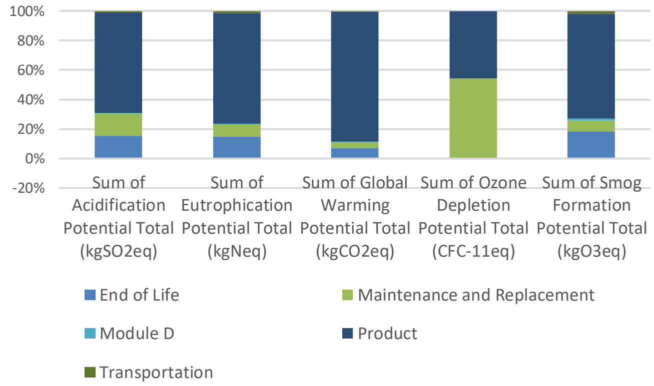


Fig 10 Wall Assembly No. 03

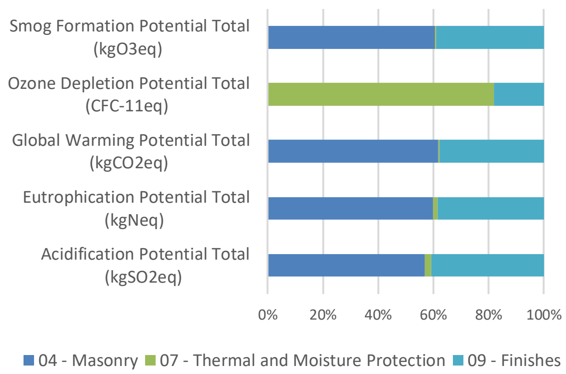
Over all Impact of Wall assembly No. 03 - fig 11



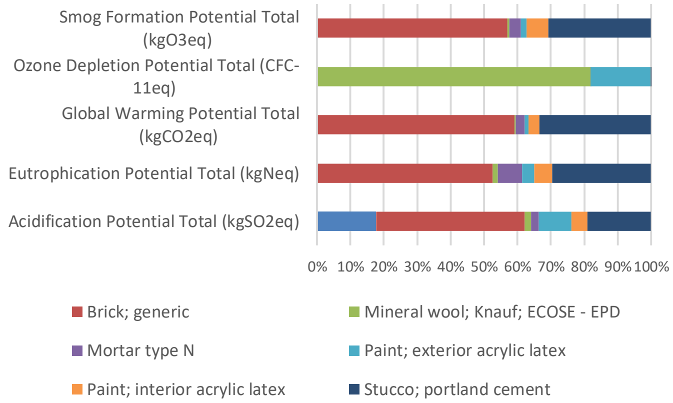
Life Cycle Stage - Wall No.03 - fig 12



Impact of masonry, Thermal Insulation and Finishes – Wall No. 03 - fig 14



Wall Assembly No. 03 - fig 15



The global warming potential of Wall no. 03 is 2160.30 kgCO2e i.e. the embodied carbon obtained for the 16 sqm wall assembly. The contributor GWP is masonry (60%) about 1333.47 kgCO2e and finishes about 817.65 kgCO2e, more precise the embodied carbon of generic brick as a walling material is 1276.48 kgCO2e being a reason for rise in GWP. The ODP of this assemble is 1.28e-06 and thermal insulation are contributing mainly in rise in OPD- 2.30e-07. Brick is only responsible for the increase in other environmental factors like smog formation, acidification and eutrophication potential.

5.1.4 Wall No. 04

This one is thermal insulation wall assembly consist 5 layers out of which three are finishes layer, one masonry layer and one thermal insulation layer. Finishes layer one is formed of 10mm thick Portland cement Stucco with exterior acrylic latex paint, second layer is of 10mm thk absorbent plaster and the other one is formed of 10mm thick Portland cement Stucco with interior acrylic latex paint. Masonry layer is made up of 150 thk AAC blocks. Thermal insulation layer is of 20mm thk mineral wool board [fig 16]

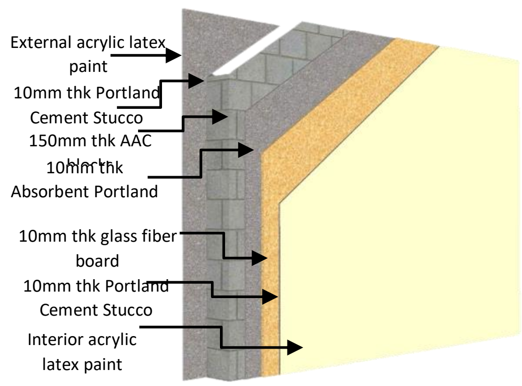
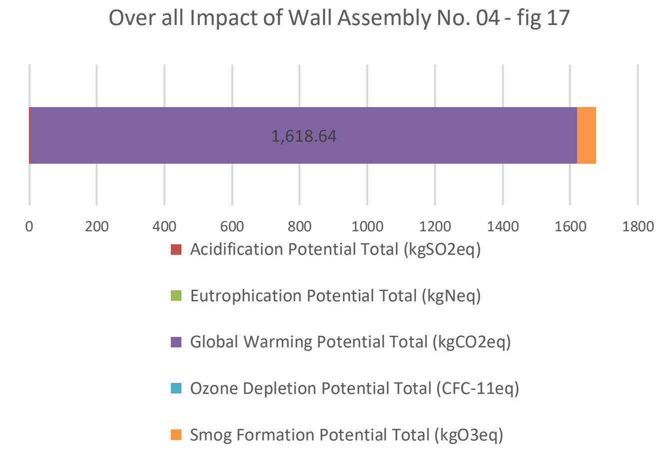
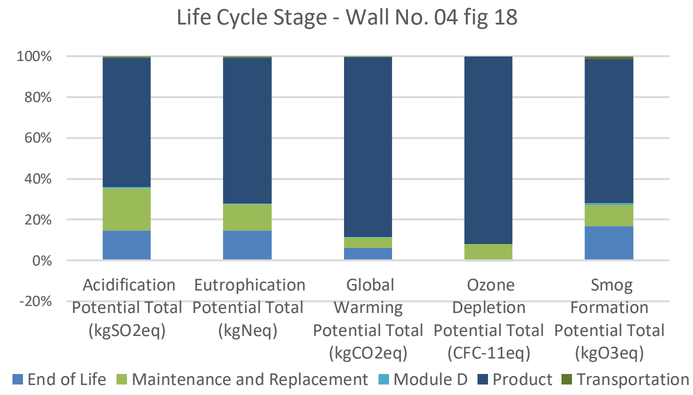
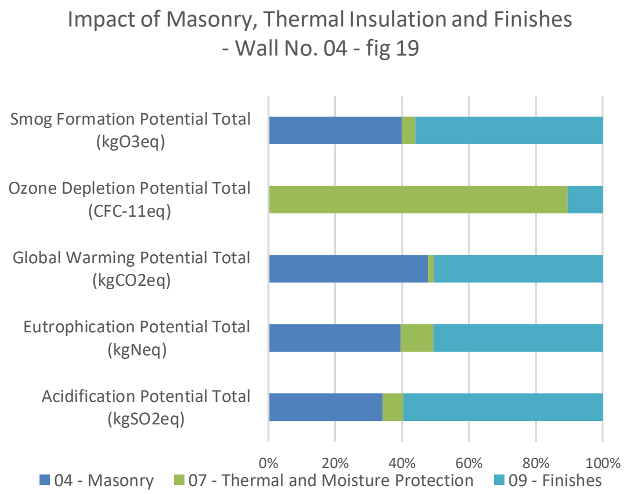
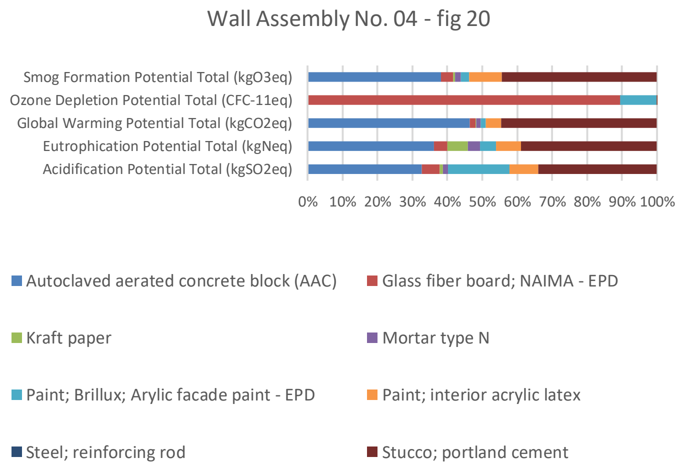


Fig 16 Wall Assembly No. 04









The global warming potential of Wall no. 04 is 1618.64 kgCO2e i.e. the embodied carbon obtained for the 16 sqm wall assembly. The contributor of GWP is Finishes (57%) about 817.66 kgCO2e and masonry about 772.32 kgCO2e, more precise the embodied carbon of AAC blocks as a walling material is 751.66 kgCO2e being a reason for rise in GWP. The ODP of this assemble is 2.17e-06 and thermal insulation are contributing mainly in rise in OPD- 1.94e-06. Stucco Portland cement is only responsible for the increase in other environmental factors like smog formation, acidification and eutrophication potential.

5.1.5 Wall No. 05

This one is cavity wall assembly consist 5 layers out of which one are finishes layer, two masonry layer and two thermal and moisture absorption layers. Finishes layer is formed of 10mm thick Portland wall board gypsum with interior acrylic latex paint. Masonry layer is made up of 100mm thk AAC blocks and 90mm thk brick with exterior acrylic latex paint. Thermal absorption layer is of fluid applied elastomeric air barrier and asphalt felt sheet having in between 10mm cavity [fig 21]

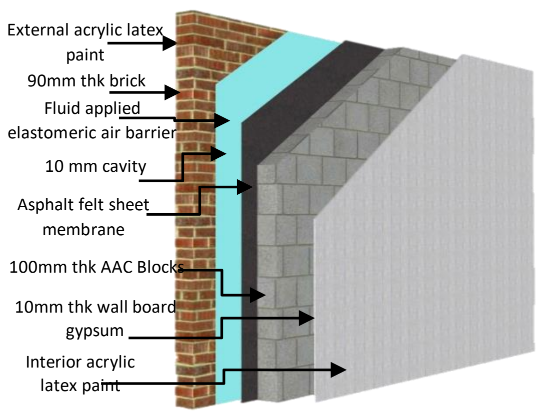
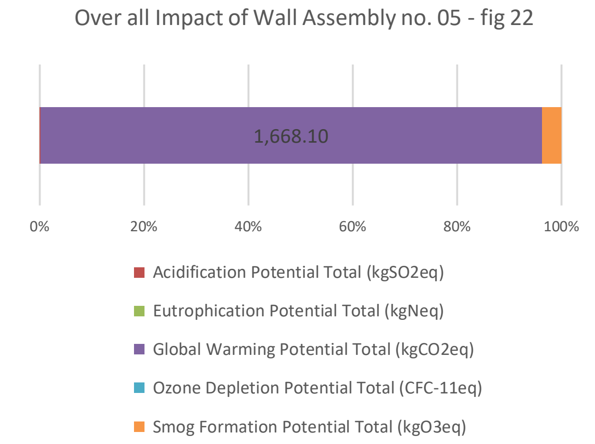
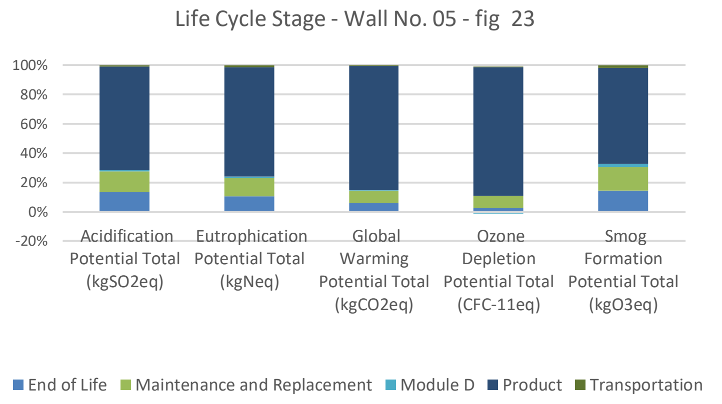
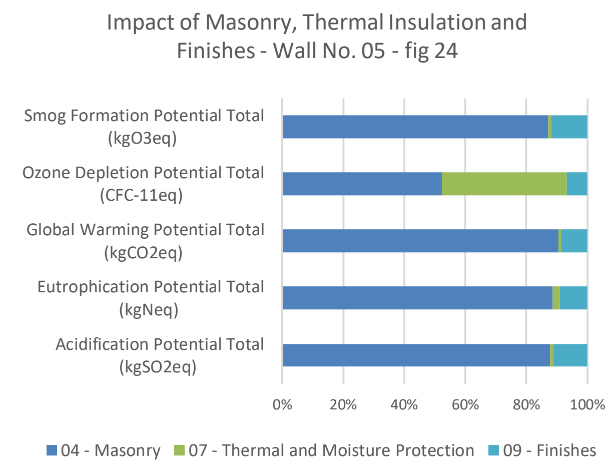
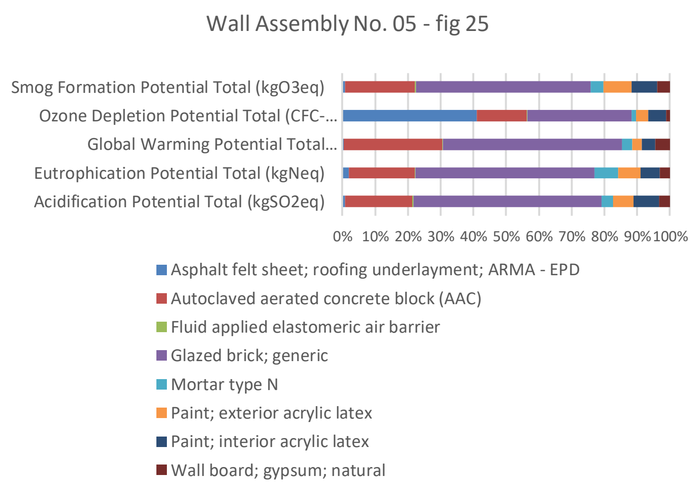


Fig 21 Wall Assembly No. 05









The global warming potential of Wall no. 05 is 1668.1 kgCO2e i.e. the embodied carbon obtained for the 16 sqm wall assembly. The contributor of GWP is masonry (90%) about 1511.69kgCO2e, more precise the embodied carbon of AAC blocks and brick as a walling material is 1413.22kgCO2e being a reason for rise in GWP. The ODP of this assemble is 7.00e-10 and thermal and moisture control are contributing mainly in rise in OPD- 2.87e-10. Glazed brick is only responsible for the increase in other environmental factors like smog formation, acidification and eutrophication potential.

5.1.6 Wall No. 06

This one is cavity wall assembly consist 3 layers out of which one are finishes layer, two masonry layers. Finishes layer is formed of 10mm thick Portland wall board gypsum with interior acrylic latex paint. Masonry layer is made up of 150mm thk AAC blocks and 90mm thk brick with exterior acrylic latex paint having in between 10mm cavity [fig 26]

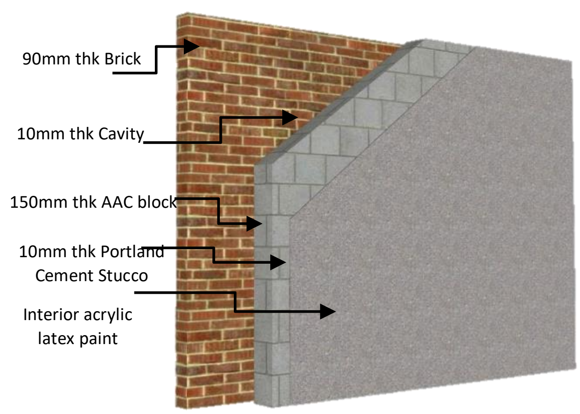
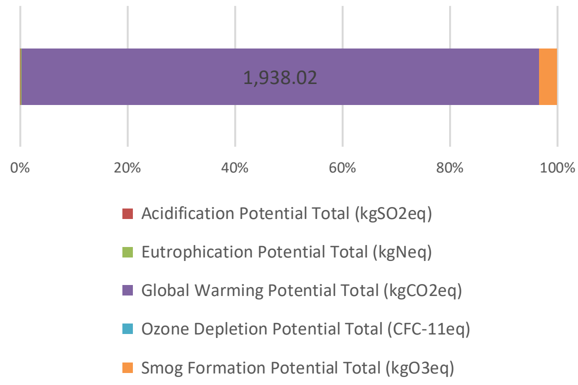
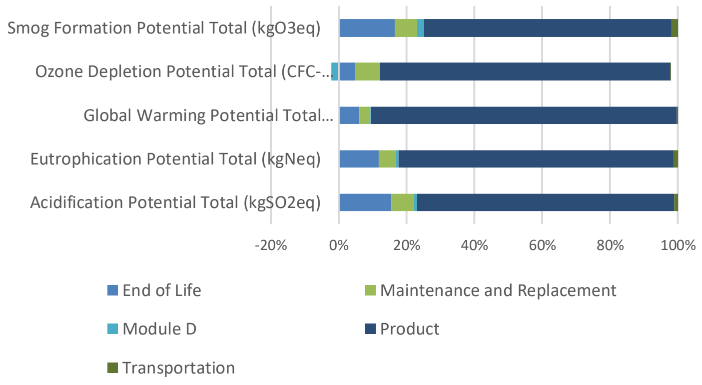


Fig 26 Wall Assembly No. 06

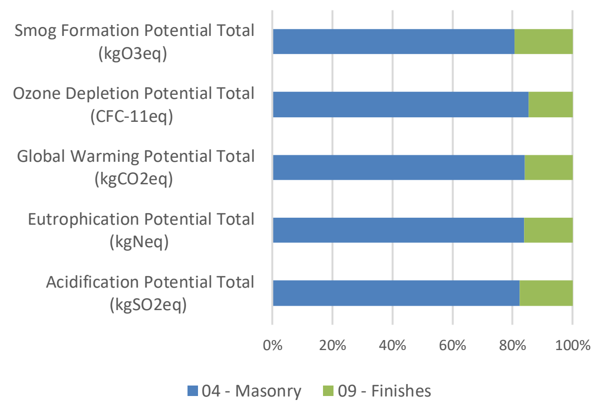
Over all Impact of Wall Assembly No. 06 -fig 27



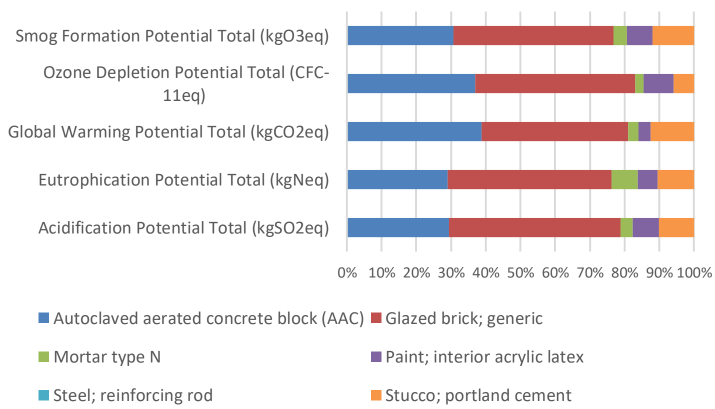
Life Cycle Stage - Wall No. 06 -fig 28



Impact of Masonry and Finishes - fig 29

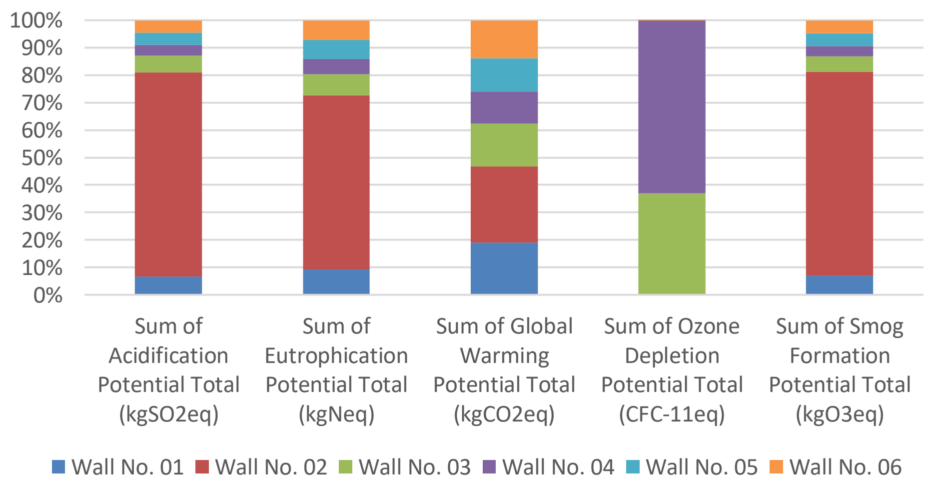


Wall Assenbly No. 06 - fig 30

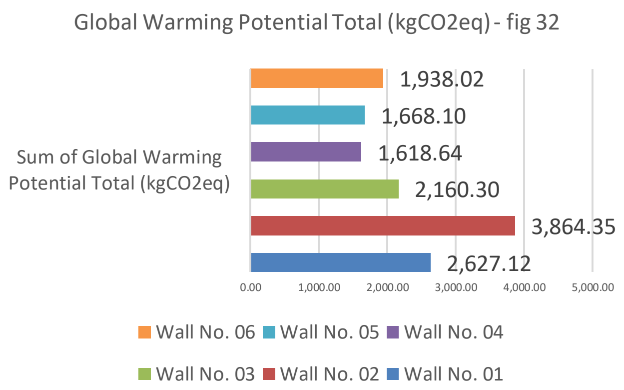


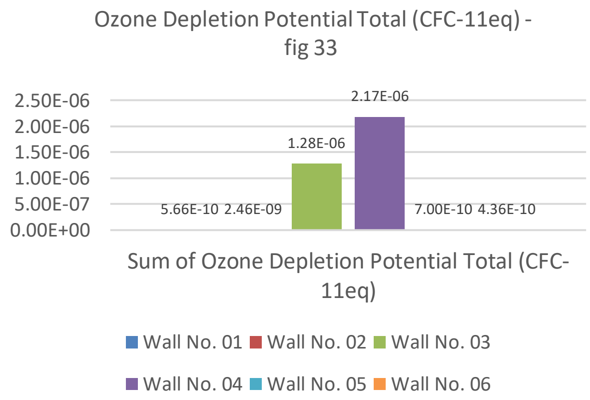
The global warming potential of Wall no. 05 is 1938.02 kgCO2e i.e. the embodied carbon obtained for the 16 sqm wall assembly. The major contributor of GWP is masonry (80%) about 1627.38kgCO2e, more precise the embodied carbon of brick as a walling material is 855.06kgCO2e being a reason for rise in GWP. The ODP of this assemble is 4.36e-10 and glazed brick is only responsible for the increase in other environmental factors like smog formation, acidification and eutrophication potential.

Comparison of all Six Wall Assembly - fig 31



After comparing all six wall assemblies (fig 31) result shows that the wall no. 01(fig 1) which is composed of brick and Portland cement stucco have around 18% impact on global warming potential (GWP) fig-32 and no remarkable impact on ozone depletion potential (ODP) fig 33 which encourages it to work better under ODP criteria, it signifies about 7% Acidification potential (AP), 9% Eutrophication potential (EP) and 6% Smog formation potential (SFP). On other hand Wall No. 02 (fig 6) which constitute of only limestone have the highest i.e. 27% GWP but no effect on ODP yet it shows maximum levels in all other environmental impact measurements which is 73% AP, 63% EP and 74% SFP. While Wall No. 03 (fig 10) which is thermal insulation wall constitute of Brick, Portland cement stucco, absorbent plaster and mineral wool board and contribute about 15% of GWP and 34.5% of ODP which shares in depletion of ozone layer, it shows 6% AP, 8%EP and 6%SFP. Wall No.04 (fig 16) is also thermal insulation wall which is composed of AAC blocks, Portland cement Stucco, Absorbent plaster and Glass fiber board as insulating material have around 12% of GWP and major impact on OPD i.e. about 64.5% which is contributing in large amount for depletion of ozone layer od all the other assemblies. It shows 5%AP, 6%EP and 4%SFP. Now wall no. 05(fig 21) is the type of cavity wall with 10mm cavity and constitute of brick, ACC block, Portland cement Stucco, fluid applied elastomeric air barrier and asphalt felt sheet having about 13% GWP and no impact on ODP, it also signifies 4%AP, 6%EP and 5%SFP. The other Cavity wall which is Wall no. 06 (fig 26) is composed of brick, AAC blocks, Portland cement Stucco and 10mm cavity have about 15% of GWP and no as such impact on OPD, it shows about %5AP, 8%EP and 5%SFP.





VI. Conclusion

The overall analysis shows that the lime stone wall assembly which is wall no. 02 contributes majorly in global warming potential although it has negligible effect on the ozone depletion potential. Thermal insulation wall assemblies i.e. Wall no. 03 and 04 had the sever impact on both GWP and ODP, insulating material like mineral wool and glass fiber board are mainly responsible for the increase in ODP. From all the wall assembles it has been observed that the important contributor for the increase in GWP is the masonry part of the wall section because it is present in the maximum quantity than other material so it is much necessary to choose the masonry having low embodied carbon at the first place so it will help in reduction of GWP. The Cavity wall assembly which is Wall no. 05 and wall 06 show low GWP, specially the wall assembly with air barrier and the asphalt felt sheet i.e. wall no.05 (fig 31) perform better in all other environmental measurement parameter it shows negligible ODP, 4%AP, 6%EP and 5%SFP.

VII References

Ali Akbarnezhad,Jianzhuang Xiao. (2017). Estimation and Minimization of Embodied Carbon of Buildings: A Review. *Buildings*, 1-24.

B.V. Venkatarama Reddy*, K. J. (2001). Embodied energy of common and alternative building materials and technologies. *ELSEVIER*, 9.

Bin Huang , Ke Xing , Stephen Pullen . (2015, december 7). Energy and carbon performance evaluation for buildings and urban precincts: review and a new modelling concept. *Elsevier*, 12.

Dixit, M. (2010). Identification of parameters for embodied energy measurment. *Eergy build*, 42(8).

Karimpour, M. (2014). Minimising the life cycle energy of the building:review and analysis. *Build Energy*, 73.

Lindsay Rasmussen, Alison G.Kwok. (2017). Addressing embodied carbon in high performance design. *PLEA 2017* (p. 7). scotland: NCEUB 2017.

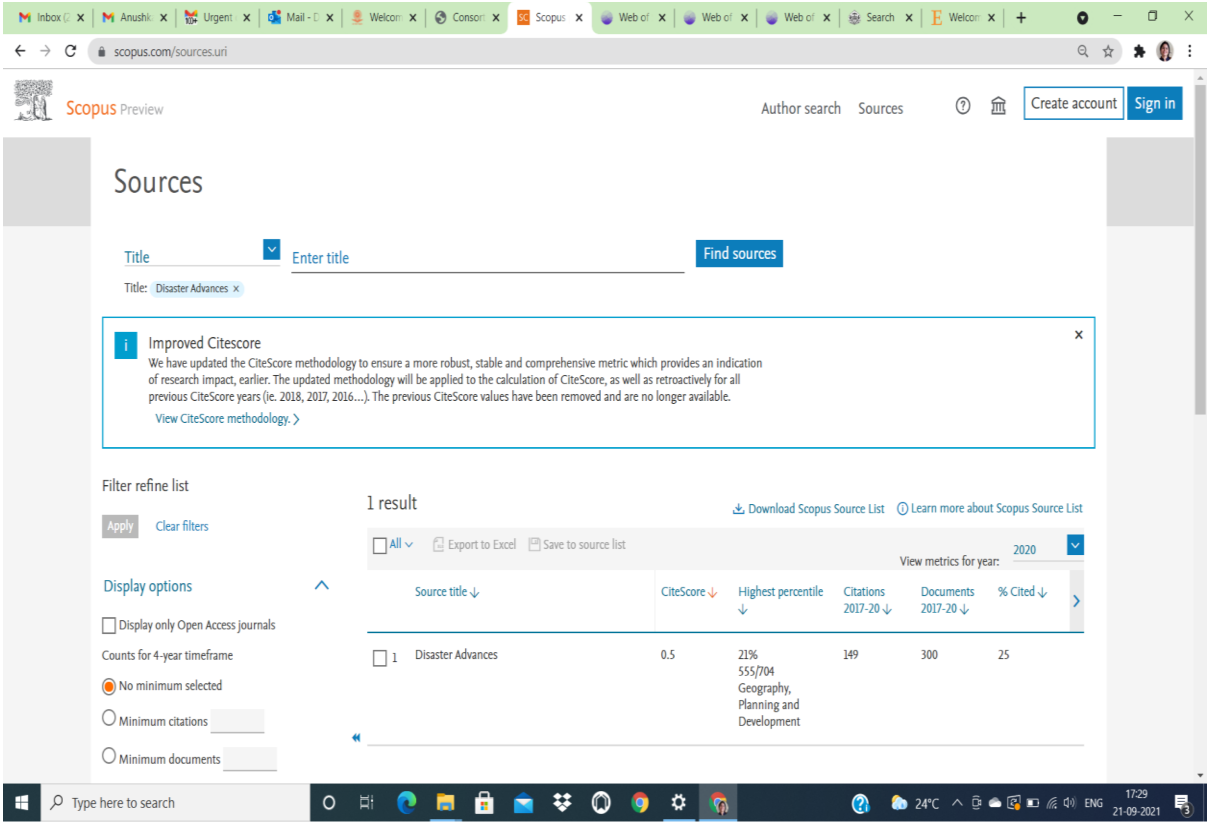
Qarout, L. (2017). *Reducing the Environmental Impacts of Building materials : Embodied energy analysis of a high performance buildings.* The University of Wisconsin-Milwaukee: P L E A.

Qarout, L. (2017). *Reducing the Environmental Impacts of Building materials : Embodied energy analysis of a high performance buildings.* The University of Wisconsin-Milwaukee: P L E A.

Qarout, L. (May 2017). *Reducing the Environmental Impacts of Building materials : Embodied energy analysis of a high performance buildings.* The University of Wisconsin-Milwaukee: P L E A.

Silvia Vilčeková, M. Č. (2015). Energy and Environmental Evaluation of Non-Transparent Constructions of Building Envelope for Wooden Houses. *energies*, 29.

Turker, D. S. (2000). *Embodied Energy.*


scopus.com/sources.uri
Scopus Preview
Author search
Sources
Create account
Sign in
Sources
Title
Enter title
Find sources
Title: Disaster Advances
Improved Citescore
We have updated the CiteScore methodology to ensure a more robust, stable and comprehensive metric which provides an indication of research impact, earlier. The updated methodology will be applied to the calculation of CiteScore, as well as retroactively for all previous CiteScore years (ie. 2018, 2017, 2016...). The previous CiteScore values have been removed and are no longer available.
View CiteScore methodology.
Filter refine list
Apply
Clear filters
Display options
Display only Open Access journals
Counts for 4-year timeframe
No minimum selected
Minimum citations
Minimum documents
1 result
Download Scopus Source List
Learn more about Scopus Source List
All
Export to Excel
Save to source list
View metrics for year:
2020
Source title
CiteScore
Highest percentile
Citations 2017-20
Documents 2017-20
% Cited
1
Disaster Advances
0.5
21%
555/704
Geography, Planning and Development
149
300
25
Type here to search
24°C
ENG
17:29
21-09-2021

Analysis of Fire hazard in healthcare Buildings through Media Elicitation

Shirolkar Meera Pankaj* and Gokhale Vasudha Ashutosh
Dr. Bhanuben Nanavati College of Architecture for Women, Karvenagar Pune, Maharashtra, INDIA
*meera.shirolkar@gmail.com

Abstract

A large number of devastating fires in Indian healthcare buildings brings out all the lacunae in the hospitals' fire safety in terms of presence of safety systems, safety regulations, fire-fighting equipment, rescue protocols and prevention mechanisms. Hospitals are spaces for care and rehabilitation. They often provide different levels of patient support. It is important that there is a safe environment for the patients and the employees that work in the hospital.

However, there are risk factors related to the building that can be a threat to the safety of the patients and employees like a fire in the building. This research presents analysis of past fire events in healthcare facilities in India. It includes evaluation of the past incidences through a systematic analysis of selected incidences based on media elicitation method aimed to find out the reasons, identify the issues related to evacuation process focusing on architectural parameters. Analysis and disseminating lessons from past incidents presented in this research are aimed to learn from past experience and thus improve future responses.

Keywords: Healthcare, Fires, Safety systems, Media elicitation.

Introduction

Fire is one of the main reasons that causes most unnatural deaths in India after road accidents and drowning. On an average, in India, every year, about 25,000 persons die due to fires occurred both in industrial and non-industrial buildings like healthcare facilities, commercial centers, institutional buildings, assembly halls, hotels, domestic buildings[5] (Fire and Security Association of India). Study of past disasters can provide valuable information about specific contexts that caused the damaging event. The complex impacts of disasters provide an impulse to learn and translate the lessons into behavioral change. Disaster is the failure of existing cognitive and material safety provisions which represent a complex phenomenon. Research regarding disasters calls for a learning process from past empirical experiences[17].

Mass media is considered as the primary source of information after environmental or man-made disasters which include television, radio, or printed media, internet-based[12] which emerged as an important communication tool[9]. Anderson[1] explains social media as a group of Internet-based applications that build on the ideological and technical basics of Web permitting the formation and exchange of user generated content. The information, amateur photos from social media become significant to disaster response efforts as they provide prompt, applicable and reliable information in the immediate post-disaster time period, activities that are developing for the reason due to persistent Information and Communication Technology[12].

This research is based on media elicitation method which is widely used method in disaster research. The information about incidences has been collected from different media sources that include digital and print media both. Each information is validated and after triangulation, the findings are analyzed.

Fire in Healthcare Facilities: Fire in healthcare facilities is a common phenomenon all over the world. In a period from 2012 to 2014, about 5,700 fires were reported in the healthcare facility in United States out of which 1,100 fires were in hospitals. The reported causes include cooking, electrical malfunction, heating and intentional actions[4] (FEMA). A fire occurred in an operation theatre at the Twenteborg Hospital Almelo, Netherlands in September 2006 with an anesthesia machine. The reason was poor maintenance of the machine which was connected to an oxygen supply that fuelled the fire which developed rapidly. Generation of a lot of heat ignited the plastic components of the machine as well as other equipment causing the fast production of smoke. The fast development of the fire made it difficult to move the patient who was fixed to a bed[7].

Fire occurred at a hospital new building in south-western South Korea on May 27, 2014 killing 21 people and injuring seven others. Out of the total casualties, one was nurse and 20 were senior patients, many of whom were hospitalized either for mental disorders or stroke complications. Out of them, hands of some dementia patients were found tied to their beds and grills were provided for the windows to prevent patients from falling out. Another incidence was Great Ormond Street Hospital fire that took place on Monday, 29th September 2008, where an oxygen cylinder blasted in a side room affecting the ceiling to collapse.

Indian Scenario: The incidences worldwide demonstrated that fire accidents can lead to a huge loss of life and assets if not handled carefully. This aspect is of prime importance in developing countries like India where a total of 18,450 cases of fire accidents were reported in 2015 with 1,193 persons injured and 17,700 killed (NCRB). The country has faced many incidences of fire breakout in healthcare buildings which resulted in considerable losses in terms of precious lives and financial assets.

SUM hospital, Bhubanaveshwara fire 2017: A fire incident occurred at the SUM hospital in Bhubanaveshwara on 17th Oct 2017 at around 7:30pm on its second-floor dialysis unit. An electrical short circuit is suspected to be the cause to trigger fire. There were 23 deaths reported due to suffocation and smoke inhalation whereas 120 were injured. Critical patients were taken off life support leading to several deaths[2].

Fig. 1: Ongoing rescue operation at SUM hospital[2].

Initially hospital staff tried to douse the fire with two fire extinguishers for nearly 20 minutes. Fire service personnel were informed when the situation went out of control. During the process, they lost the critical time for fire-fighting. The fire immediately spread through an oxygen pipeline to the dialysis unit, the intensive care unit (ICU) and the emergency ward of the hospital.

Fire tenders reached the spot and brought the fire under control. Seven fire tending vehicles took more than 2 hours to bring the blaze under control. A Bronto Sky lift has been pressed into service to rescue 500 indoor patients who were trapped in the building by breaking open door and windows. In 2013 a fire audit report had found lapses in the fire safety measures that were not fulfilled. The reason was lack of communication, negligence and lack of firefighting preparedness.

AMRI Hospital Kolkata Fire 2011: A massive fire incident occurred around 3:30 am in an annex building basement of the seven-storeyed AMRI hospital Kolkata on 9th December 2011.

The hospital authorities did not inform the fire department about the incident. It was the local police station that made the call, the fire fighting force reached the spot almost two hours late due to the narrow lane (with parking on both sides) leading to hospital building. 28 fire-tenders and three sky-lifts were pressed into action and the blaze was put out late in the afternoon. As per report the basement where the fire started, housed a pharmacy, a central storeroom and the biomedical department, all containing inflammable articles. The building was centrally air-conditioned and there was no ventilation channel for the smoke to come out. Poisonous smoke was sucked by air conditioning ducts that carried it through the rooms and the corridors of the seven-story centrally air-conditioned hospital.

The fire spread fast from the basement of the hospital, engulfing one ward after the other and trapping hundreds of people. While many patients died of burns, most died due to suffocation caused by carbon monoxide accumulation all over the building. Total 164 patients were admitted in the hospital, out of them 90 patients died mostly who were on life support system and due to asphyxiation. The survivors were shifted to five hospitals. The hospital fire safety systems were inadequate. The behavior of hospital staff and doctors was disputed as per report[15].

Fig. 2: Ongoing rescue operation at AMRI hospital.

Source: Indiatoday.in

SCB Medical college Cuttak, Odisha 2016: This is a usual case of repeated fire incidents that have taken place in SCB Medical College, Cuttak, Odisha due to inadequate firefighting preparedness and lack of safety measures. A fire was caused by a short-circuit in one of the air conditioners in the duty room of the doctors and nurses on the second floor on May 31st, 2016. Panicky situation arose when the fire broke out at 3.30pm. The authorities shifted all the patients as entire corridor and other spaces were filled with black smoke. Windowpanes were broken to create outlet for smoke.

Three fire tenders were deployed to douse the flames. Twenty fire personnel took nearly half an hour to bring the fire under control. No one was injured in the incident. The authorities had to shift out 104 patients from the wards of Institute of Cardiovascular Sciences. These included 20 patients undergoing treatment at the two intensive care units (ICU) located on the floor where the fire broke out. Inadequate fire safety measures were reported[14].

The second fire erupted in the main operation theater (OT) of surgery department at the hospital on 14th Feb, 2019. Soon after, a firefighting team started to douse the flames. Short circuit was suspected to be the cause behind the fire.

No casualty or injury was reported in the incident[11]. Fire broke out the third time on 8th April 2019 at the records section of the SCB medical college and hospital in Odisha's Cuttack city. Many important documents were reportedly reduced to ashes in the blaze. No casualties were reported. Fire department was informed, acted immediately and reached the hospital and doused the flames. The reason of the outbreak of fire is unknown[10].

ESIC Kamgar hospital, Marol, Mumbai, 2018: A fire accident took place at ESIC Kamgar hospital, Marol, Mumbai claiming the lives of 10 people on December 17, 2018. As many as 140 people were rescued from the spot. An investigation that was conducted two days later revealed that the fire was caused due to sparks flowing from a welding machine that was being operated nearby. No safety measures were adopted by the hospital and the two workers who were operating the welding workers absconded from the spot. The MIDC police arrested the contractor who got the contract for the construction happening in the hospital[2].

Fig. 3: Fire fighters dousing the fire during the rescue operations at Rohini hospital in Warangal[16].

A fire broke out in Rohini Hospital which is a three storey building in Hanamkonda Subedari, Telangana on Monday, October 2017 at 4:30 pm, when workers were replacing an oxygen cylinder in operation theatre on the third floor. It is suspected that there was a short circuit in the intensive care unit (ICU), which was located near the operation theatre on the second floor of the three-storied hospital building. It caused the blast of the oxygen cylinders, spreading the fire and thick smoke. Two surgeries were underway when the theatre caught fire. The staff of the hospital had not responded in time to rescue the patients from the operation theatre and ICU[13].

Local residents helped in evacuating patients from the operation theatre and ICU. Fire safety systems were in place but fell short in operating during the event. Panic spread as the emergency firefighting system including fire hose failed to work. The hospital did possess the no objection certificate related to fire from the GWMC. Two deaths and two severe injured patients were reported out of total 199 patients, where the rest were shifted to six other hospitals in the city.

A major fire broke out on 27th Aug, 2016 in a Government hospital's medicine department in West Bengal's Murshidabad district, killing 3 and injuring 50 children as the fire spread to the neonatal unit of the hospital on Saturday. Several more were reportedly trapped in the hospital. The fire was caused due to a short-circuit in the medicine department of the hospital. The fire spread from the AC of a VIP cabin on the first floor. Soon after the fire broke out, patients were seen coming out of the hospital while some infants were taken out of the hospital ward.

Many patients broke windows to escape from the hospital. Panic prevailed in the hospital as people ran haphazardly leading to a stampede[6]. The emergency exit door of the hospital was closed causing chaotic situation along the escape route. There was no disaster management plan in place[18]. Two fire tenders were rushed to the spot to douse the fire.

Fig. 4: Patients break windows to escape from Govt hospital in Murshidabad[6]

A fire triggered in Shishu Bhavan Pediatric Hospital situated in Cuttack on 15thNov 2015. Patients had a narrow escape on Sunday after fire broke out in the newly born children ward of the hospital. The reason for the fire is suspected to be a short circuit due to which sparks triggered out from one of the warmers meant to heal new born which was housing 20 patients, three of whom were under life supporting systems at the time of the mishap. The incident triggered panic and chaos in the ward with 22 newborns, which were evacuated by hospital staff and attendants immediately[8].The fire services department rushed with three fire tenders to the spot and the flames were brought under control after one hour. No casualty was reported.

Discussion

The major causes of fire based on analyses were electrical short circuits, presence of combustible material, deliberate human act and explosion of gas cylinder, pyro techniques, carelessness and ignorance. The major causes for casualties were found deficient in architectural planning aspects such as complex layout of building, inadequate staircases and exits, inadequate safety systems and way finding difficulties. Other reasons identified which hampered the evacuation of inhabitants were exit doors shut or opening inside, obstructed staircases and passageways, storage of gas cylinders near kitchen platform and fireworks display.

It was found that many hospital buildings were located in high density area which was accessible by narrow lanes that delayed the rescue operation and resulted in increasing the rate of casualties. Research reveals that there is a lack of study of disaster response in India with reference to fire safety from architectural perspective.

Existing codes designed for fire safety and emergency situations are based on physical characteristic and infrastructural requirements where occupant's response is not addressed adequately. Fire safety is often viewed as a provision of building and hardware systems such as fire resistance grading, fire escape, automatic sprinklers and smoke regulator.

It has been observed that these integral features do not essentially generate occupant safety at the anticipated level. It is stressed that the healthcare providers' need direction to; in what way an event command organization would take effort in a mass fatality incident and immediate role to perform in case of occurrence of fire. Most of the healthcare facilities need for basic and advanced life care, sanitization and segregation procedures, triage modus operandi, personal security mechanisms; and usage and monitoring of emergency apparatus. Safety of healthcare facilities is a serious issue to tackle this situation. Fundamental changes in health care processes, culture and the physical environment are required to facilitate the caregivers and the resources for enabling safe care.

Conclusion

History of fire occurrence is full of valuable information which needs to be studied in the present context. This research investigated the past trend of fire hazard to elucidate major factors and major fires at global as well as at national level with respect to typology of building, reported cause of fire and damage along with the casualties reported. This research provides a unique opportunity to use current and emerging evidence to improve the physical environment in healthcare facilities to render them safe from fire hazards.

References

1. Anderson R., Analysis of social network sites and supporting functions, Proceedings of the American Society for Information Science and Technology, 1-2 **(2010)**

2. Beyondcarlton, Retrieved Jan Monday, 2019, from www.beyondcarlton.org: http://www.beyondcarlton.org/7-worst-fire-accidents-india-2018/ **(2018)**

3. Debabrata M. and Pradhan A., *Times of India*, Retrieved January Monday, 2019, from https://timesofindia.indiatimes.com: https://timesofindia.indiatimes.com/city/bhubaneswar/22-killed-as-fire-engulfs-SUM-hospital-in-Bhubaneswar-manyinjured/articleshow/54903980.cms **(2016)**

4. FEMA, Retrieved from https://www.usfa.fema.gov/downloads/pdf/statistics/v14i5.pdf **(2016)**

5. Fire and Security Association of India, Retrieved August Monday, 2017, from www.fsai.in **(2013)**

6. FP S., firstpost.com. Retrieved Jan Monday, 2019, from https://www.firstpost.com: https://www.firstpost.com/india/west-bengal-fire-breaks-out-in-govt-hospital-in-murshidabad-one-dead-several-trapped-2979340.html **(2016)**

7. Hoondert, State of the art fire safety concept for evacuation of different types of vulnerable patients in dutch hospitals, Delft University of Technology **(2017)**

8. Jaiswal B., *Times of India*, Retrieved January Monday, 2019, from https://timesofindia.indiatimes.com: https://timesofindia.indiatimes.com/city/cuttack/Fire-at-Cuttacks-Sishu-Bhawan/articleshow/49968962.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst **(2015)**

9. Kawasaki A., Meguro K. and Henry M., Comparing the disaster information gathering behavior and post-disaster actions of Japanese and foreigners in the Kanto area after the 2011 Tohoku Earthquake, Proceedings of the 2012 WCEE, Lisbon, Portugal, 24-28 **(2012)**

10. Odhisha Suntimes b., *Odishasun Times*, Retrieved May Monday, 2019, from https://odishasuntimes.com: https://odishasuntimes.com/fire-breaks-out-at-scb-hospital-in-odishas-cuttack **(2019)**

11. Odisha Suntimes b., *Odishasun Times*, Retrieved May Monday, 2019, from https://odishasuntimes.com: https://odishasuntimes.com/odisha-fire-breaks-out-at-scb-hospital **(2019)**

12. Palen L., Vieweg S., Sutton J., Liu S. and Hughes A., Crisis Informatics: Studying Crisis in a Networked World, Third International Conference on e-Social Science, Ann Arbor Michigan **(2007)**

13. Reddy P.L., *Telangana Today*, Retrieved January Monday, 2019, from https://telanganatoday.com/warangal-one-dead-two-critically-injured-in-rohini-hospitals-fire **(2017)**

14. Sharma V., *Telegraph India*, Retrieved May Monday, 2019, from https://www.telegraphindia.com/states/odisha/fire-at-scb-safety-on-sickbed/cid/1506112 **(2016)**

15. Singh S.S., *The Hindu.com*, Retrieved January Monday, 2019, from https://www.thehindu.com/ news/national/other-states/90-killed-in-kolkata-hospital-fire/article2700650.ece **(2011)**

16. Telanganatoday, *Telangana Today*, Retrieved January Monday, 2019, from https://cdn.telanganatoday.com: https://cdn.telanganatoday.com/wpcontent/uploads/2017/10/Rohini-Hospitals-fire.jpg **(2017)**

17. Voss M. and Wagner K., Learning from (small) disasters, *Natural Hazards*, **55(3**), 657-669 **(2010)**

18. Yengkhom S., *Times of India*, Retrieved Jan Monday, 2019, from http://timesofindia.indiatimes.com/articleshow/53886978.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst **(2016)**.

(Received 10th March 2020, accepted 12th May 2020)

SAVITRIBAI PHULE PUNE UNIVERSITY

UGC-CARE List

Home

UGC

Search

UGC-CARE List

You searched for "**International Journal of Architecture, Engineering and Construction**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	International Journal of Architecture, Engineering and Construction	International Association for Sustainable Development and Management	1911-110X	1911-1118	from June-2019 to October- 2023	Discontinued from Oct. 2023

Showing 1 to 1 of 1 entries

Previous 1 Next

International Journal of Architecture, Engineering and Construction
Vol 9, No 1, March 2020, 12020005, 1-6

Integral Elements of Residential Liveable Environments: Private Gardens

Aarti S. Verma[1,*] and Abhijit Natu[2]

[1]Dr.B.N.College of Architecture, Savitribai Phule Pune University, Pune, India
[2]BKPS College of Architecture, Savitribai Phule Pune University, Pune, India

Abstract: Residential architecture involves private gardens as ancillary spaces mostly enabling leisure activities. Literature has substantiated role of home gardens in maintaining a healthy quality of life within cities. Based on this premise, this paper is an empirical study of 100 private residential gardens in the city of Pune (India) to understand people's association with their gardens. Random stratified sampling method is used to select private residential gardens across the city. Observation and personal in-depth interviews were used as tools of study. The qualitative methods helped in identifying the values people hold for their private gardens which were aesthetic values, ecological values, microclimate enhancement and socio-cultural values as significant attributes of private residential gardens. The original contribution of the study lies in identification of values attached to private gardens and their manifestation in garden form. The study deliberates inclusion of private open spaces within housing to have equal consideration while formulating developmental norms for housing to ensure better liveability.

Keywords: Private gardens, values, nature, healthy environment

DOI: http://dx.doi.org/10.7492/IJAEC.2020.005

1 INTRODUCTION

With growing urbanisation, housing demands in developing countries have resulted into higher density housing with smaller garden spaces. These garden spaces associated with dwelling units reciprocate the socio-economic conditions of the city-specific zones and of the current Architectural design of housing. The affluent residential designs have elaborate garden spaces whereas the informal sectors of housing have to settle with sporadic open spaces that may not have the possibility to be considered as gardens. These changes due to urbanisation have changed the morphology of private residential gardens too. The earlier low rise structures had gardens on ground, whereas with apartment culture, these garden spaces shifted from ground to their balconies and terraces. Hence today a typical developing city witnesses simultaneous coexistence of varied typologies of private residential gardens. These gardens are looked upon as open spaces planned as ancillary to the built architecture. Even though they are a by-product of architectural design they play a crucial role in ensuring Man-Nature relationship which is vital to a healthy living.

This study explores the multiple value associations of private residential gardens through qualitative analysis and asserts acknowledging their role in housing developments for a healthy living environment.

2 LITERATURE REVIEW OF PRIVATE GARDENS

Interpretation of values differs with disciplines. This study refers to values as non-economic values mostly defined in the sociological disciplines. Home gardens have affirmed horticultural values (Behe *et al.* 2003; Cerra and Crain 2016; Chengyan *et al.* 2011; Hurd Brian H. 2006; Majumdar and Selvan 2018), cultural values (Bhatti and Church 2004; Christie 2004; Kenney 2000), environmental or ecological values (Hurd 2006; Hurd Brian H. 2006; Jaganmohan *et al.* 2012; Yue *et al.* 2011) microclimate enhancement (Widiastuti *et al.* 2016), health values (Soga *et al.* 2017; Thompson 2018; Stigsdotter 2004; van Lier *et al.* 2017) and hedonistic values (Bhatti 2014; Cruz-Crdenas and Oleas 2018). They have proved to be beneficial in improving a city's sustainability (Haq 2011; Rostami *et al.* 2013). They provide settings for individual healing, convey personal meanings and memories, and reflect environmental concerns. Thus they are locales to experience diverse relationship between humans and nature (Francis and Reimann 1999). They are metaphors for the human condition which stresses the significance of gardens in deciding the quality of life (Harrison 2008).

*Corresponding author. E-mail: aarti_verma@yahoo.com

Gardens in Indian context have also exhibited strong cultural, symbolic and scientific value associations (Nagendra 2016; Natu 2017; Raveendranathan 2018; Vasudevan 2002).

Recent research has shown an enhanced preference for private open spaces attached to dwelling units (termed as garden spaces) (Dillman and Dillman 1987; Foley 1980). High rise residences with high density have restricted accessibility to green spaces on ground. Private gardens attached to residences in such cases provide for the respite to the dwellers. Studies done in Europe also suggest that providing for balcony spaces that could be converted into gardens is one of the factors for successful low or medium rise high density housing. Recommendations to include private open spaces within dwelling units has been done in housing proposals (Vasilevska and Ribar 2011). But studies have shown lesser research done focussing on natural environments within housing in spite of acknowledging their significant health contributions (Weichhart 1983). Recent study done in the city of Pune also supports urban agricultural practices carried out within residential areas adding to the sustainability to the environment (Zasada *et al.* 2018).

Literature studies have already substantiated role of home gardens in asserting health, microclimate and ecological values but quality of life is also measured in terms of the happiness quotient and satisfaction quotient of the residents. Anthropological studies have emphasized a strong correlation between connectedness with nature and happiness (Arsene 2013; Capaldi *et al.* 2014; Mayer and Frantz 2004). Intangible aspects like satisfaction and happiness play a decisive role in assessing quality of life. Home gardens become excellent locales to offer these values in urban environment. Acknowledging these multiple value associations, the study focusses on assessing value associations of private residential gardens in the city of Pune.

3 STUDY AREA

Pune is a metropolitan city, in the western part of Maharashtra State of India. It is considered as the cultural capital of Maharashtra and hence exhibits a rich socio-cultural milieu with strong cultural values in majority of its population. Also known as "The Oxford of the East" due to the renowned educational institutes it brings in a lot of population influx from the other parts of India. Its close proximity to Mumbai has induced an exponential growth in commerce and IT sector resulting into huge migration of population. These migrations have resulted into housing development especially on the fringes. The core city still retains its traditional housing typology whereas the fringes see a contemporary housing typology of affordable as well as lavish apartments. This diversity of cultural backgrounds and housing typologies makes Pune an excellent case study to understand people's association with their home gardens.

4 MATERIALS AND METHODS

To capture socio-geographic diversity of Pune city, home gardens were selected employing random stratified area cluster method for sampling. A total of 100 home gardens (10% of which were purposive samples to ensure diversity) were studied and analysed for their characteristics and people's association with them. The gardens were studied for their size and location, typology, spatial arrangements of plants and landscape elements, artefacts, and for the gardening techniques used. Further in-depth interviews were conducted with home owners engaged in shaping these gardens to understand their relationship with the gardens. The unstructured interviews lasting for around 30 minutes brought forth their aspirations and motivations for gardening, their families' involvement in making the gardens, time spent by them in their gardens and all such intangible aspects that could not be assessed through observation.

5 RESULTS AND DISCUSSION

Due to varied housing typology, the associated garden spaces could be categorised into three typologies: "Gardens on Ground" ranging from 50 m^2 to around 200 m^2, "Gardens in Balcony" ranging from 10 m^2 to 30 m^2 and "Gardens on roofs" ranging from 50 m^2 to 200 m^2. Amongst these, "Gardens on Ground" were 46%, "Gardens in Balcony" were 43% and "Gardens on Roofs" were 11%.

The expressions of these gardens were mostly influenced by personal choices and their connection with nature. Some distinctive value associations are discussed below.

5.1 Multiple Value Associations of Gardens

Majority of gardens displayed an aesthetic value depicted through use of artefacts, decorative plants and designed elements as seen in Figure 1. The spatial arrangements, the utilitarian spaces and planting palette emphasized on design approach, thus also suggesting a Prestige value to the gardens. The Traditional Cultural values were depicted through decorations done during festivals as seen in Figure 2. Culture was also depicted as a way of living rather than adhering to traditional values. Gardens were valued for health and hence medicinal plants were used, Utilitarian value was observed when productive plants were planted for their fruit and other products, love for nature and religious value was observed through associational value of plants. Gardens designed by home-owners displayed stronger anthropological association between people and nature. Past memories with nature influenced their making of gardens. Symbolism was seen as an important association through use of elements like Tulsi Vrindvan or space for *Rangoli*.

Figure 1. Garden depicting aesthetical value through use of ornamental plants and colours

Figure 2. Cultural values depicted through decorations during festival celebrations

Gardens in unplanned residential areas depicted an even stronger connection with nature. Planting was done by reuse of cartons as plant containers placed on ledges, or outside the window, over the weather sheds and along the compound wall. Presence of plants was not affected due to space restrictions. Love for nature was most strongly depicted through the smallest possible gesture of planting. Gardens in these contexts could be contemplated as an idea, an emotion and an aspiration of a leisurely activity.

Thus the physicality of gardens depicted a strong intangible association with nature visualized through aesthetical, cultural, religious and utilitarian values generating high satisfaction.

5.2 Ecological Values Supporting Local Biodiversity

These gardens exhibited the strongest connection with nature to achieve ecological value. The experiential quality of these gardens superseded its visual qualities. The demographic variables suggested that the user group was well educated and belonged to a higher economic group or middle-income group but the observation cannot be limited to this category. Role of women in gardening was also noticeable through kitchen gardens and plantations of herbs and medicinal plants. These people were also enthusiastic about reusing potted materials for planting, local tyres and unused materials for potted plants (Figure 3) and using sustainable techniques like organic manure and composting as gardening techniques (Figure 4). Ecological value was higher through the use of sustainable materials and techniques. This value correlated with love for nature too. Planting to support local biodiversity, use of sustainable techniques and materials and planting native species emerged as distinctive themes rendering ecological value to the gardens. Their ecological and biodiversity awareness enabled them to make informed choices about plant material contributing to improvement of the urban ecology. Their association with nature transcended above the temporality of garden expressions.

Figure 3. Use of unused discarded tyres for planting

Figure 4. Use of dried leaves as soil growing medium

5.3 Microclimate Enhancement through Gardens

The focus of these gardens was similar to the other two typologies with an added intent of microclimate control. Personal values and ecological values were effectively combined to achieve ambient microclimatic conditions. The case study seen in Figure 5 demonstrates use of vertical gardens and water system to cool the interiors. Attempting renewable energy measure and carving out spaces for solar panels and heaters was an important consideration too. Vertical gardening was adopted by home owners as shading devices as can be seen in Figure 6.

Figure 5. Intermittent panels of water systems along with vertical gardening cooling the internal rooms

Figure 6. Self-exploration of planting palette; Green wall used as shading device for the house

5.4 Aesthetical Values Complementing Architecture

Involvement of landscape architects and professionals to enhance architectural expression of residences through incorporation of landscape design was observed in larger gardens. This expression certainly adds up to the aesthetical value of the city. This aesthetical component in turn enhances the hedonistic value associated with the land cost.

5.5 Social Values Enhancing Urban Living for All Age Groups

Socio-economic value of private residential gardens has also been observed during the study. The informed and educated home owners have employed the village population from the fringe areas to enable growth of productive landscapes in the gardens. This has provided economic benefits to the villagers as well as it has helped transfer of traditional knowledge. The traditional cliché of gardening being women-oriented activity has also seen a change since 40% of the homeowners engaged in gardening were men. Children introduced to principles of nature turn into conscious adults with a positive outlook towards nature (Sabri and Abbaspourasadolah 2014). It was also found that children as user groups in 30% of the case studies where they were actively enthusiastic about gardening. Some of the garden enthusiasts from the sample studied have even shared their knowledge and experience of gardening on blogs. They have also earned credits by participating in various gardening competitions. Gardens have also been places for family get-togethers and social events.

All these associational values render a high hedonistic value to the gardens. People have been extremely passionate and satisfied with gardening. These gardens irrespective of their size, scale and location have been outdoor living spaces attached to houses. Not just the home owners but their families' involvement in garden making process has also been a contributing factor in their overall happiness. The complexity of overlaps of these values with each other makes it difficult to quantify their contribution and hence this study attempts to qualitatively synthesize the findings.

6 CONCLUSION

This study synthesizes value associations of 100 gardens representative of the contemporary architectural and social vocabulary. It identifies a rich diversity of associational values with private residential gardens. Utilitarian values, ecological values, aesthetical values, microclimate enhancement and socio-economic value are some of the distinctive attributes of such gardens. They become important locations for urban farming engaging all the members of the house in gardening thus encouraging people's participation in greening of the environment. This has not only promoted organic edible landscape but also gardening as a healthy activity both physically and mentally. Any Indian city today with some variations would witness similar residential gardens spaces. This study substantiates the role of home gardens towards a healthier environment but argues on the actuality of its occurrence in contemporary housing environments.

This study contemplates whether traditional housing forms facilitated better garden spaces inducing a healthy life style and whether explorations of the same house forms can happen in contemporary times. This study could be verified in other cities with varying degree of social and cultural associations too.

This study deliberates a parallel thought to research in architectural discipline addressing the impact of architectural planning on private open spaces. Hedonistic models suggesting marketing strategies using public open spaces as value indicators for housing schemes have been focussed through past studies. This study emphasizes that along with public open spaces, private open spaces are equally important in housing environments. Along with offering the tangible benefits of microclimate modifications and ecological benefits, private gardens are significant sources of intangible benefits directly affecting human life. The cultural and symbolic associations with plants, the technological advancements to improve microclimate through gardens, the socio-cultural attributes and the personal value quotients together make private residential gardens significant elements of better quality of life in urban areas.

Integrative approach towards incorporating garden places in each house would ensure better living condition at a miniscule scale and cumulatively contribute towards liveability in cities. It postulates research in architecture to also focus on changing house-forms with integrated open spaces. The study hence urges planners and designers to look upon Private open spaces attached to residences as not just ancillary spaces within the housing developments but mainstream its inclusion in planning process.

REFERENCES

Arsene, G.-G. (2013). The human-nature relationship The emergence of environmental ethics. Banat University, Timisoara, Romania, 1, 1–36.

Behe, B. K., Moore, E. H., Cameron, A., and Carter, F. S. (2003). Repositioning Selected Herbaceous Perennials as Indoor Flowering Potted Plants Using Perceptual Mapping. *HortScience*, 38(3), 460–464.

Bhatti, M. (2014). Garden Stories: Auto/biography, gender and gardening. *Sociological Research Online*, 19(3), 12. Available at: http://www.socresonline.org.uk/19/3/12.html

Bhatti, M., and Church, A. (2004). Home, the culture of nature and meanings of gardens in late modernity. *Housing Studies*, 19(1), 37–51. https://doi.org/10.1080/0267303042000152168

Capaldi, C. A., Dopko, R. L., and Zelenski, J. M. (2014). The relationship between nature connectedness and happiness: a meta-analysis. *Frontiers in Psychology*, 5(976). https://doi.org/10.3389/fpsyg.2014.00976

Cerra, J. F., and Crain, R. (2016). Urban birds and planting design: strategies for incorporating ecological goals into residential landscapes. *Urban Ecosystem*, 19:1823–1846. https://doi.org/10.1007/s11252-016-0570-0

Chengyan Yu, J. D., Bridget Behe, Charles Hall, Benjamin Campbell, and Roberto Lopez. (2011). Investigating consumer preferences for organic, local or sustainable plants. *HortScience*, 46(4), 610–615. https://doi.org/ 10.21273/HORTSCI.46.4.610

Christie, M. E. (2004). Kitchenspace, fiestas, and cultural reproduction in Mexican housełot gardens. *Geographical Review*, 94(3), 368–390.

Cruz-Crdenas, J., and Oleas, N. H. (2018). Private Urban Garden Satisfaction and Its Determinants in Quito, Ecuador. *SAGE Open*, 8(1), 2158244018767242. https:// doi.org/10.1177/2158244018767242

Dillman, J. J., and Dillman, D. A. (1987). Private Outside Space as a Factor in Housing Acceptability. *Housing and Society*, 14(1), 20–29. https://doi.org/10.1080/08882746.1987.11429989

Foley, D. L. (1980). The Sociology of Housing. *Annual Review of Sociology*, 6(1), 457–478. https://doi.org/10.1146/annurev.so.06.080180.002325

Francis, M., and Reimann, A. (1999). The California landscape garden: ecology, culture, and design. University of California Press, Berkeley, California, United States.

Haq, S. M. A. (2011). Urban green spaces and an integrative approach to sustainable environment. *Journal of environmental protection*, 2(05), 601. https://doi.org/10.4236/jep.2011.2

Harrison, R. P. (2008). Gardens: an essay on the Human Condition: University of Chicago Press, Chicago, United States.

Hurd, B. H. (2006). Water Conservation and Residential Landscapes: Household Preferences, Household Choices. *Journal of Agricultural and Resource Economics*, 31(2), 173–192. Available at: https://www.jstor.org/stable/40987314

Hurd Brian H., H. R. S., and White John M. (2006). Residential Landscapes, Homeowner Attitudes, and Waterwise Choices in New Mexico. *HortTechnology*, 16(2), 241–246. Available at: http://horttech.ashspublications.org/content/16/2/241.full.pdf+html

Jaganmohan, M., Vailshery, L., Gopal, D., and Nagendra, H. (2012). Plant diversity and distribution in urban domestic gardens and apartments in Bangalore, India. *Urban Ecosystems*, 15(4), 911–925.

Fraser, E. D., and Kenney, W. A. (2000). Cultural Background and Landscape History As Factors Affecting Perceptions Of The Urban Forest. *Journal of Arboriculture*, 26(2), 106–113.

Majumdar, T., and Selvan, T. (2018). Floristic Composition and Structure of Urban Landscapes of Agartala, Tripura. *Indian Journal of Ecology*, 45(3), 642–653.

Mayer, F., and Frantz, C. (2004). The Connectedness to Nature Scale: A Measure of Individuals' Feeling in Community with Nature. *Journal of Environmental Psychology*, 24, 503–515. https://doi.org/10.1016/j.jenvp.2004.10.001

Nagendra, H. (2016). Nature in the City: Bengaluru in the Past, Present, and Future, Oxford University Press, United States..

Natu, A. (2017). Contextualising the Landscape Design to Cultural Traditions: A Case of Community Open Spaces in Pune, India. *The International Journal of the Constructed Environment*, 8 (1), 41–52.

Raveendranathan, V. (2018). Nature in the City: Bengaluru in the Past, Present, and Future. South Asia. *Journal of South Asian Studies*, 41(3), 688–690. https://doi.org/10.1080/00856401.2018.1489753

Rostami, R., Lamit, H., Khoshnava, S. M., and Rostami, R. (2013). Urban Green Spaces and City Sustainability. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences Paper*, 15(2), 441–446.

Sabri, C. R., and Abbaspourasadolah, J. (2014). Principles of Nature in the Design of Playgrounds. *International Journal of Architecture, Engineering and Construction*, 3(3), 210–223. https://doi.org/10.7492/IJAEC.2014.017

Soga, M., Gaston, K. J., and Yamaura, Y. (2017). Gardening is beneficial for health: A meta-analysis. *Preventive Medicine Reports*, 5, 92–99. https://doi.org/10.1016/j.pmedr.2016.11.007

Thompson, R. (2018). Gardening for health: a regular dose of gardening. *Clinical Medicine*, 18(3), 201–205. https://doi.org/10.7861/clinmedicine.18-3-201

Ulrika K. Stigsdotter, P. G. (2004). A Garden at Your Doorstep May Reduce Stress -Private Gardens as Restorative Environments in the City. Available at: http://www.researchgate.net/publication/251508830

van Lier, L. E., Utter, J., Denny, S., Lucassen, M., Dyson, B., and Clark, T. (2017). Home Gardening and the Health and Well-Being of Adolescents. *Health Promot Pract*, 18(1), 34–43. https://doi.org/10.1177/1524839916673606

Vasilevska, L., and Ribar, M. (2011). Low/rise high density housing–recommendation and key principles in the process of urban and architectural design. *Thematic Proceedings: Innovation as a Function of Engineering Development–IDE*, 259–274.

Vasudevan, K. (2002). Ancient Gardens of India. Available at: http://www.chitralakshana.com/ancient-gardens.html

Weichhart, P. (1983). Assessment of the natural environment—A determinant of residential preferences. *Urban Ecology*, 7(4), 325–343. https://doi.org/ 10.1016/0304-4009(83)90019-0

Widiastuti, R., Prianto, E., and Budi, W. S. (2016). Performance Evaluation of Vertical Gardens. *International Journal of Architecture, Engineering and Construction*, 5(1), 13–20. https://doi.org/10.7492/IJAEC.2016.002

Yue, C., Dennis, J. H., Behe, B. K., Hall, C. R., Campbell, B. L., and Lopez, R. G. (2011). Investigating Consumer Preference for Organic, Local, or Sustainable Plants. *HortScience*, 46(4), 610–615.

Zasada, I., Weltin, M., Zoll, F., and Benninger, S. L. (2018). Urban Agricultural Practice in Residential Areas of Pune (India) and the Contribution to Urban Sustainability. Available at: http://ageconsearch.umn.edu/record/276992/files/509.pdf

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**International Journal of Architecture, Engineering and Construction**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	International Journal of Architecture, Engineering and Construction	International Association for Sustainable Development and Management	1911-110X	1911-1118	from June-2019 to October- 2023	Discontinued from Oct. 2023

Showing 1 to 1 of 1 entries

Previous 1 Next

International Journal of Architecture, Engineering and Construction
Vol 9, No 4, December 2020, 22020005, 1-12

Decision-Making Model of Residential Redevelopment: A Multi-Disciplinary Perspective

Vaishali Anagal[1] and Abhijit Natu[2,*]

[1]Dr. B. N. College of Architecture for Women, Maharashtra, India
[2]B. K. P. S. College of Architecture, Maharashtra, India

Abstract: Housing decisions are one of the significant life cycle events not just because housing is a basic need, but also out of the fact that it is a necessary form of an asset. The various housing decisions considered in the literature include staying, moving, and adapting in different forms. Housing decisions and housing behavior of both the owners and tenants have been well researched. However, residential redevelopment as a decision by owner-occupants seems to be unexplored in the realm of housing decisions. This paper reviews the literature on housing decisions and housing behavior of households. It borrows concepts and theories from various disciplines such as housing, economics, environmental psychology, urban geography, land economics, etc. and views it from a multi-disciplinary perspective. It elucidates the rationale of redevelopment, factors that affect residential redevelopment, and the factors that prompt households to consider redevelopment decisions over other housing decisions. This outcome and contribution are presented in conceptual and multi-disciplinary models to look at residential redevelopment as a housing decision by owner-occupants, which explains the triggers of residential redevelopment and factors that affect the decision of redevelopment based on the literature.

Keywords: House obsolescence, residential satisfaction, land economics, prospect and loss aversion, financial viability

DOI: http://dx.doi.org/10.7492/IJAEC.2020.036

1 INTRODUCTION

The redevelopment of the built environment as a phenomenon is not new. Built environments are dynamic, and people transform their environments to suit their needs. Buildings are designed for a life span. During their life cycle, buildings get transformed to cater to their users' changing requirements and aspirations. If buildings are incapable of transforming to satisfy these requirements, their useful life comes to an end. The incongruence between users' housing needs and aspirations and their current housing condition compels them to make certain housing decisions.

Along with the housing conditions and corresponding life cycle stages of occupants, many factors affect this decision-making process. Section 2 explains the rationale of redevelopment from the perspective of building conditions and land economics. At the same time, occupants' behavior, attitude, and responses to housing conditions are reviewed in section 3. In section 4, theories and concepts from various disciplines are synthesized to develop a conceptual and theoretical framework of residential redevelopment decision-making.

2 REDEVELOPMENT RATIONALE

According to Smith (1985) obsolescence of a building is an inevitable and a continuous process since buildings have limited life and become unfit for their users due to physical decay and unsuitability for everyday use (Civic Trust London 1962). Redevelopment becomes a continuous process at a city level since different parts of cities get developed at different times and face obsolescence in different degrees. The large-scale redevelopment projects under urban renewal were undertaken to overcome the social and economic decay because of blighted core areas, overcrowding, and traffic congestion in urban areas in Europe and the USA. After World War II, the devastation caused by war added to the then existing problem of the housing shortage (Grebler 1964) and necessitated urban redevelopment projects. Initially, government-led urban redevelopment projects involving total clearance and redevelopment (Wagner 1963; Edward 2014; Bello and Nwosu 2011) were carried out to give way to new buildings with mixed uses, better road network, strengthening

*Corresponding author. E-mail: vmanagal@rediffmail.com

mass transport, provision of urban amenities. Insufficient funds available with local governments to carry out this large scale redevelopment were a fundamental issue all over Europe (Grebler 1964; Wagner 1963) and other parts of the world. Therefore, other approaches like rehabilitation and upgrading (Hindman *et al.* 2015; Onkar *et al.* 2008; Smith 1985; Civic Trust London 1962), economic revitalization (Onkar *et al.* 2008; Grebler 1964; Bello and Nwosu 2011) and people-centric approach (Barosio *et al.* 2016) were subsequently developed.

From historical times, physical decay of the building and safety concerns continue to be prime stimulants of redevelopment until modern times. Spontaneous redevelopment is a natural process where redevelopment is taken by individuals or private entrepreneurs in their interests (Smith 1985). The spontaneous redevelopment in modern times cannot be attributed to the deterioration of a building due to aging. The redevelopment phenomenon can be attributed to various reasons, including physical obsolescence, functional obsolescence, and economic obsolescence (Flager 2003). The spontaneous redevelopment also targets seeking financial benefits that can be accrued out of the land's development potential. To realize the need for redevelopment, obsolescence and its various dimensions need to be understood.

2.1 Physical Obsolescence

Every building is designed for a specific period for which it can serve its intended use with anticipated maintenance but without significant repair. This is termed as its design working life (Blok *et al.* 2003). Some buildings may lead to physical obsolescence well before or after their design working life (Dias 2013). The life span for which it can function for its intended use per its structural requirements and adequate structural safety with necessary maintenance but without major repair is called technical service life (Blok *et al.* 2003). In other words, technical service life is when the structure has adequate resistance to withstand environmental actions that cause deterioration (ACI 2000). It is the period until which the structure can supply the required performance (Hermans 1999).

The technical working life of a building is dependent on physical deterioration, which further depends on various factors including building use, materials used, detailing, building location, maintenance (Hermans 1999), quality of construction and materials, the external environment in contact with the building component (Dias 2003) accessibility and ability of inspection required for maintenance (Dias 2013). Physical deterioration of a building can leads to unsafe living environments, which may further call for redevelopment. Thus, the end of technical service life is an end of a building's service life (Bradley and Kohler 2007).

2.2 Functional Obsolescence

A building's technical service life, too, does not ensure that the building will be used for its technical life span. This fact can be ascribed to the end of the functional life of a building. The functional life is when the building can fulfill its users' current functional requirements (ACI 2000). Thus, a building's useful life span for its users to build its intended purpose may be with repairs and adaptations (Hermans 1999; Blok *et al.* 2003). Frank Duffy views a building in different layers such as site, structure, skin, services, space plan, and stuff, each has different functional lives (Brand 1994), as shown in Table 1.

The functional life of structural parts is higher as compared to other parts. The skin may face aesthetic obsolescence resulting from outdated appearance due to fashion change (Flager 2003). The space plan is most subjected to change due to dynamic requirements of users arising out of change in socio-cultural profile, technology (Crowther 1999), lifestyle, aspirations and also, family size and structure (Blok *et al.* 2003; Blok and Herwijnen 2006). If a building can undergo these modifications, its functional life can be prolonged by adaptations. On the other hand, a building's inadequacy of undergoing desired modifications leads to demolition of the building and construction of a new one, i.e., redevelopment (Crowther 1999). Thus, the functional criteria of a building rather than technical criteria define its life span (Hermans 1999). According to Brookes and Huges (1975) report that redevelopment is preferred to renovation for two reasons: structural stability (physical obsolescence) and the unsuitability of the house's spatial layout to accommodate improvements, i.e., lack of adaptability.

Table 1. Duffy's shearing layers of change (Brand 1994)

Layer	Elements	Life span
Site	Geographical setting whose context and boundaries continue for generations	
Structure	The load-bearing frame of the building, including the foundation	30–300
Skin	Facade or external face of the building	Up to 20 years
Services	Electrical, HVAC system, water supply and drainage, communication services, vertical transportation	7–15 years
Space plan	Partition walls, false ceilings	3–30 years
Stuff	Furniture	Changes very often

2.3 Economic Obsolescence

Housing, a part of real estate, is viewed as a form of an asset. A real asset is a physical asset fixed at a location which can be further categorized into two parts: sites (land) and improvements (buildings) (Jaffe 1989). Both the site and building have economic value. However, the value of land appreciates, while the building's value goes on depreciating due to deterioration over some time. The loss of building value is referred to as depreciation. Depreciation may be recovered through repair and maintenance to a certain extent. However, depreciation may be incurable when repair and maintenance costs cannot be justified in economic terms. When the building faces incurable depreciation, it will undergo redevelopment as a result of market forces. Here depreciation of a building can be viewed as a significant catalyst for redevelopment (Flager 2003).

This can be further explained by Duffy's life cycle capital cost analysis, which explains investment in repair and maintenance incurred on various layers of buildings. It indicates that the cost incurred in repair and maintenance and alterations and renovations is doubled compared to the original cost of a building within a span of 50 years after the construction. As per the CPWD maintenance manual (CPWD 2012), RCC's expected economic life framed building under expected occupancy and maintenance conditions is 75 years. However, various empirical studies on the actual life of a building reveal different figures.

According to Ran (2015) the residential buildings' lifespan in four major cities of Taiwan ranges between 35–40 years. The economic life refers to the period for which a building is in use before its replacement. It is more economically advantageous than spending on its repair and maintenance for its continuation of use. The economic life of a building has an essential role in the decision of redevelopment by property owners. The literature suggests that the end of any of this lifespan or combination of these will lead to building obsolescence and necessitate consideration of the building's redevelopment.

2.4 Development Potential of Land

A decision to redevelop a residential property instead of any real estate property is quite a complex phenomenon. Physical and functional obsolescence of a building alone cannot determine redevelopment unless complemented by land development potential.

Land supply is always lesser than its demand, accelerated by increasing urbanization (Fly and Morehouse 1926). Land reuse through redevelopment has been considered an effective solution to accommodate changing and growing demands (Zhou *et al.* 2017). A Real estate developer considers a decision of investment based on returns on investments. Developers estimate depreciation of building value and appreciation of land value to define the profitability of the project. Land value is determined by land development potential. When the value of land is high enough to repay with profits, costly improvements (buildings) are considered productive (Fly and Morehouse 1926). Codes and regulations mainly govern land development potential. As pointed out by Liu *et al.* (2014) buildings are pulled down well before the end of their technical lifespan to seek quick returns on the investment due to land development potential offered by codes and regulations (Liu *et al.* 2014). China's land policy has resulted in large scale demolition and redevelopment of the residential building after 2006 (Xu *et al.* 2019). According to Liu *et al.* (2014) the average service lifespan of demolished buildings in China is 34 years, which is much shorter than its designed lifespan.

2.5 Legal Aspects

Legal aspects have a significant bearing on any land development. Land development is governed by planning legislation at the central and state level and development control regulations at the local level. Codes and regulations determine land development potential through tools such as floor space index (FSI), transferable development rights, premium FSI, etc. Other regulations, such as side margins, ground coverage, building height, permissible balcony, and terraces, affect the architectural planning to a great extent and affect the profitability of the project. Thus, the legal aspect defines the viability of any development project. Keeping in view multiple issues in the redevelopment of multi-dwelling housing projects, a redevelopment process was legally formalized in 2009 in Maharashtra State (2009) and has been recently revised in July 2019 by the Government of Maharashtra (2019), India. Thus, redevelopment projects are governed by legal aspects, including planning legislation, codes, regulations, other laws such as model-by-laws of housing societies, etc.

3 RESIDENTS' PERSPECTIVE AND THE HOUSING THEORIES

In the case of redevelopment projects taken up by owner-occupants, the decision to redevelop undergoes a critical process. Especially in the case of multi-family housing projects, it needs to be a collective decision. It is imperative to study how individual households take their housing decisions during different life cycle stages.

3.1 Housing Need Theory

Different life cycle stages lead to different spatial requirements of housing. Family size and family structure affect housing choices and decisions. As reported by Foote *et al.* (1960), the survey of consumer expenditures distinguishes eight family types based on their size and structure. This family composition, accompanied by their family income, has a bearing on their housing decisions. New families created by marriages demand either a new house or increased space in their parental house. In specific cultural settings, staying with in-laws is a common practice either out of need or custom (Ratcliff 1949). Without children, school-going children and maturing children take different housing decisions of tenure type (ownership, renting), staying, or moving for the same income group. Age and sex distribution in a family has a close relationship with the number of bedrooms. Young children below 8–10 years can share a bedroom with their parents, while children reaching puberty with different sexes need different bedrooms. Adults with different sexes but not a couple need separate sleeping rooms (Ratcliff 1949). Age of the family head is another essential criterion that defines the housing goals of a family (Ratcliff 1949; Foote *et al.* 1960).

Rossi (1955) viewed households' housing behavior taking into account the family's life cycle stages as a prime focus. He observed that a family's housing requirements change as per their life cycle stages. He drew a relationship between the size and type of household and the size and kind of space required for the family. The life cycle stages and subsequent family growth through marriages, births, and family shrinkage through deaths and divorces change the household size and, consequently, the demand for space and space. Rossi considers that changing family structure prompts changing family needs and if they perceive their current house is unfit for meeting their needs and aspirations. As a result, they get dissatisfied and decide to move out.

3.2 Housing Deficit and Adjustment Theory

Ratcliff (1949) views the social stratum as a determining factor of housing space requirements. The house's spaciousness, separate rooms of living, dining rooms, entertainment rooms, guest rooms, and servant quarters is sometimes seen as a social status measure. With increasing income, the community's prestige induces a person to buy a new house or refer one house over the other (Fly and Morehouse 1926).

The Veblenian social-psychological model of human behavior (Patsiaouras 2010) postulates that man is a social animal; his behavior conforms to the broader culture subcultures and close groups he belongs to. His present social associations shape his needs. Veblen presumes that most economic consumptions, including cars and houses, are influenced more by man's prestige seeking attitude than his needs and satisfaction (Patsiaouras 2010). In his research in mass housing using the Means-End-Chain model, Mahmud (2007) explores the influence of housing users' design expectations on housing modifications. In another study, Coolen and Hoekstra (2001) finds that their values and goals shape users' housing choices and behavior (Zinas and Jusan 2010).

Morris and Winter (1975) developed a theory of housing adjustment in which they evaluate households' housing behavior in the light of family norms and cultural norms as a core concern. They argue that households continuously review their housing conditions to verify whether it is congruent with the family norms and cultural norms. In case the household finds their housing condition not according to societal norms, it is perceived as a deficit that they call a normative housing deficit. Households respond to this housing deficit in three different ways: residential mobility, residential adaptation, family adaptation.

Morris and Winter (1975) break away from the idea of earlier researchers who claim that residential mobility is the only response to the housing dissatisfaction. They think that occupants respond to the housing deficit with other forms of housing adjustments, such as residential adaptation or family adaptation, in addition to residential mobility. Here, residential adaptation refers to modulating, rearranging the internal layout, renovating the home, changing the functions of the rooms, additions, and alterations to cater to households' changing requirements. If residential adaptation is not possible due to households' financial status, they may opt for family adaptation to bring congruity between housing conditions and family structure. Family adaptation can be related to a childbearing decision related to nuclear family formation or acceptance of living in a joint family. Childbearing plans might be postponed due to lack of space, or households likely purchase a bigger house for childbearing. In other cases, joint families may split into nuclear families to resolve the issue of space crunch.

3.3 Psychological Construct Theory

Galster (1985) disapproves of earlier researchers' approaches to consider "residential satisfaction" as the best social indicator for guiding housing policies. He hypothesized that households consciously or unconsciously rank their preferences about improving their housing condition. He coined the term "marginal housing improvement priority" to overcome the state of dissatisfaction. This is their limited wish list that can increment their "wellbeing" with each of the improvements. He argues that the indicator of "marginal housing improvement priority" provides a better understanding of housing preferences than the indicator of housing satisfaction.

According to Galster (1985), households create a reference point to evaluate each existing house's residential condition by comparing it with reference conditions. If there is conformity between existing housing conditions and the reference point, a state of "residential satisfaction" is achieved. Whereas, if the current housing is not following the reference situation beyond a specific predetermined unacceptable limit (to which Galster (1985) calls as "threshold deficiency"), households can respond in two possible ways. One, the household can overcome the state of dissatisfaction by adaptation. Here, it is essential to note that the adaptation response considered by Galster (1985) is quite different than what Morris and Winter (1975) have considered. Galster's concept of adaptation involves the adaptation of households' needs and aspirations. He believes that households adapt their needs by redefining them, reducing their aspirations, and amending their housing condition evaluation to bring in a certain degree of satisfaction. Secondly, in cases where such adaptation is not possible, households may choose to alter their dwelling or move to a suitable house over time to reduce the gap between the reference point and housing condition. However, the financial condition of households may limit the latter option.

3.4 Concept of Residential Satisfaction

Residential satisfaction is a gratification feeling when households have or achieve their required or desired house conditions (Mohit and Al-KhanbashiRaja 2014). In the residential satisfaction model Amérigo (1992) elucidates that objective aspects of residential environment when assessed by households become subjective aspects and give rise to a certain degree of satisfaction. Households' characteristics, including demographic and psychological characteristics, affect a degree of residential satisfaction, which is individuals' positive affective state about the residential environment. Amérigo (1992) considers that a level of residential satisfaction defines behavioral intentions of adaptations or mobility. Physical characteristics of house and neighborhood, demographic characteristics of households are considered to be significant determinants of residential satisfaction (Hashim 2003; Jiboye 2012; Balestra and Sultan 2013; Ibem and Amole 2013; Mohit and Al-KhanbashiRaja 2014). There is a close association between residential satisfaction and emotional attachment to the place (Liao 2004). In his empirical study on the propensity to move, Liao (2004) reveals that residential satisfaction and place attachment act as intervening factors in residential mobility. Perez *et al.* (2001) investigated the residential satisfaction of older adults in Madrid; Spain revealed that home-related aspects and neighborhood-related aspects account for the most significant factors determining residential satisfaction for older people following by building-related aspects. According to Perez *et al.* (2001), elderly residents have greater residential satisfaction owing to their length of stay and neighborhood ties, and so, they are reluctant to move. Ample literature on residential satisfaction reveals that physical characteristics of a house such as natural light and ventilation, number of rooms especially bedrooms, finishes, a state of repair and maintenance, cost of repair and maintenance, adaptability of house, infrastructure in residential environment affect level of satisfaction. This corroborates with the rationale of redevelopment explained in section 2.

3.5 Concept of Place Attachment

Residential place attachment refers to the attachment to both the home and the local area. Anton and Lawrence (2014) identify that people attached to their homes and neighborhoods experience positive health, community participation, better social and political involvement, and better quality of life. There are two components of attachment, including place identity and place dependence. According to Proshansky (1978), the place identity is associated with memories, feelings, ideas, attitudes, preferences, meanings, etc. It is also related to the behavior and experience of individuals that they get in places that fulfill their biological, psychological, social, and cultural needs (Proshansky *et al.* 1983).

Place attachment is positively correlated with length of tenure. Occupants in old developments have long associations with their homes and neighborhood. Large-scale forced redevelopment projects at the urban scale are criticized for the displacement of the original residents from the neighborhood, which results in disruption of neighborly ties and social fabric (Wu and He 2005; Wu 2016). Other residential mobility studies suggest that place attachment acts as an intervening factor in residential mobility (Clark 2017). Individuals' better attachment to their homes than to their local areas (Hidalgo and Hernandez 2001) can be explained by the defined territory of homes and individuals' more control over their space. People can also experience four identity principles with their homes: distinctiveness, continuity, self-efficacy, and self-esteem.

The spontaneous redevelopment by owner-occupants ensures continuity of place, keeping their local ties intact and ascertaining continuity of their identity. There are hardly any empirical studies that attempt to identify the role of place attachment in motivation to stay in the same place by redeveloping a housing project. It is worth studying if place attachment drives people to wait for redevelopment and undergo housing adjustments till such time.

3.6 Residential Mobility

The following aspects of residential mobility are considered to be important: (1) Existing housing conditions, current and future housing needs, and it is bearing on residential mobility (Rossi 1955; Morris and Winter 1975; Hooimeijer and Oskamp 1996). (2) Change in life cycle events such as births, deaths, job change, marriages and divorce, and its relevance to residential mobility (Ratcliff 1949; Rossi 1955; Foote *et al.* 1960). (3) Demographic characteristics as an intervening factor in mobility decisions (Ratcliff 1949; Clark 2017).

Hooimeijer and Oskamp (1996) argue that residential mobility is not only merely motivated by current needs and corresponding current housing situations. The anticipated future housing needs also stimulate it. They believe that other life goals, such as job opportunities, cohabitation, or separation with a spouse, trigger the need to move. The classic theories of Rossi (1955) and Galster (1985) and also the other empirical and theoretical studies in residential satisfaction, place attachment, and residential mobility indicate that current housing conditions and its perception by users prompt some sorts of housing decisions. Residential satisfaction, place attachment, and household demographic characteristics including age, sex, occupation status, financial status, life cycle stage, family composition, tenure type, length of tenure, etc. affect the housing decision-making process.

It is important to note that most of these empirical studies consider tenure type (ownership and rental housing) as determinants in housing decisions. However, this research does not consider "redevelopment" as a housing decision by house owners to respond to housing conditions to bring incongruity between current housing and their needs and aspirations. Apart from the factors affecting the housing decision discussed above, the "economic" factor also affects redevelopment.

3.7 Economic Theories from the Perspective of Residential Redevelopment

The understanding of land economics is essential to understand land as a commodity. Also, understanding a project's financial viability is imperative in the decision-making of residential redevelopment projects. Consumer theories pertain to the economic behavior of human beings. The relevance of these consumer theories to redevelopment processes needs to be explored.

3.7.1 Land economics

In the case of land, the land price not only includes its value but also includes its expected value. This valuation considers future prices, future demand, future incomes, and future use of the land. The land characteristic that it does not wear out through repeated use makes it different from other commodities (Fly and Morehouse 1926). Property owners are likely to have a dilemma to choose between improving the existing property to prolong its life and redeveloping it by demolition. Brookes and Huges (1975) present an economic model of choice between redevelopment and rehabilitation developed by Needleman (1965). Which considers four factors while considering this decision, which includes the rate of interest, the future length of the improved property, the difference between running costs of new and improved property, and the difference between new and improved rent returns a property. For owner-occupied residential buildings, the revenue from rent is not applicable. In this case, Brooks and Huges' modification to this model is more appropriate for applying it to owner-occupied residential buildings. They replace running costs and rents between a redeveloped and improved property with a quantified difference in the standard of accommodation between redeveloped and improved dwelling. His model postulates that property improvement is worthwhile if the capital cost of redevelopment is more than the sum of the cost of improvement and the current value of redevelopment in Y years' time and the difference in accommodation standards between a redeveloped and improved residence. As suggested by them, this cost will differ with time Y; since the rate of interest, living standards, and life expectancy of the property will change with time. The future life expectancy of building by improvements, repair, and maintenance compared to future life expectancy by redevelopment can be considered essential for decision-making. For old buildings, future life expectancy by repair and maintenance increases by 4–5 years, whereas future life expectancy by redevelopment can be increased by 35–40 years (Gajendragadkar 2018).

3.7.2 Prospect theory, loss aversion, and endowment effect

Prospect theory, loss aversion, and the concept of endowment effect from economics have been applied in the studies related to residential mobility and to study residential property development decision-making. A man tends to look for the future (prospects) and make decisions by anticipating the future. At the same time, most people are risk-averse, meaning that they dislike accepting risks while taking any decision. In making decisions by anticipating the future, man values what he has (endowments) than what he might gain (prospect) since the future is uncertain.

Clark and Lisowski (2017) use prospect and loss aversion theory to study a decision behavior in moving or staying. According to them, people look at gains and losses during the housing decision-making process. During a certain length of stay at a particular location, occupants experience certain advantages in terms of convenient shops, restaurants, and neighborly ties, etc. which create endowments for them. When combined with loss aversion attitude, the endowment effect will strengthen a decision to stay in the same location.

Bao and Meng (2017) employ prospect and loss aversion theory to study buyers' and sellers' housing prices and behavior in the housing market. They consider two reference points for house transactions, which include previous purchase price and estimated future price. The current house price is seen concerning one of these reference points, and losses and gains are calculated to decide the transaction. Kőszegi and Rabin (2006) propose that the estimated future price is considered a reference point rather than considering the previous purchase price.

In another study, Bao and Gong (2016) explore the endowment effect in housing decisions made by buyers and sellers concerning their willingness to pay (WTP) and willingness to buy (WTB). They observe the significant role of endowment in forming judgmental bias in housing decisions that they attribute to sellers' attachment to their house. As per Kahneman and Tversky (1979) proposition, losses are more painful than gains are enjoyable, which explains the seller's reluctance to sell the house at a lower price than the buying price. Sellers attempt to recover those losses with higher prices, resulting in the gap in willing to accept (WTA) and WTP. Buisson (2016) looks at sellers' behavior in two-time frames and argues that the effect of loss aversion depends on the time horizon selected by a seller. According to him, in a shorter time frame, the loss version's effect decreases the reservation value (WTA) determined by the seller, whereas it does not affect WTA in an infinite time frame. He explains these results because, in a limited (finite) period, the seller has to look at the offers available at his hand. He can either accept the best offer at a given time or wait until his WTA price is offered to him by a buyer. In a finite time-limit, a seller will have to accept the offer out of his need to move to another place, and thus, the seller is forced to accept the loss, which decreases his reservation value (WTA). Buisson (2016) further elucidates if one can keep one's house in the market without selling for an indefinite time and postpone one's decision to sell, the loss can be avoided.

The application of prospect and loss aversion theory in housing is limited to residential mobility and house transactions between buyers and sellers in routine housing market transactions. Residential redevelopment projects involve the transaction of land and building between home occupants and developers. The land is owned collectively by flat owners. They transact the land development potential with the developer to get returns in terms of the new building, site development, and other benefits. During this transaction, some losses are involved from the occupants' perspective, including land development potential and endowments related to the original house regarding its position in the building, a particular view, neighbors, etc. New building and site development with improved infrastructure as per market trends, higher specifications, monetary benefits individually and collectively and prolonged building life etc. can be regarded as gains or prospects in this transaction. Both the original flat owners and developers are bound by a specific time frame to decide on redevelopment. Many developers will be willing to bid (willingness to offer) for a redevelopment project at a given time. Simultaneously, there must be a willingness to accept any of these offers as a collective decision from existing owners. Prospects, losses, and endowment effects as prescribed by Clark and Lisowski (2017), WTA and WTP in an infinite time frame as postulated by Buisson (2016) have not been explored theoretically empirically in the decision making the process of residential redevelopment. This signifies a research gap in the literature. The theoretical adaptation of prospect theory, loss aversion, and endowments effect to a redevelopment project is presented below in Figure 1.

4 HOUSING DECISION-MAKING: SYNTHESIS OF THEORIES AND CONCEPTS

As elaborated in the literature review, the housing conditions in terms of the end of service life (physical obsolescence), the end of the functional life of the building (functional obsolescence), and the end of the economic life of the building (economic obsolescence) evoke residents to reconsider their housing situation. Along with these objective factors, households' evaluation of their housing condition and social and family norms also initiate the housing decision-making process.

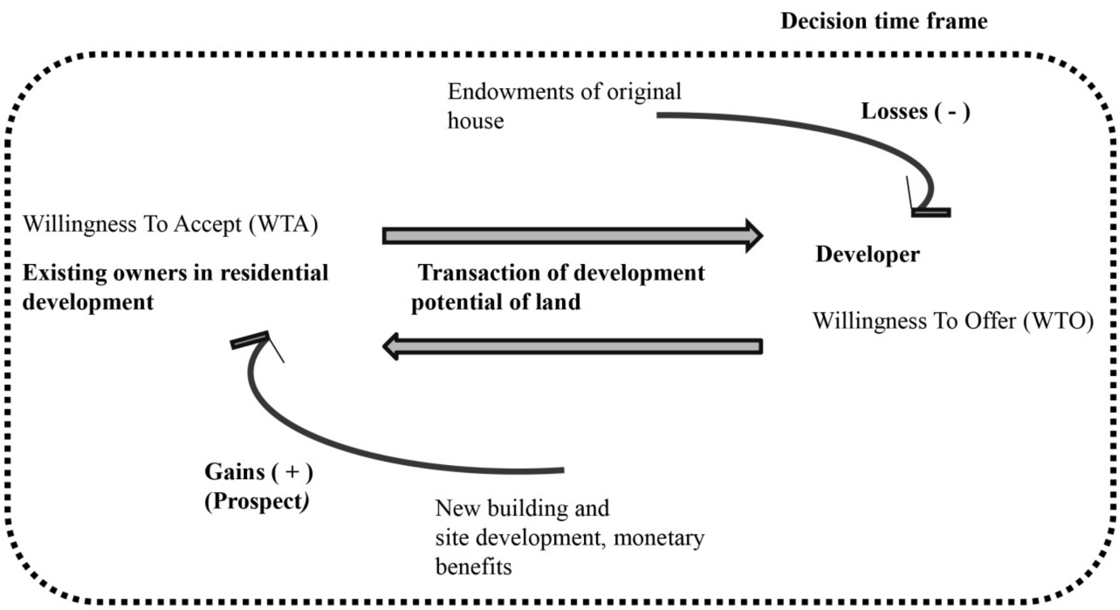


Figure 1. Adaptation of prospect and loss aversion theory to residential development projects

Rossi's housing need theory (1955) consists of residential mobility decisions due to housing dis-satisfaction arising out of the existing housing situation. Lack of congruence between housing needs arising out of life cycle stages of household and housing conditions gives the propensity to move, he believes. At the same time, Morris and Winter (1975) hypothesize that occupants keep evaluating their housing situation concerning social and family norms. A misfit between norms and actual housing conditions leads to housing dis-satisfaction, which they term as housing deficit. To overcome this housing deficit, households consider adjustments, including moving to another house, which fits into the norms, family adaptation, and dwelling adaptation. Galster (1985) adds a different behavioral dimension to the residents' perception of housing conditions. According to him, residents construct a reference condition with which they compare their current housing. If the current housing condition is beyond a specific pre-determined unacceptable limit of "dissatisfaction", residents respond through adaptation. Adding to Morris and Winter's (1975) family and dwelling adaptation, Galster (1985) conceives adaptation as another response to housing conditions where households redefine their needs and aspirations and thus, amend their evaluation of housing conditions to achieve some level of satisfaction.

It can be deducted from the literature that actual housing condition and residents' perception about these housing conditions concerning their life cycle stage (Rossi 1955), social and family norms (Morris and Winter 1975), pre-determined reference condition (Galster 1985) conceived by the users create either a state of housing satisfaction or dissatisfaction. Households are trying to attain a state of satisfaction by responding to their housing situation. In literature, five forms of responses have been discussed, including staying in the same location, moving, an adaptation of dwelling, family adaptation, an adaptation of housing needs and aspirations. It is essential to review how various factors shape these responses. Place attachment and loss aversion attitude of residents act as intervening factors for residential mobility. Life cycle stages like change in job, school going kids, family growth due to marriage or childbearing, etc. will compel residents to move to more desirable housing conditions. However, socio-economic characteristic like purchasing power of households to buy a house in another suitable location affects moving. In such a case, residents try to adapt to the current housing situation by changing external, internal finishes, changing the internal spatial layout, renovation in wet areas (kitchen and bathrooms), alterations, additions, etc. housing condition following their needs and aspirations. However, housing adaptation depends on three major factors, including tenure status, affordability, and, most importantly, the housing unit's adaptability potential. Owners have more flexibility for dwelling adaptations as compared to tenants. However, households' financial capacity to afford such adaptations will constrain this decision and compel households to consider some other form of adaptation like family adaptation or adaptation of needs and aspirations. Thus, any of the housing decisions of staying, moving, and adaptations may pose some constraints to address actual and perceived housing conditions. The development potential of land offered by development control rules can allow owner-occupants to redevelop their houses as per their needs and aspirations and overcome building obsolescence and perceived housing conditions. Redevelopment allows owner-occupants to enjoy their endowments of place attachment, neighborly ties, and convenience as postulated by Clark and Lisowski (2017) and still achieve the prospects of redevelopment such as the increased size of housing unit, improved housing condition that can satisfy their current lifestyle and needs, improved infrastructure at building and site level. Therefore, redevelopment can be considered a vital housing decision by owner-occupants when other housing decisions do not offer good congruence between actual housing conditions and the desired housing condition. The development potential of the land can offer this congruence through the redevelopment of their housing.

5 MULTI-DISCIPLINARY MODEL OF DECISION-MAKING PROCESS OF RESIDENTIAL REDEVELOPMENT

One significant theoretical gap that can be identified from literature is that "redevelopment" has not been considered a response to house owners' existing housing situation to overcome a state of dissatisfaction with current housing. Subsequently, the factors that either augment or mediate the decision to redevelop existing housing have not been discussed in depth. Housing redevelopment as a response to housing conditions is revealed through Urban Redevelopment literature. However, urban renewal is a forced decision by the local authorities under eminent domain. Residential redevelopment as a spontaneous collective decision by house owners to respond to current housing conditions needs serious research attention. Along with the other variables, such as demographic characteristics and psychological aspects of owner-occupants, land economics appear to be one of the major determinants affecting the housing decision making process. A conceptual framework is proposed to represent a housing decision-making process of redevelopment as shown in Figure 2.

The literature that needs recognition of housing decisions is triggered by current housing conditions and occupants' perception of housing conditions. To understand the notion of current housing conditions, various concepts from diverse fields are borrowed. The concept of physical obsolescence is borrowed from the field of facility management. In contrast, the idea of functional obsolescence comes from the realm of adaptable buildings, and the

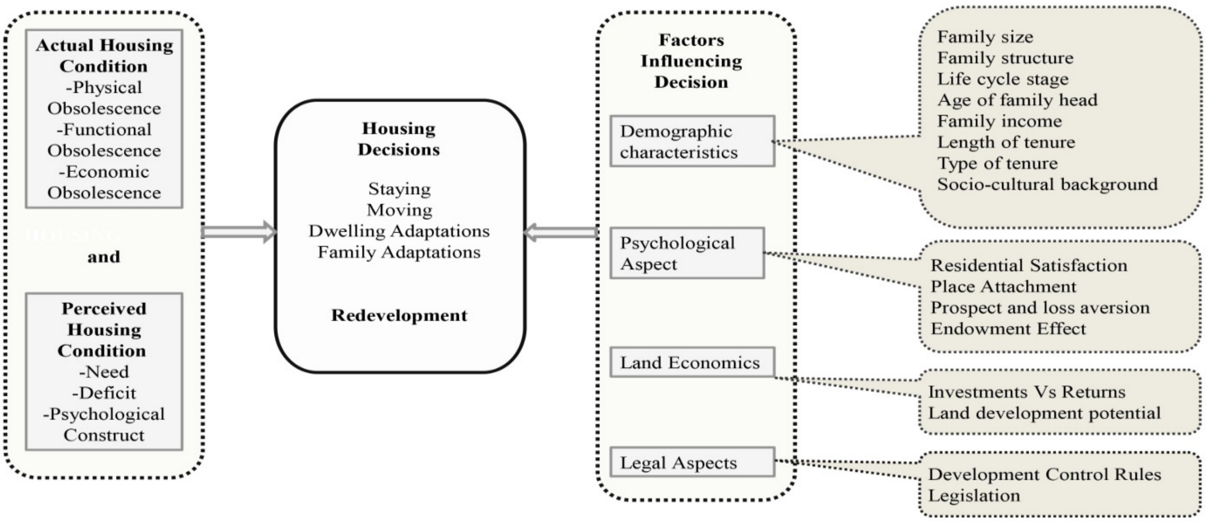


Figure 2. Conceptual model of decision making of residential redevelopment

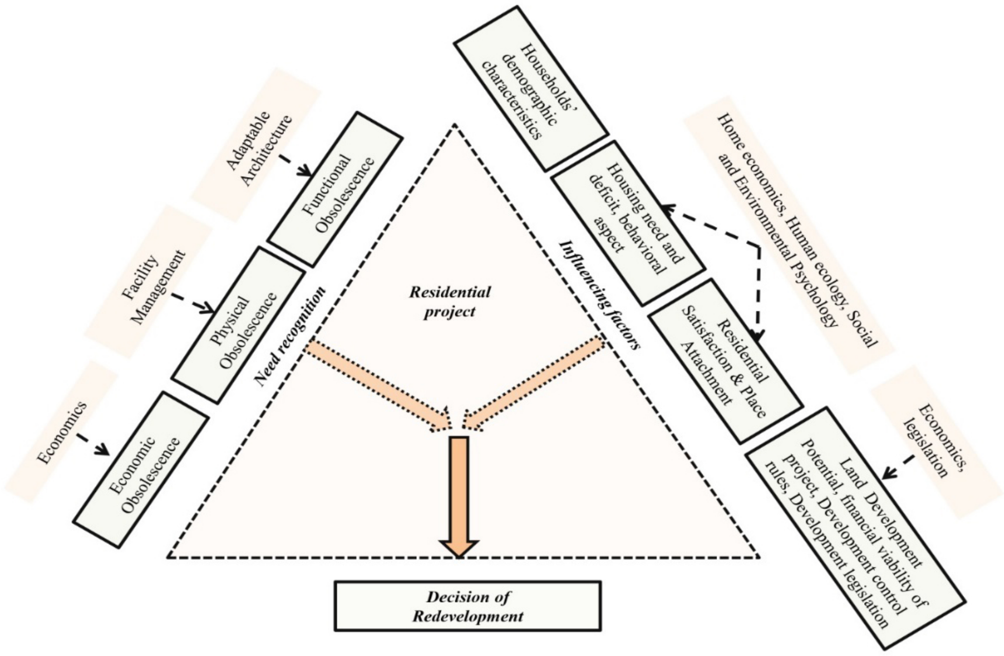


Figure 3. Multi-disciplinary model of decision making of residential redevelopment

theory of economic obsolescence is taken from real estate economics. Literature in housing behavioral theories connected with households' perception and responses to these housing conditions is borrowed from home economics, human ecology, and social psychology. Environmental psychologists conceive that residential satisfaction and place attachment and its relevance to residential mobility further explain occupants' housing behavior. Economics seems to be an essential field that cannot be discounted while considering the redevelopment of residential projects.

The application of prospect theory, the concept of loss aversion, and the endowment effect in understanding households' housing behavior have had limited application so far. These theories need further exploration in residential redevelopment decision-making, as discussed in section 3.7.2. Other economic theories such as anticipation principal in land economics, the financial viability of a project, consumer behavioral theories, and legislative aspects of redevelopment are relevant in the study of decision making of residential redevelopment. A multi-disciplinary theoretical model of decision making of residential redevelopment can be represented as below Figure 3.

6 CONCLUSIONS

The significant research gap identified from the literature is that residential redevelopment as a housing decision has not yet been studied as a house owners' response to housing conditions. This paper identifies "redevelopment" as a housing decision considered by owner-occupied housing. It can be concluded from the conceptual model developed in this research paper that "redevelopment of owner-occupied housing" is a housing decision which is triggered by actual housing condition and perceived housing condition like other housing decisions of staying, moving and adaptations. Various factors that affect this housing decision include owners' demographic characteristics, residential satisfaction, place attachment, and risk-averse attitudes. The other essential factors that affect redevelopment decisions include the project's financial feasibility and development control rules. These two factors can either promote or demote the decision of redevelopment. The redevelopment decision is taken by owner-occupants when "redevelopment" becomes more advantageous over other housing decisions. The decision of spontaneous redevelopment of owner-occupied housing can be well explained with the conceptual and multi-disciplinary model presented in this research paper.

REFERENCES

ACI Committee 365 (2000). *Service-Life Prediction - State-of-the-Art Report, Manual of Concrete Practice*, Part 5. American Concrete Institute, Farmington Hills, MI, USA.

Amérigo, M. (1992). A model of residential satisfaction. *Socio-Environmental Metamorphoses: Builtscape, Landscape, Ethnoscape*, *Proceedings of the 12th International Conference of the IAPS*, Chalkidikik, Greece.

Anton, C. E., and Lawrence, C. (2014). Home is where the heart is: the effect of place of residence on place attachment and community participation. *Journal of Environmental Psychology*, 40, 451–461. https://doi.org/10.1016/j.jenvp.2014.10.007

Balestra, C., and Sultan, J. (2013). Home sweet home: the determinants of residential satisfaction and its relation with well-being. *OECD Statistics Working Papers*. https://doi.org/10.1787/5jzbcx0czc0x-en

Bao, H. X., and Gong, C. M. (2016). Endowment effect and housing decisions. *International Journal of Strategic Property Management*, 20(4), 341–353. http://dx.doi.org/10.3846/1648715X.2016.1192069

Bao, H. X., and Meng, C. (2017). Loss aversion and residential property development decisions in the People's Republic of China: a semi-parametric estimation. Asian Development Bank Institute working paper 640. http://dx.doi.org/10.2139/ssrn.2942659

Barosio, M., Eynard, E., Marietta, C., Giulia, M., and Tabasso, M. (2016). From urban renewal to urban regeneration: classification criteria for urban interventions, Turin 1995–2015: evolution of planning tools and approaches. *Journal of Urban Regeneration and Renewal*, 9(4), 367–380.

Bello, V. A., and Nwosu, A. E. (2011). Effects of urban renewal on residential property values in two neighborhoods of Akure, Nigeria. *FUTY Journal of the Environment*, 6(2), 42–53. http://dx.doi.org/10.4314/fje.v6i2.4

Blok, R., and Herwijnen, F. V. (2006). Quantifying structural flexibility for performance-based lifecycle design of buildings. *Joint CIB, Tensinet, IASS International Conference on Adaptability in Design and Construction*, July 3–5, 2006, Eindhoven, Netherlands.

Blok, R., Herwijnen, F. V., Kozlowski, A., and Wolinski, S. (2003). Service life and life cycle of building structures. *COST C12 Seminar on Improvement of Building's Structural Quality by New Technologies*, European Commission, Brussels, Belgium.

Bradley, P. E., and Niklaus, K. (2007). Methodology for the survival analysis of urban building stocks. *Building Research and Information*, 35(5), 529–542. http://dx.doi.org/10.1080/09613210701266939

Brand, S. (1994). *How Buildings Learn: What Happens after They are Built*. Penguin Books, New York, United States of America.

Brookes, J. A., and Huges, K. (1975). Housing redevelopment and rehabilitation: a case study in comparative economics. *The Town Planning Review*, 46(2), 215–225. https://www.jstor.org/stable/40103103

Buisson, F. (2016). Prospect theory and loss aversion in the housing market. *Journal of Real Estate Research*, 38(2), 229–249. http://dx.doi.org/10.1080/10835547.2016.12091444

Civic Trust London (1962). *Urban Redevelopment*. London, United Kingdom.

Clark, W. A. (2017). Residential mobility in context: interpreting behavior in the housing market. *Papers*, 102(4), 575–605. http://dx.doi.org/10.5565/rev/papers.2411

Clark, W. A., and Lisowski, W. (2017). Prospect theory and the decision to move or stay. *Proceedings of National Academy of Sciences of the United States of America*, 114(36), 7432–7440. https://doi.org/10.1073/pnas.1708505114

Coolen, H., and Hoekstra, J. (2001). Values as determinants of preferences for housing attributes. *Journal of Housing and Built Environment*, 16, 285–306. https://doi.org/10.1023/A:1012587323814

CPWD (2012). *Central Public Works Department Maintenance Manual*. New Delhi, India.

Crowther, P. (1999). Designing for disassembly to extend service life and increase sustainability: architectural disassembly. *The 8th International Conference Durability of Building Materials and Components*, NRC-CNRC, Vancouver, Canada.

Dias, W. (2003). Useful life of buildings. University of Moratuwa, Moratuwa, Sri Lanka.

Dias, W. P. S. (2013). Factors influencing the service life of buildings. *Journal of the Institution of Engineers*, Sri Lanka, 46(4) 1–7.

Durmisevic, E. (2006). Transformable building structures: design for disassembly as a way to introduce sustainable engineering to building design & construction, Ph.D. Thesis, TU Delft, The Netherlands.

Edward, S. A. (2014). Urban renewal – a case study in Hong Kong. *FIG Congress 2014, Engaging the Challenges – Enhancing the Relevance*, Kuala Lumpur, Malaysia.

Flager, F. L. (2003). The design of building structures for improved life-cycle performance. MSc Thesis, Massachusetts Institute of Technology, Massachusetts, Unites States of America.

Fly, R., and Morehouse, E. (1926). *Elements of Land Economics*. The MacMillan Company, NewYork, United States of America.

Foote, N., Janet, A. L., Foley, M., and Winnick, L. (1960). *Housing Choices and Constraints, Action Series in Housing and Community Development*. McGraw Hill Book Company Inc., New York, United States of America.

Gajendragadkar, M. (2018). How to do a successful redevelopment of a housing society. Available at <https://youtu.be/Z0utipsa12o> (accessed on 2018/28/11).

Galster, G. C. (1985). Evaluating indicators for housing policy: residential satisfaction vs marginal improvement priorities. *Social Indicators Research*, 16(4), 415–448. https://doi.org/10.1007/BF00333289

Grebler, L. (1964). *Urban Renewal in European Countries: Its Emergence and Potentials*. University of Pennsylvania Press, Philadelphia, United States of America.

Hashim, A. H. (2003). Residential satisfaction and social integration in public low-cost housing in Malaysia. *Pertanika Journal of Social Science and Humanities*, 11(1), 1–10.

Hermans, M. (1999). Building performance starts at hand-over: the importance of life span information. *Durability of Building Materials and Components*, Ottawa ON, K1A 0R6, Canada.

Hidalgo, M.C., and Hernandez, B. (2001). Place attachment: conceptual and empirical questions. *Journal of Environmental Psychology*, 21(3), 273–281. https://doi.org/10.1006/jevp.2001.0221

Hindman, M., Olivia, L.H., Sean, M., Rao, S., Shah, Y., and Zhu, Z. (2015). addressing slum redevelopment issues in India. University of Michigan. Michigan, United States of America.

Hooimeijer, P., and Oskamp, A. (1996). A simulation model of residential mobility and housing choice. *Netherlands Journal of Housing and the Built Environment*, 11, 313–336. https://doi.org/10.1007/BF02496594

Ibem, E. O., and Amole, D. (2013). Residential satisfaction in public core housing in Abeokuta, Ogun State, Nigeria, *Social Indicators Research*, 113, 563–581.

Jaffe, A. J. (1989). Concepts of property, theories of housing, and the choice of housing policy. *The Netherlands Journal of Housing and Environmental Research*, 4(4), 311–320. https://www.jstor.org/stable/43928426

Jiboye. A. D. (2012). Post-occupancy evaluation of residential satisfaction in Lagos, Nigeria: Feedback for residential improvement. *Frontiers of Architectural Research*, 1, 236–243. https://doi.org/10.1016/j.foar.2012.08.001

Kahneman, D., and Tversky, A. (1979). Prospect theory: an analysis of decisions under risk. *Econometrica*, 47(2), 263–291. http://dx.doi.org/10.2307/1914185

Kőszegi, B., and Rabin, M. (2006). A model of reference-dependent preferences. *The Quarterly Journal of Economics*, 121(4), 1133–1165. https://doi.org/10.1093/qje/121.4.1133

Liao, P. S. (2004). Emotional attachment, residential satisfaction, and mobility propensity. *Journal of Population Study*, 28(6), 49–79.

Liu, G., Xu, K., Zhang, X., and Zhang, G. (2014). Factors influencing the service lifespan of buildings: an improved hedonic model. *Habitat International*, 43, 274–282. https://doi.org/10.1016/j.habitatint.2014.04.009

Mahmud, M. J. (2007). Identification of user's expectations in mass housing using means-end chain research model. *Journal Alam Bina*, 9(4), 1–19.

Mohit, M. A., and Al-KhanbashiRaja, A. M. (2014). Residential satisfaction, concept, theories and empirical studies. *Urban Planning and Local Governance*, III, 47–66. http://dx.doi.org/10.21837/pm.v12i3.131

Morris, E. W., and Winter, M. (1975). A theory of family housing adjustment. *Journal of Marriage and Family*, 37(1), 79–88. http://dx.doi.org/10.2307/351032

Needleman, L. (1965). *The Economics of Housing*, Staples Press, London, United Kingdom.

Onkar, P., Dhote, K., and Sharma, A. (2008). Exploring the concept of urban renewal in the Indian context. *Institute of Town Planners India Journal*, 5(2), 42 – 46.

Patsiaouras, G. (2010). Rethinking Veblen's contribution to consumer research: a phenomenological enquiry into the perception of "status consumption" by middle-income British consumers. Ph.D. Thesis, School of Management, University of Leicester, Leicester, United Kingdom.

Perez, F. R., Mayoralas, G. F., Rivera, F. E., and Abuin, J. M. (2001). Ageing in place: predictors of the residential satisfaction of elderly. *Social Indicators Research*, 54, 173–208. https://doi.org/10.1023/A:1010852607362

Proshansky, H. M. (1978). The city and self-identity. *Environment and Behavior*, 10, 147–169. https://doi.org/10.1177/0013916578102002

Proshansky, H. M., Fabian, A. K., and Kaminoff, R. (1983). Place-identity: physical world socialization of the self. *Journal of Environmental Psychology*, 3(1), 57–83. https://doi.org/10.1016/S0272-4944(83)80021-8

Ran, H. (2015). The investigation and analysis on the lifespan of residential buildings. *The 3rd International Conference on Education, Management, Arts, Economics and Social Science*, Atlantis Press.

Ratcliff, R. U. (1949). *Urban Land Economics*. McGraw Hill Book Company Inc., New York, United States of America.

Rossi, P. (1955). *Why Families Move*. Free Press, Glencoe, Scotland.

Smith, P. (1985). Comprehensive planning theory and the urban renewal program in Canada. Institute of Urban Studies, University of Winnipeg, Winnipeg, Canada.

The Government of Maharashtra, (2019). Revised Redevelopment Direction dated 4th July 2019 issued U/S 79A of MCS Act, 1960. Co-operation, Marketing and Textiles Department, Mumbai, India.

The Government of Maharastra, (2009). Directive under Section 79(A) of Maharashtra Co-operative Societies Act 1960 to all the Co-operative Housing Societies in the State of Maharashtra. Marketing and Textiles Department, Mumbai, India.

Thomsen, A., and Flier, K.V. (2011). Obsolescence, conceptual model, and proposal for case studies. *The 23rd ENHR Conference*, Toulouse, France.

Wagner, P. (1963). The scope and financing of urban renewal and development. National Planning Commission, Washington DC, United States of America.

Wu, F. (2016). State dominance in urban redevelopment: beyond gentrification in urban China. *Urban Affairs Review*, 52(5), 631–658. https://doi.org/10.1177/1078087415612930

Wu, F., and He, S. (2005). Changes in traditional urban areas and impacts of urban redevelopment: a case study of three neighborhoods in Nanjing, China. *Journal of Economic and Social Geography*, 96(1), 75–95. https://doi.org/10.1111/j.1467-9663.2005.00440.x

Xu, K., Shen, G. Q., Liu, G., and Martek, I. (2019). Demolition of existing buildings in urban renewal projects: a decision support system in the China context. *Sustainability*, 11(2). https://doi.org/10.3390/su11020491

Zhou, T., Zhao, R., and Zhou, Y. (2017). Factors influencing land development and redevelopment during China's rapid urbanization: evidence from Haikou city, 2003–2016. *Sustainability*, 9(11). https://doi.org/10.3390/su9112011

Zinas, B. Z., and Jusan, M. B. (2010). Choice behavior of housing attributes: theory and measurement. *Asian Journal of Environment-Behavior Studies*, 1–18. https://doi.org/10.21834/aje-bs.v2i2.175

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**International Journal of Architecture, Engineering and Construction**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	International Journal of Architecture, Engineering and Construction	International Association for Sustainable Development and Management	1911-110X	1911-1118	from June-2019 to October- 2023	Discontinued from Oct. 2023

Showing 1 to 1 of 1 entries

Previous 1 Next

International Journal of Architecture, Engineering and Construction
Vol 9, No 4, December 2020, 12020025, 1-11

Investigation on the Feasibility of Steel Construction Technology for Indian Residential Buildings

Poorva Kulkarni* and Vasudha Gokhale

Dr. B.N. College of Architecture for Women, Karve Nagar, Pune 52, Maharashtra, India

Abstract: Steel construction technology offers many undeniable advantages over concrete construction; however, reinforced concrete construction is used ubiquitously in India. The use of steel construction technology for housing is at a premature stage where the ambiguity and uncertainty about the qualities of this technology lead to risk-averse decisions against its use. This paper aimed to put forth the intrinsic qualities of steel construction considering sustainability aspects and cost as compared to reinforced concrete construction. To achieve this aim, steel construction technology is compared with reinforced concrete from diverse perspectives considering a residential building located at Pune, India, as a case. This research concluded that steel construction is economical, less time-consuming, structurally sound, and environment-friendly than reinforced concrete construction. This research highlighted more tangible benefits demonstrating the advantages of steel construction to inform architects and planners in order to facilitate wider adoption of steel construction in the housing sector.

Keywords: Sustainability, composite, residential building, steel construction, comparative analysis

DOI: http://dx.doi.org/10.7492/IJAEC.2020.033

1 INTRODUCTION

Population increase across the globe is coupled with the demand for building construction for residential buildings to cater to the rising need for housing. However, activities involved in the building construction process harm the environment in terms of exhaustion of natural resources, increased pollution, and waste generation significantly. It has been claimed that 40% percent of total global energy is consumed by building construction operations leading to immense exhaustion of natural resources on the earth (Akadiri *et al.* 2012). The research suggested that the building industry extracts more than 10% of the resources of fresh water, 25% of wood, and 40% of material and energy flows worldwide. It has been forecasted that the growing population and consequently increasing demand for constructional activities will result in about 60% growth in environmental impact in 2030 (Sharma *et al.* 2011). Noticeably, buildings contribute significantly to the overall addition of carbon emissions worldwide (Teng and Pan 2019). This phenomenon points towards the optimum use of energy, water, and material, and other precious natural resources for reducing the impact on ecological systems. The building sector contributes to socio-economic development. It impacts the environment not only because of the extraction of raw material and mining but manufacturing, processing, construction, maintenance, and demolition processes also consume a considerable amount of energy, and release emissions (Taha *et al.* 2016). To reduce impacts due to constructional activities, various approaches and concepts have emerged like sustainable construction, energy efficiency, ecological design, etc. (Ortiz *et al.* 2009).

Material selection always has a strong connection with an architectural design where the choice of material should focus on environmentally friendly materials. Steel is a sustainable material that offers numerous benefits that include reusability, recyclability. This quality of steel is of profound importance in developing country like India, where waste disposal at landfills is a big challenge. Currently, steel is in large-scale use in the commercial and industrial sectors as the major structural material; however, its use in the residential sector is yet to be realized. The residential building sector still uses conventional on-site construction methods, which result in extended construction time, low productivity, poor quality of construction, safety issues, and a large quantity of waste generation (Chen *et al.* 2010). Literature established an ambiguity, and uncertainty about the suitability of steel construction affects its adoption in practice. Conventional production theory postulates limitations in using emerging techniques against existing time-tested techniques, which are technically, socially, and commercially viable. The risk-averse behavior of individuals in the adoption of new technology has stimulated this research where it has been established that ambiguity and uncertainty regard-

*Corresponding author. E-mail: poorva.kulkarni@bnca.ac.in

ing an emergent technology largely affect its adoption. People adopt technology for the benefits offered rather than its characteristic features. In addition, ambiguity and risk aversion dictate the economic behavior of an individual. The lack of knowledge about steel construction and the unfamiliarity of this system results in its limited use, particularly in the construction of residential units. This research is intended to highlight the inherent characteristics of steel as a sustainable building material to advance knowledge about steel construction from different perspectives. It provides a multidimensional comparison between steel structure and reinforced concrete structure as an attempt to explore the acceptability of steel farmed buildings in residential construction, focusing on the consumption of material and resource as well as economic aspects.

2 NATURE OF CONSTRUCTION INDUSTRY

The construction industry is comprised of numerous actors involved in all the phases of the project, i.e., from the design and development phase to the end-of-life phase, referred to as the deconstruction or demolition phase. It is often defined as an industry where all parties act to design, build, alter, or maintain the built environment over its life cycle, which includes developers, planners, architects, engineers, builders, and operators. However, the construction activity is recognized as a complete process where inputs are machinery, personnel, material, and money, which are, in turn, consumed by the system to produce a building construction unit (Dozzi and AbouRizk 1993).

The Indian construction industry is considered as an underdeveloped industry due to significantly less progress in terms of research, technology awareness, and spread as compared to the advancements, which are routinely practiced in other industrial and commercial sectors. Its performance is also found lower than other industries in terms of quality of products, functionality, and overall productivity. The industry is still highly labor-intensive, operating with conventional methods while other industries move fast towards modernization and automation (Yitmen 2007). It is a project-based and service-enhanced industry that involves the collaboration of multiple participants at a single project. This phenomenon limits the adoption of innovations by and large (Xue *et al.* 2014). Researchers endorsed that the construction industry is a source-intensive industry that profoundly impacts human health and the environment. This phenomenon warrant adoption of sustainable practices in the maximum possible way in construction activities (Barrett *et al.* 2005)

3 NEED FOR SUSTAINABLE MATERIAL

The importance of sustainable material for construction and technology is not recognized in the building sector in the past, by and large. The construction sector practices attributed to a significant portion of the environmental deterioration annually, directly or indirectly (Usman 2012). According to Du Plessis (2007), agenda 21 considers sustainable construction as an integrated process intended to maintain and recreate harmony between the built and natural environment. It considers sustainable construction as an integrated process intended to maintain and recreate harmony between the built and natural environment (Kibert 2012). Research indicated that the energy efficiency of buildings could be increased by designing with good design philosophies, intelligent and thoughtful use of material and technology considering the embodied energy as well as operation and maintenance requirements (Holtzhausen 2007). Appropriate selection of building materials adds to improve the quality of the living environment. It can provide more comfort and health benefits to the occupants and help to achieve the goal of sustainable construction in the development process (Ding 2014). An energy-efficient design invariably includes incorporating the operating energy of the building in question in addition to the embodied energy, which depends on the choice of material (Ding 2014). It has been suggested that the selection of building materials should be based on performance specifications in addition to the consideration of their GHG emissions in order to contribute to minimizing environmental impacts (Du Plessis 2002).

4 ADVANTAGES OF MODERN TECHNOLOGY

Speedy construction, appropriate architectural designs, smart selection of material, and technology is the need of the day (Kasim *et al.* 2005). Prefabrication, which represents an off-site construction process and similar advanced construction methods, offers several advantages like fast construction with better quality control. It has been stated that replacing smaller bricks with large-sized boulders in the construction of pyramids uses prefabricated wall panels (Khalfan and Maqsood 2014). This phenomenon renders the use of such practices important in changing market scenarios (Gibb and Isaack 2003). Many countries adopted advanced methods of construction with the increased use of industrialized techniques, off-site production, and systematic building philosophy against conventional techniques (Pan *et al.* 2012). The techniques like prefabrication, preassembly, modularization are often collectively referred to as "prework" (Song *et al.* 2005). Large scale use of prefabricated residential buildings in the US, Japan, and many advanced countries is the testimony of this paradigm shift across the world (Barlow and Ozaki 2005). Measures have been taken by the government of the United Kingdom, promoting the use of advanced methods of construction in the housing sector where modern methods of construction are recognized as a process that produces more quality residential units in comparatively lesser time.

Some examples are off-site manufactured residential units in Germany, Australia, and industrialized houses in Malaysia (Kadir *et al.* 2006), and prefabricated high-rise residential apartments in Hong Kong (Jaillon and Poon 2009). To cater to the large scale demand for rapid and economical housing, the Chinese government has taken initiatives to shift from labor-intensive traditional constructional methods to advanced technological approach. As a result, the Chinese housing sector is aimed at the manufacturing or prefabrication of housing units (and Skitmore, (Zhang and Skitmore 2012)). This aspect is mostly missing in the Indian residential sector.

5 STEEL AS A GREEN MATERIAL FOR CONSTRUCTION

Steel has many positive environmental impacts in terms of recyclability, reusability, refurbishment, and sustainability aspects (Gorgolewski *et al.* 2006). Given the large-scale generation of construction waste, its management becomes a problem in such circumstances; recyclability and reusability of steel make it one of the most promising building materials. It is recognized that steel is a 100% recyclable material at the end of its life without loss of the material's inherent qualities (Bowyer *et al.* 2015). Concrete is also recyclable to a certain extent, but its recycling rate is significantly low as compared to steel. As per the steel recycling institute, only 50% of reinforcing bars present in concrete were recycled in the year 2006, whereas recycling of steel structural members was 95% (Petkar 2014). Steel is a unique structural material, the component of which can be effectively reprocessed. It has a closed-loop material cycle, which refers to a process of continuing materials in the life cycle with their reuse and recycling without disposing them at the end of the building or product's life cycle (Durmisevic and Noort 2003).

At the design phase, it is desirable to select environment-friendly materials that have low embodied energy as well as it must satisfy the requirement of the concepts like "design for deconstruction" (DFD) and "design for recycling" (DFR). Steel has a low embodied energy; besides, it can be used for a dismountable building system as a component made of steel can easily be separated and directly reused. In the construction phase, there is less noise and air pollution as many components are manufactured off-site, brought to the site for assembly. This phenomenon results in a reduced environmental impact; besides, steel construction is comparatively easy to maintain and offer ease of operation (Burgan *et al.* 2006). The research suggests that the reuse of building material and component result in a reduction of the embodied energy of buildings (Sattary and Thorpe 2016). Noticeably 95% of the embodied energy can be saved through the reuse of materials in construction, which in turn check environmental damages because of excessive mining (Vijayalaxmi 2010). Recycling and reuse reduce the number of primary resources needed to produce per unit of the component; besides, there are less hazardous environmental impacts (Fujita and Iwata 2008). The use of structural steel provides an opportunity to implement the sustainability criteria right from the process of extraction and beneficiation of raw materials during the design and construction of buildings up to the end of life (Saleem and Qureshi 2018).

6 ADVANTAGES OF STEEL COMPOSITE BUILDINGS

Steel-concrete composite construction is a structural system used for long-span structures having lower story heights as it offers advantages of steel and concrete, both where the qualities include high ductility, lateral stiffness, adequate fire resistance, and low material costs (Hallala 2017). It is lightweight, earthquake resistant, and offers properties like structural integrity, dimensional stability, and sound absorption properties. Besides, it takes less time to complete a project than a reinforced cement concrete (RCC) building. It is an important aspect as delay in construction results in increased cost due to construction material related causes at the pre-construction stage as well as process-related causes during the construction stage (Gebrehiwet 2017).

Although structural steel members are sleek, they are ductile and can resist impact loadings and absorb more shocks induced by external forces like earthquakes. (Zaveri *et al.* 2016). As structural steel members are slender compared to concrete structural members, they provide more carpet area, which is a very significant factor in the context of densely populated buildings in urban areas where land prices are sky-reaching.

Steel is recognized as more expensive than other materials; however, it proves to be cost-effective and affordable material if cost-saving is achieved with its use during the lifespan efficiently (Saleem and Qureshi 2018). The fact that steel is more economical than concrete is mostly unknown to the people in the absence of explicit knowledge about the actual cost difference, adequate comparative analysis, and information (Lombard 2011). The most crucial advantage is faster construction, which steel construction offers as the time required for constructing the primary structural frame and floors is about 40% faster as compared to RCC structure. As the environmental impact that a structure has is a critical consideration, 100% steel components used in steel-framed buildings could be recycled without degrading its characteristic features (Drennan 2017). Construction with steel is time-efficient, which results in saving on cost in addition to other advantages like flexibility and extended life span of steel buildings against conventional construction (Veljkovic 2016).

However, the use of steel is scant in the Indian construction industry, compared to other developed and developing countries worldwide. People still consider buildings the best option and are reluctant to switch over from RCC to steel.

7 INDIAN CONSTRUCTION SECTOR

The Indian construction industry contributes about 10% of the gross domestic product (GDP) and 51.2% of the gross fixed capital. On the other hand, this sector is held responsible for high-energy consumption, environmental pollution, solid waste generation, environmental damage, resource depletion global greenhouse gas emissions (Ortiz *et al.* 2009). The predominantly used structural materials include steel and reinforced concrete, both of which possess different characteristics in structural strength, durability, density, stiffness, and constructability. Research indicated that both the materials and their respective production flow impact the environment significantly, considering the quantity of material produced and consumed in the Indian building industry. The Indian construction industry is dominated by large-scale use of in-situ reinforced concrete, whereas steel is used as a structural material to some extent. The typical construction process for RCC includes formwork, reinforcement bars placement, and concrete pouring, which is highly time-consuming (Johnson 2006).

Currently, RCC framed buildings are perceived as the best option for construction in the housing sector in terms of technical know-how, ease in construction, and cost. The construction practices are changing at a slower pace as the use of precast RCC construction can be observed in some of the projects located in urban areas. As per the current estimate of the housing shortage in Indian urban areas accounts for 10 million units and the supply intervention is significantly less than the actual demand of the sector. The demand-supply analysis indicated that about 0.6 million residential units are required annually in the top eight Indian cities versus a supply of 0.2 million units per year, which shows the vast supply gap for urban housing. Reflecting on this use of steel-framed construction is envisaged as a suitable option that is sustainable and can satisfy the urgent need for housing in a shorter time. Besides, research indicated that steel composite structures are more economical than that of RCC structure considering speedy construction, facilitating faster return on capital investment (Dabhade *et al.* 2009).

8 RESEARCH METHOD

The case study includes a two-storied building constructed with steel located in the city of Pune. The steel and RCC buildings, which are hereafter referred to as building A and building B, respectively, are further analyzed for quantitative parameters. The parameters considered for comparison include the quantity of material used, cost of materials, time for the complete execution of the structural system, and quantity of water used in construction. The data collected for analysis is acquired from an existing steel building, as shown in Figure 1. For realistic comparison, a hypothetical RCC building was devised with a similar footprint and architectural form, as shown in Figure 2.

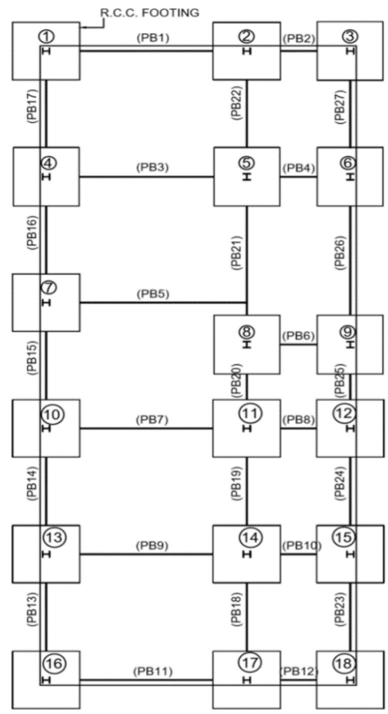


Figure 1. Building A

8.1 Building A

Building A, an existing steel composite building located in Pune, India, covering 110.92 m^2, is selected for the analysis. It is constructed with structural members made of steel with concrete decking used for floor slabs. The quantity of material used in construction is calculated for the two essential parts of the building, i.e., foundation and superstructure, as per detailed architectural drawings. For obtaining the quantities of steel consumed, the bill of quantities was referred, which included the quantity of steel for the structural members like stanchions, steel joists, decking sheets, etc. The analysis is based on the following assumptions:

(1) For steel composite building, the Fe 250 grade of steel is used.
(2) For the RCC building, the Fe 415 grade of steel is used.
(3) The density of mild steel is 7,850 kg/m^3.

The foundation of the steel building was made of RCC as a standard practice considering the threat of moisture penetration and rusting of the steel foundation if

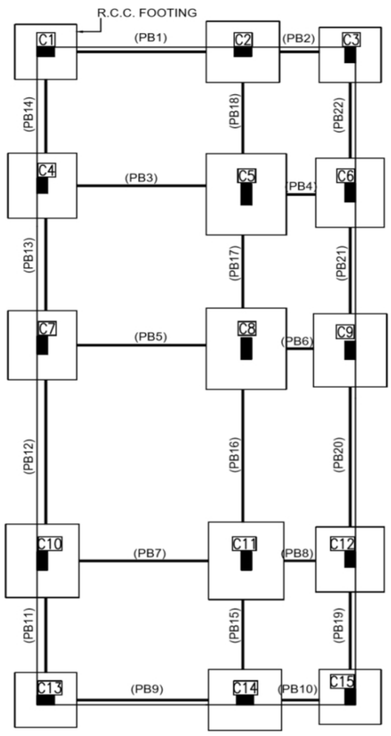


Figure 2. Building B

not covered by concrete. However, concrete is used in decking slab, plinth slab, and plinth beams. Steel is used in structural members such as steel stanchions, beams; in addition, it also includes the reinforcement bars used in RCC members. Table 1 summarises the total quantity of materials for building A.

Table 1. The total quantity of material in building A

Description	Concrete (m^3)	Steel (kg)
Substructure	31.32	48.67
Superstructure	47.41	22,011.52
Total	78.73	22,060.19

8.2 Building B

The architectural drawings were prepared for a similar building with an identical floor plan and floor area 110.92 m^2 with RCC as a structural material, which is referred to as Building B. The structural details provided by the structural engineer were considered for analysis. Table 2 summarises the total quantity of materials for building B. Detailed calculations are provided in Table B1 to Table B4 of Appendix A.

Table 2. The total quantity of material in building B

Description	Concrete (m^3)	Steel (kg)
Substructure	20.33	31.40
Superstructure	77.07	28,417.00
Total	97.40	28,448.40

Table 3 represents the overall results of the quantities for both the buildings, i.e., building A and building B, respectively.

Based on the material quantities, the cost incurred against these quantities is further explored, as shown in Table 4. The cost of steel 45 rupees per kg is considered, while the cost of 1 m^3 of concrete is considered Rs 4000 as an average cost based on the current market rates. It has been found that the cost of building B, which is constructed with RCC, is more against the material consumed as compared to building A constructed with steel as a primary structural material.

Considering the importance of time required for construction, which is a significant criterion in the present context, it is further explored for both the buildings. Based on data, it has been found that the structural part of building A was constructed in 9 weeks, the details of which are as shown in Table 5.

Literature established that buildings constructed with steel as primary structural material need less time for construction as compared to an RCC building. The time required for the construction of RCC structural members is shown in Table 6. The time required for the RCC building found more than that for a steel composite building by 9 weeks.

Literature established the importance of saving on the quantity of water in construction operations aimed at conserving natural resources. This aspect is examined in the

Table 3. Overall summary of material quantities for buildings A and B

Description	Building A steel composite building	Building B RCC building
Quantity of steel in kg	22,060.19	28,448.40
Quantity of concrete in m^3	78.73	97.40

Table 4. Cost of building materials

Building	Steel			Concrete			Total cost (rupees)
	Quantity (kg)	Rate (rupees/kg)	Cost (rupees)	Quantity (m^3)	Rate (rupees/m^3)	Cost (rupees)	
Building A	22,060.19	45	992,708.55	78.73	4,000	314,920	1,307,628.55
Building B	28,448.40	45	1,280,178.00	97.40	4,000	389,600	1,669,778.00

Table 5. Time for construction (steel building - A)

No.	Nature of work	Time (week)
1	Clearing the site centreline and excavation	1
2	Laying PCC curing	1
3	Laying steel and casting foundations	1
4	Curing	1
5	Column formwork and casting columns up to plinth	2
6	Erection of stanchions, decking slabs, and concreting	3
Total time consumed		9

Table 6. Time for construction (RCC building - B)

No.	Nature of work	Time (week)
1	Clearing the site centreline and excavation	1
2	Laying PCC curing	1
3	Laying steel and casting foundations	1
4	Curing	1
5	Column formwork and casting columns up to plinth	2
7	Centering and laying steel for plinth beams	1
8	Columns in plinth	1
9	Preparing plinth and laying PCC	2
10	Columns in the ground and first floor	2
11	First slab and beam centering, laying steel and casting slab	4
12	Curing of slab	2
Total time consumed		18

Table 7. Quantity of water required in the construction

Building	Quantity of concrete (m^3)	Quantity of water per m^3(litres)	Quantity of water consumed (litres)
Building A	78.73	180	14,171.40
Building B	94.70	180	17,532.00

context of building A and B, as shown in Table 7. Analysis indicated considerably less quantity of water required for the construction of building A as compared to building B.

9 RESULTS AND DISCUSSION

It has been found that although RCC is used as a principal structural building material for building B. It also uses steel in the form of steel reinforcement in considerable quantity. The quantity of steel used in building B was found 28,448.40 kg, which is about 22% more than that of steel in building A that accounts for 23,313.52 kg. Analysis indicated that the RCC building uses steel in large quantities in the form of reinforcement, which has resulted in significant cost implications, as steel is a comparatively cost-intensive material than concrete. As per analysis in RCC building, the total investment against steel was Rs 1,280,178.00, which is more than that of steel building that is Rs 1,051,298.55.

The quantity of concrete used for building A was marginally less than building B, which is 78.73 m^3 for steel building and 97.40 m^3 for concrete building. This is because of more quantity of concrete used in the foundation of the steel building. The concrete required for substructure in a steel building is 31.3 m^3, which is more than the quantity of concrete required for an RCC building, i.e., 20.33 m^3 due to structural requirements. Based on the quantity of concrete consumed, the cost for concrete was Rs 389,600 for building B and Rs 314,920 for building A, which is Rs 74,680 more for concrete building as compared to RCC building.

From an economic perspective, the steel building is found economical than the RCC building as the total cost of building B found Rs 1,669,778.00 against Rs 1,307,628.55 for building A. The 28% cost escalation for RCC construction indicates that the use of steel results in substantial savings.

From the environmental viewpoint, steel building was found more sustainable. The analysis indicated that the quantity of concrete in the RCC building is more than that used in the steel composite building. As concrete has less potential for recycling, it is likely to contribute to dumping subsequently, cause harm to the environment. On the other hand, the steel building uses comparatively less quantity of concrete, while a large share of material is in the form of steel that is significantly recyclable.

The water requirement for RCC structure was found17% more than that of steel composite structure, required for only deck slab, plinth slab, and foundations, which are made of concrete. This aspect suggests large saving on the water, which is a scarce resource, particularly in urban areas, in addition to saving on the cost incurred against it. Being predominantly in-situ construction, RCC construction found more time-consuming. The time required for construction for the RCC building was approx. 40% more than that required for steel building as this construction technology requires extended time for curing. The extended time may impose high costs on the initial expenditure estimates as well as delay in the occupation of the project.

Steel buildings are structurally stronger as axial forces and reactions are less in composite columns than RCC columns. Besides, steel buildings are earthquake resistant, durable, and easily reusable. One of the most significant aspects of any steel building than similar RCC buildings is a considerable saving in time. It is because the

RCC building always needs a predecessor activity completed to go further for successor activity. For example, the first floor can be constructed after the ground floor structure is completed; hence considerable time is consumed in waiting. Another is the time consumed in curing, a requirement of RCC construction to attain required structural strength. On the contrary, in a steel building, the whole structural framework can be constructed at one stretch of time, and there is no wastage of time for waiting. In the case of precast concrete slab used for decking, the time for curing is not needed.

10 CONCLUSION

This study presented a detailed account of steel construction, which is an emerging technology in the context of the Indian residential construction sector. The comparative analysis of steel building and conventional reinforced concrete buildings performed in this work revealed that steel construction possesses several benefits. It is evident that the use of steel structures results in lower negative environmental impact in energy use, consumption of raw material, and waste generation. One of the most significant features found is saving vast quantities of water, which is a valuable natural resource. This virtue of steel is valuable, considering the scarce water resources in India and global warming. Savings due to time efficiency can have a significant impact in terms of cost. It is observed that the steel-framed structures offer a comparatively shorter construction period compared to the reinforced concrete structural alternatives. This time difference can primarily be attributed to the reduction in the fabrication of components of the assembly of the steel frame for steel structure compared to an RCC building. Furthermore, its characteristics like strength, usability, durability, usability, flexibility, less weight renders steel structure more earthquake resistant. In terms of quality, it can be said that steel construction is significantly more stable as compared to reinforced concrete construction. In addition, it offers greater ease of installation of the plumbing and electrical works with more accuracy. Steel also offers architectural advantages as steel buildings can have good aesthetic appeal; besides, it is economical for mass construction. Given its recyclability and reusability, it is recognized as a sustainable material. The outcome of a comparative analysis of the cost factor is supposed to disprove the fallacy that steel construction technology is expensive. This research will help architects and designers to make rational decisions, leading to the appropriate diffusion and adoption of steel construction as an environmentally benign construction technology for residential buildings in the future.

REFERENCES

Akadiri, P., Chinyio, E., and Olomolaiye, P. (2012). Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings*, 2(2), 126–152. https://doi:10.3390/buildings2020126

Barlow, J., and Ozaki, R. (2005). Building mass customised housing through innovation in the production system: Lessons from Japan. *Environment and Planning A*, 37(1), 9–20. https://doi.org/10.1068/a3579

Barrett, J., Birch, R., Cherrett, N., and Wiedmann, T. (2005). Exploring the application of the ecological footprint to sustainable consumption policy. *Journal of Environmental Policy and Planning*, 7(4), 303–316. https://doi.org/10.1080/15239080500441095

Bowyer, J., Bratkovich, S., Fernholz, K., Frank, M., Groot, H., Howe, J., and Pepke, E. (2015). Understanding steel recovery and recycling rates and limits to recycling. Dovetail Partners Outlook.

Burgan, B. A., and Sansom, M. R. (2006). Sustainable steel construction. *Journal of Constructional Steel Research*, 62(11), 1178–1183. https://doi.org/10.1016/j.jcsr.2006.06.029

Chen, Y., Okudan, G., and Riley, D. (2010). Sustainable performance criteria for construction method selection in concrete buildings. *Automation in Construction*, 19(2), 235–244. https://doi.org/10.1016/j.autcon.2009.10.004

Dabhade, U., Hedaoo, N., Gupta, L., and Ronghe, G. (2009). Time and cost evaluation of construction of steel-framed composite floor with precast concrete floor structure. *The 26th International Symposium on Automation and Robotics in Construction*, Austin, U.S.A.

Ding, G. K. (2014). Life cycle assessment of sustainable building materials: An overview. *Eco-efficient construction and building materials*, 38–62. https://doi.org/10.1533/9780857097729.1.38

Dozzi, S., and AbouRizk, S. (1993). Productivity in construction. Institute for Research in Construction, National Research Council, Ontario, Canada.

Drennan, M. (2017). Comparative construction costs of typical low-rise office buildings in South Africa. M.E. thesis, Stellenbosch University, Stellenbosch, South Africa.

Du Plessis, C. (2002). Agenda 21 for sustainable construction in developing countries. CSIR, UNEP-IETC, Pretoria, South Africa.

Du Plessis, C. (2007). A strategic framework for sustainable construction in developing countries. *Construction Management and Economics*, 25(1), 67–76. https://doi.org/10.1080/01446190600601313

Durmisevic, E., and Noort, N. (2003). Reuse potential of steel in building construction. *The 11th Rinker International Conference: Deconstruction and materials*, Florida, United States.

Fujita, M., and Iwata, M. (2008). Reuse system of building steel structures. *Structure and Infrastructure Engineering*, 4(3), 207–220. https://doi.org/10.1080/15732470600720351

Gebrehiwet, T., and Luo, H. (2017). Analysis of delay impact on construction project based on R.I.I. and correlation coefficient. *Empirical study*, 196, 366–374. https://doi.org/10.1016/j.proeng.2017.07.212

Gibb, A., and Isaack, F. (2003). Re-engineering through preassembly: Client expectations and drivers. *Building Research and Information*, 31(2), 146–60. https://doi.org/10.1080/09613210302000

Gorgolewski, M., Straka, V., Edmonds, J., and Sergio, C. (2006). Facilitating greater reuse and recycling of structural steel in the construction and demolition process. Ryerson University, Canadian Institute of Steel Construction, Ontario, Canada.

Hallala, B. B. (2017). Cost-effectiveness of composite frames in condominium houses. Wolaita Sodo University, Wolaita Sodo, Ethiopia.

Holtzhausen, H. (2007). Embodied energy and its impact on architectural decisions. *W.I.T. Transactions on Ecology and the Environment*, 102, 377–385. https://doi.10.2495/SDP070361

Jaillon, L., and Poon, C. (2009). The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector. *Automation in Construction*, 18, 239–48. https://doi.org/10.1016/j.autcon.2008.09.002

Johnson, T. (2006). Comparison of environmental impacts of steel and concrete as building materials using the life cycle assessment method. Master's thesis, Massachusetts Institute of Technology, Massachusetts, United States.

Kadir, M., Lee, W., Jaafar, M., Sapuan, S., and Ali, A. (2006). Construction performance comparison between conventional and industrialised building systems in Malaysia. *Structural Survey*, 24(5), 412–24. https://doi.org/10.1108/02630800610712004

Kasim, N., Anumba, C., and Dainty, A. (2005). Improving materials management practices on fast-track construction projects. *Proceedings Twenty-First Annual Association of Researchers in Construction Management (ARCOM) Conference*, London, UK.

Khalfan, M., and Maqsood, T. (2014). Current state of off-site manufacturing in Australian and Chinese residential construction. *Journal of Construction Engineering*, 1–5. http://dx.doi.org/10.1155/2014/164863.

Kibert, C. (2012). *Sustainable Construction Green Building Design and Delivery.* 3rd Edition, John Wiley and Sons, New Jersey, United States.

Lombard, A. (2011). Decision making between hybrid and in-situ concrete construction in South Africa. Ph.D. thesis, Stellenbosch University, Stellenbosch, South Africa.

Ortiz, O., Castells, F., and Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, 23(1), 28–39. https://doi.org/10.1016/j.conbuildmat.2007.11.012

Pan, W., Dainty, A., and Gibb, A. (2012). Establishing and weighing decision criteria for building system selection in housing construction. *Proceedings of 11th joint C.I.B., ASCE Journal of Construction Engineering and Management, Prefabrication in Construction*, Helsinki, Finland.

Petkar, S. (2014). Environmental Impact of Construction Materials and Practices. Ph.D. thesis, National Institute of Construction Management and Research, Pune, India.

Saleem, M., and Qureshi, H. (2018). Design solutions for sustainable construction of pre-engineered steel buildings. *Sustainability*, 10(6), 1761. https://doi.org/10.3390/su10061761

Sattary, S., and Thorpe, D. (2016). Potential carbon emission reductions in Australian construction systems through bioclimatic principles. *Sustainable Cities and Society*. 23, 105–113. https://doi.org/10.1016/j.scs.2016.03.006

Sharma, A., Saxena, A., Sethi, M., Shree, V., and Varun (2011). Life cycle assessment of buildings: A review. *Renewable and Sustainable Energy Reviews*, 15(1), 871–875. https://doi.org/10.1016/j.rser.2010.09.008

Song, J., Fagerlund, W., Haas, C., Tatum, C., and Vanegas, J. (2005). Considering prework on industrial projects. *Journal of Construction Engineering and Management*, 131(6), 723–733. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:6(723)

Taha, S., Ibrahim, M., and Ali, A. (2016). Steel as a Sustainable Choice Towards the Green Building Concept. WIT Press, Southampton, U.K.

Teng, Y., and Pan, W. (2019). Systematic embodied carbon assessment and reduction of prefabricated high-rise public residential buildings in Hong Kong. *Journal of Cleaner Production*, 238, 117791. doi:https://doi.org/10.1016/j.jclepro.2019.117791

Usman, A. U., and Khamidi, M.F. (2012). Sustainable building material for green building construction, conservation, and refurbishing. *Conference on Management in Construction Research Association (MiCRA)*, Kuala Lumpur, Malaysia.

Veljkovic, M. (2016). *Sustainable Steel Buildings: A Practical Guide for Structures and Envelopes.* John Wiley and Sons, New Jersey, United States.

Vijayalaxmi, J. (2010). Towards sustainable architecture–a case with greentainer. Local environment, 15(3), 245–259. https://doi.org/10.1080/13549830903575596

Xue, X., Zhang, R., and Dai, J. (2014). Innovation in construction: A critical review and future research. *International Journal of Innovation Science*, 6(2), 111–126.https://doi.org/10.1260/1757-2223.6.2.111

Yitmen, I. (2007). The challenge of change for innovation in construction: A North Cyprus perspective. *Building and Environment*, 42(3), 1319–1328. https://doi.org/10.1016/j.buildenv.2005.10.032

Zaveri, B., Gadhiya, J., and Dhameliya, H. (2016). A review on the comparative study of steel, RCC and composite building. *International Journal of Innovative Research in Science, Engineering and Technology*, 5(1), 354–365. https://doi:10.15680/IJIRSET.2015.0501045

Zhang, X., and Skitmore, M. (2012). Industrialized housing in China: A coin with two sides. *International Journal of Strategic Property Management*, 16(2), 143–157. https://doi.org/10.3846/1648715X.2011.638945

APPENDIX A: DETAILED CALCULATIONS FOR BUILDINGS A AND B

A BUILDING A

A.1 Substructure

The quantity of concrete in the substructure included the lower part PCC bed and upper part column footing up to the plinth level (RCC Stubs). The quantity of concrete used in the lower and upper part of the foundation for 18 steel stanchions is calculated, as shown in Table A1 and Table A2.

The total quantity of concrete for substructure (A+B) is equal to 31.32 m^3. Since the foundation for a steel building is made of RCC, which includes cement concrete with steel bars used as reinforcement, the quantity of which is calculated as per the thumb rules used by RCC consultants concerning IS code 456 (plain and reinforced concrete), which is 0.02% of the volume of concrete. Therefore, the quantity of steel reinforcement @ 0.02% of 31.32 m^3 is equal to 0.0062 m^3. Upon converting it into kilograms by using the density of 7,850 kg/m^3, it comes out to be 48.67 kg.

A.2 Superstructure

A.2.1 Quantity of concrete and steel in slabs and plinth beams

The quantity of concrete used in the steel superstructure is calculated for concrete filling for decking slab, PCC for plinth slab, and plinth beams are explained as follows.

The quantity of steel includes steel reinforcement in two decking slabs. In contrast, steel reinforcement in the plinth slab is negligible and thus not considered for analysis, but the calculation includes steel reinforcement for the plinth beams. The area of the decking slab is 110.72 m^2 (6.86 × 16.14), and the steel reinforcement @ 6.10 kg/m^2 is calculated to be 684.252 kg; thus, for two decking slabs, the quantity of steel is 1,350.78 kg. For plinth beams, the quantity of concrete is 6.47 m^3, the quantity of steel @ 6% of the volume of concrete is 0.38 m^3, and the quantity of steel considering the density of steel @ 7,850 kg/m^3 is 2,983 kg.

A.2.2 Quantity of steel in stanchions

Universal columns (152 × 152 × 30) were used for providing 18 stanchions with 5.84 m length (height of two floors, i.e., G+1).

The total mass of steel required for stanchions is 5.844 × 30 × 18 = 3,156.00 Kg.

A.2.3 Quantity of steel in primary and secondary beams

Sixteen primary beams (narrow parallel flange beam) were used in both orthographic directions are used as primary beams with the following details:

Size = 250 mm × 150 mm.

Weight @ 34.08 kg/m.

Length in X-direction = 6.86 m.

Weight = 6.86 × 34.08 = 233.78 kg.

Weight of 16 beams = 233.78 × 16 = 3,740.48 kg.

Weight of beams at two floors = 3,740.48 × 2 = 7,480.96 kg.

Length in Y-direction = 32.28 m.

Weight = 32.28 × 34.08 = 1,100.102 kg.

Weight of beams at two floors = 1,100.102 × 2 = 2,200.20 kg.

Total weight = 7,480.96 + 2,200.20 = 9,681.16 kg.

Table A1. Quantity of concrete in the lower part (A) of the foundation

Column numbers	Size of PCC bed (L × B × D)	Number	Quantity (m^3)	Size of column footing (L × B × D)	Number	Quantity (m^3)	Total quantity (m^3)
C1, C2, C3, C4, C5, C6, C7, C8, C9 C10, C11, C12, C13, C14, C15, C16, C17, C18	1.75 × 1.75 × 0.15 = 0.45	18	8.10	1.40 × 1.48 × 0.45 = 0.96	18	17.28	8.10 + 17.28 = 25.38

Table A2. Quantity of concrete in the upper part (B) of the foundation

RCC stubs column numbers	Column size (L × B × D)	Numbers	Quantity (m^3)
C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18	0.55 × 0.58 × 1.05 = 0.33	18	5.94

For secondary beams, the weight is considered 50% of the primary beams, i.e., 9,681.16/2 = 4,840.58 kg. Therefore, the total steel in beams = 9,681.16 + 4,840.58 = 14,521.74 kg. Table A3 shows the total quantity of steel for the superstructure.

Table A3. The total quantity of steel for the superstructure

No.	Item	Quantity (kg)
1	Steel reinforcement in decking slabs	1,350.78
2	Steel reinforcement in plinth beams	2,983.00
3	Steel Stanchions	3,156.00
4	Primary and secondary beams	14,521.74
	Total	22,011.52

B BUILDING B

B.1 Substructure

It included PCC bed and column footing up to the plinth level in the lower part, while the upper part includes the stub column from the foundation up to the plinth level. Quantity for concrete in the lower part and upper part of the foundation is calculated for 15 number of RCC columns as per the structural plan, which is presented in Table B1 and Table B2, respectively.

The quantity of concrete in RCC substructure = 19.08+1.25 = 20.33 m^3.

The quantity of steel reinforcement in the RCC substructure @ 0.02% of concrete volume, i.e., 0.004 m^3 is 31.40 kg with the density of steel 7,850 kg/m^3.

B.2 Superstructure

The quantity of concrete and steel reinforcement for beams, slabs, columns are further obtained based on detailed drawings for building B. The quantity of concrete in beams per floor is obtained for 7 numbers of beams, the details of which are shown in Table B3.

The quantity of concrete for beams on three floors is 6.47 × 3 = 19.41 m^3.

The quantity of concrete for three 0.15 mm thick RCC slabs and 15 number of RCC columns is further calculated, as shown in Table B4.

Quantity of concrete for two lower and one roof slab = 16.60 × 3 = 49.80 m^3.

Quantity for columns in two floors = 3.93 × 2 = 7.86 m^3.

Table B1. Quantity for concrete in the lower part of the foundation

Column nos.	Size of PCC bed (L × B × D)	Numbers	Quantity (m^3)	Size of column footing (L × B × D)	Numbers	Quantity (m^3)	Total quantity (m^3)
C1, C13	1.35 × 1.35 × 0.15 = 0.27	2	0.54	1.50 × 1.50 × 0.55 = 0.61	2	1.21	1.75
C2, C12, C14	1.50 × 1.60 × 0.15 = 0.36	3	1.08	1.20 × 1.30 × 0.50 = 0.78	3	2.34	3.42
C3, C15	1.35 × 1.35 × 0.15 = 0.27	2	0.54	1.50 × 1.05 × 0.55 = 0.60	2	1.21	1.75
C4	1.50 × 1.60 × 0.15 = 0.36	1	0.36	1.20 × 1.30 × 0.55 = 0.85	1	0.85	1.21
C5, C8	1.75 × 2.00 × 0.15 = 0.52	2	1.05	1.45 × 1.70 × 0.55 = 1.35	2	2.71	3.76
C6, C7	1.50 × 1.70 × 0.15 = 0.38	2	0.76	1.20 × 1.40 × 0.55 = 0.92	2	1.84	2.60
C9, C10	1.60 × 1.80 × 0.15 = 0.43	2	0.86	1.30 × 1.50 × 0.55 = 1.07	2	2.14	3.00
C11	1.60 × 1.90 × 0.15 = 0.46	1	0.45	1.30 × 1.60 × 0.55	1	1.14	1.59
			5.64			13.44	19.08

Table B2. Quantity of concrete in the upper part of foundation B

Column nos.	Column size (L × B × D)	Numbers	Volume (m^3)
C1, C2, C3, C4, C9, C10, C11, C12, C13, C14, C15	0.23 × 0.38 × 1.05 = 0.09	11	0.99
C5, C8	0.23 × 0.53 × 1.05 = 0.12	2	0.24
C6, C7	0.23 × 0.45 × 1.05 = 0.10	2	0.20
Quantity of concrete for the upper part of foundation (B)			1.25

Table B3. Quantity of concrete in beams

Name	Size: (L × B × D)	Number	Total quantity (m^3)
B1	$6.25 \times 0.23 \times 0.45 = 0.646$	5	3.23
B2	$15.68 \times 0.23 \times 0.45 = 1.62$	2	3.24
	Total		6.47

Table B4. Quantity of concrete in RCC slab and column per floor

Name	Size (L × B × D)	Number	Quantity (m^3)
Slab	$6.86 \times 16.14 \times 0.15 = 16.60$	1	16.60
Column C1 to C15	$0.23 \times 0.38 \times 3.0 = 0.26$	15	3.93

Quantity of concrete for RCC superstructure = 19.41 m^3+ 49.80 m^3+ 7.86 m^3 = 77.07 m^3.

The total quantity of concrete in building B (Substructure and superstructure):

77.07 + 20.33 = 97.4 m^3.

Steel reinforcement is to be calculated based on the volume of concrete used, which is excluding plinth slab as reinforcement used for it is negligible.

The quantity of concrete for RCC slab = 77.07 - 16.60 = 60.47 m^3.

The quantity of steel reinforcement is 6% of the total volume = 3.62 m^3.

The quantity of steel @ 7,850 kg/m^3 = 28,417 kg.

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**International Journal of Architecture, Engineering and Construction**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	International Journal of Architecture, Engineering and Construction	International Association for Sustainable Development and Management	1911-110X	1911-1118	from June-2019 to October- 2023	Discontinued from Oct. 2023

Showing 1 to 1 of 1 entries

Previous 1 Next

International Journal of Architecture, Engineering and Construction
Vol 9, No 4, December 2020, 12020025, 1-11

Investigation on the Feasibility of Steel Construction Technology for Indian Residential Buildings

Poorva Kulkarni* and Vasudha Gokhale

Dr. B.N. College of Architecture for Women, Karve Nagar, Pune 52, Maharashtra, India

Abstract: Steel construction technology offers many undeniable advantages over concrete construction; however, reinforced concrete construction is used ubiquitously in India. The use of steel construction technology for housing is at a premature stage where the ambiguity and uncertainty about the qualities of this technology lead to risk-averse decisions against its use. This paper aimed to put forth the intrinsic qualities of steel construction considering sustainability aspects and cost as compared to reinforced concrete construction. To achieve this aim, steel construction technology is compared with reinforced concrete from diverse perspectives considering a residential building located at Pune, India, as a case. This research concluded that steel construction is economical, less time-consuming, structurally sound, and environment-friendly than reinforced concrete construction. This research highlighted more tangible benefits demonstrating the advantages of steel construction to inform architects and planners in order to facilitate wider adoption of steel construction in the housing sector.

Keywords: Sustainability, composite, residential building, steel construction, comparative analysis

DOI: http://dx.doi.org/10.7492/IJAEC.2020.033

1 INTRODUCTION

Population increase across the globe is coupled with the demand for building construction for residential buildings to cater to the rising need for housing. However, activities involved in the building construction process harm the environment in terms of exhaustion of natural resources, increased pollution, and waste generation significantly. It has been claimed that 40% percent of total global energy is consumed by building construction operations leading to immense exhaustion of natural resources on the earth (Akadiri *et al.* 2012). The research suggested that the building industry extracts more than 10% of the resources of fresh water, 25% of wood, and 40% of material and energy flows worldwide. It has been forecasted that the growing population and consequently increasing demand for constructional activities will result in about 60% growth in environmental impact in 2030 (Sharma *et al.* 2011). Noticeably, buildings contribute significantly to the overall addition of carbon emissions worldwide (Teng and Pan 2019). This phenomenon points towards the optimum use of energy, water, and material, and other precious natural resources for reducing the impact on ecological systems. The building sector contributes to socio-economic development. It impacts the environment not only because of the extraction of raw material and mining but manufacturing, processing, construction, maintenance, and demolition processes also consume a considerable amount of energy, and release emissions (Taha *et al.* 2016). To reduce impacts due to constructional activities, various approaches and concepts have emerged like sustainable construction, energy efficiency, ecological design, etc. (Ortiz *et al.* 2009).

Material selection always has a strong connection with an architectural design where the choice of material should focus on environmentally friendly materials. Steel is a sustainable material that offers numerous benefits that include reusability, recyclability. This quality of steel is of profound importance in developing country like India, where waste disposal at landfills is a big challenge. Currently, steel is in large-scale use in the commercial and industrial sectors as the major structural material; however, its use in the residential sector is yet to be realized. The residential building sector still uses conventional on-site construction methods, which result in extended construction time, low productivity, poor quality of construction, safety issues, and a large quantity of waste generation (Chen *et al.* 2010). Literature established an ambiguity, and uncertainty about the suitability of steel construction affects its adoption in practice. Conventional production theory postulates limitations in using emerging techniques against existing time-tested techniques, which are technically, socially, and commercially viable. The risk-averse behavior of individuals in the adoption of new technology has stimulated this research where it has been established that ambiguity and uncertainty regard-

*Corresponding author. E-mail: poorva.kulkarni@bnca.ac.in

ing an emergent technology largely affect its adoption. People adopt technology for the benefits offered rather than its characteristic features. In addition, ambiguity and risk aversion dictate the economic behavior of an individual. The lack of knowledge about steel construction and the unfamiliarity of this system results in its limited use, particularly in the construction of residential units. This research is intended to highlight the inherent characteristics of steel as a sustainable building material to advance knowledge about steel construction from different perspectives. It provides a multidimensional comparison between steel structure and reinforced concrete structure as an attempt to explore the acceptability of steel farmed buildings in residential construction, focusing on the consumption of material and resource as well as economic aspects.

2 NATURE OF CONSTRUCTION INDUSTRY

The construction industry is comprised of numerous actors involved in all the phases of the project, i.e., from the design and development phase to the end-of-life phase, referred to as the deconstruction or demolition phase. It is often defined as an industry where all parties act to design, build, alter, or maintain the built environment over its life cycle, which includes developers, planners, architects, engineers, builders, and operators. However, the construction activity is recognized as a complete process where inputs are machinery, personnel, material, and money, which are, in turn, consumed by the system to produce a building construction unit (Dozzi and AbouRizk 1993).

The Indian construction industry is considered as an underdeveloped industry due to significantly less progress in terms of research, technology awareness, and spread as compared to the advancements, which are routinely practiced in other industrial and commercial sectors. Its performance is also found lower than other industries in terms of quality of products, functionality, and overall productivity. The industry is still highly labor-intensive, operating with conventional methods while other industries move fast towards modernization and automation (Yitmen 2007). It is a project-based and service-enhanced industry that involves the collaboration of multiple participants at a single project. This phenomenon limits the adoption of innovations by and large (Xue *et al.* 2014). Researchers endorsed that the construction industry is a source-intensive industry that profoundly impacts human health and the environment. This phenomenon warrant adoption of sustainable practices in the maximum possible way in construction activities (Barrett *et al.* 2005)

3 NEED FOR SUSTAINABLE MATERIAL

The importance of sustainable material for construction and technology is not recognized in the building sector in the past, by and large. The construction sector practices attributed to a significant portion of the environmental deterioration annually, directly or indirectly (Usman 2012). According to Du Plessis (2007), agenda 21 considers sustainable construction as an integrated process intended to maintain and recreate harmony between the built and natural environment. It considers sustainable construction as an integrated process intended to maintain and recreate harmony between the built and natural environment (Kibert 2012). Research indicated that the energy efficiency of buildings could be increased by designing with good design philosophies, intelligent and thoughtful use of material and technology considering the embodied energy as well as operation and maintenance requirements (Holtzhausen 2007). Appropriate selection of building materials adds to improve the quality of the living environment. It can provide more comfort and health benefits to the occupants and help to achieve the goal of sustainable construction in the development process (Ding 2014). An energy-efficient design invariably includes incorporating the operating energy of the building in question in addition to the embodied energy, which depends on the choice of material (Ding 2014). It has been suggested that the selection of building materials should be based on performance specifications in addition to the consideration of their GHG emissions in order to contribute to minimizing environmental impacts (Du Plessis 2002).

4 ADVANTAGES OF MODERN TECHNOLOGY

Speedy construction, appropriate architectural designs, smart selection of material, and technology is the need of the day (Kasim *et al.* 2005). Prefabrication, which represents an off-site construction process and similar advanced construction methods, offers several advantages like fast construction with better quality control. It has been stated that replacing smaller bricks with large-sized boulders in the construction of pyramids uses prefabricated wall panels (Khalfan and Maqsood 2014). This phenomenon renders the use of such practices important in changing market scenarios (Gibb and Isaack 2003). Many countries adopted advanced methods of construction with the increased use of industrialized techniques, off-site production, and systematic building philosophy against conventional techniques (Pan *et al.* 2012). The techniques like prefabrication, preassembly, modularization are often collectively referred to as "prework" (Song *et al.* 2005). Large scale use of prefabricated residential buildings in the US, Japan, and many advanced countries is the testimony of this paradigm shift across the world (Barlow and Ozaki 2005). Measures have been taken by the government of the United Kingdom, promoting the use of advanced methods of construction in the housing sector where modern methods of construction are recognized as a process that produces more quality residential units in comparatively lesser time.

Some examples are off-site manufactured residential units in Germany, Australia, and industrialized houses in Malaysia (Kadir *et al.* 2006), and prefabricated high-rise residential apartments in Hong Kong (Jaillon and Poon 2009). To cater to the large scale demand for rapid and economical housing, the Chinese government has taken initiatives to shift from labor-intensive traditional constructional methods to advanced technological approach. As a result, the Chinese housing sector is aimed at the manufacturing or prefabrication of housing units (and Skitmore, (Zhang and Skitmore 2012)). This aspect is mostly missing in the Indian residential sector.

5 STEEL AS A GREEN MATERIAL FOR CONSTRUCTION

Steel has many positive environmental impacts in terms of recyclability, reusability, refurbishment, and sustainability aspects (Gorgolewski *et al.* 2006). Given the large-scale generation of construction waste, its management becomes a problem in such circumstances; recyclability and reusability of steel make it one of the most promising building materials. It is recognized that steel is a 100% recyclable material at the end of its life without loss of the material's inherent qualities (Bowyer *et al.* 2015). Concrete is also recyclable to a certain extent, but its recycling rate is significantly low as compared to steel. As per the steel recycling institute, only 50% of reinforcing bars present in concrete were recycled in the year 2006, whereas recycling of steel structural members was 95% (Petkar 2014). Steel is a unique structural material, the component of which can be effectively reprocessed. It has a closed-loop material cycle, which refers to a process of continuing materials in the life cycle with their reuse and recycling without disposing them at the end of the building or product's life cycle (Durmisevic and Noort 2003).

At the design phase, it is desirable to select environment-friendly materials that have low embodied energy as well as it must satisfy the requirement of the concepts like "design for deconstruction" (DFD) and "design for recycling" (DFR). Steel has a low embodied energy; besides, it can be used for a dismountable building system as a component made of steel can easily be separated and directly reused. In the construction phase, there is less noise and air pollution as many components are manufactured off-site, brought to the site for assembly. This phenomenon results in a reduced environmental impact; besides, steel construction is comparatively easy to maintain and offer ease of operation (Burgan *et al.* 2006). The research suggests that the reuse of building material and component result in a reduction of the embodied energy of buildings (Sattary and Thorpe 2016). Noticeably 95% of the embodied energy can be saved through the reuse of materials in construction, which in turn check environmental damages because of excessive mining (Vijayalaxmi 2010). Recycling and reuse reduce the number of primary resources needed to produce per unit of the component; besides, there are less hazardous environmental impacts (Fujita and Iwata 2008). The use of structural steel provides an opportunity to implement the sustainability criteria right from the process of extraction and beneficiation of raw materials during the design and construction of buildings up to the end of life (Saleem and Qureshi 2018).

6 ADVANTAGES OF STEEL COMPOSITE BUILDINGS

Steel-concrete composite construction is a structural system used for long-span structures having lower story heights as it offers advantages of steel and concrete, both where the qualities include high ductility, lateral stiffness, adequate fire resistance, and low material costs (Hallala 2017). It is lightweight, earthquake resistant, and offers properties like structural integrity, dimensional stability, and sound absorption properties. Besides, it takes less time to complete a project than a reinforced cement concrete (RCC) building. It is an important aspect as delay in construction results in increased cost due to construction material related causes at the pre-construction stage as well as process-related causes during the construction stage (Gebrehiwet 2017).

Although structural steel members are sleek, they are ductile and can resist impact loadings and absorb more shocks induced by external forces like earthquakes. (Zaveri *et al.* 2016). As structural steel members are slender compared to concrete structural members, they provide more carpet area, which is a very significant factor in the context of densely populated buildings in urban areas where land prices are sky-reaching.

Steel is recognized as more expensive than other materials; however, it proves to be cost-effective and affordable material if cost-saving is achieved with its use during the lifespan efficiently (Saleem and Qureshi 2018). The fact that steel is more economical than concrete is mostly unknown to the people in the absence of explicit knowledge about the actual cost difference, adequate comparative analysis, and information (Lombard 2011). The most crucial advantage is faster construction, which steel construction offers as the time required for constructing the primary structural frame and floors is about 40% faster as compared to RCC structure. As the environmental impact that a structure has is a critical consideration, 100% steel components used in steel-framed buildings could be recycled without degrading its characteristic features (Drennan 2017). Construction with steel is time-efficient, which results in saving on cost in addition to other advantages like flexibility and extended life span of steel buildings against conventional construction (Veljkovic 2016).

However, the use of steel is scant in the Indian construction industry, compared to other developed and developing countries worldwide. People still consider buildings the best option and are reluctant to switch over from RCC to steel.

7 INDIAN CONSTRUCTION SECTOR

The Indian construction industry contributes about 10% of the gross domestic product (GDP) and 51.2% of the gross fixed capital. On the other hand, this sector is held responsible for high-energy consumption, environmental pollution, solid waste generation, environmental damage, resource depletion global greenhouse gas emissions (Ortiz *et al.* 2009). The predominantly used structural materials include steel and reinforced concrete, both of which possess different characteristics in structural strength, durability, density, stiffness, and constructability. Research indicated that both the materials and their respective production flow impact the environment significantly, considering the quantity of material produced and consumed in the Indian building industry. The Indian construction industry is dominated by large-scale use of in-situ reinforced concrete, whereas steel is used as a structural material to some extent. The typical construction process for RCC includes formwork, reinforcement bars placement, and concrete pouring, which is highly time-consuming (Johnson 2006).

Currently, RCC framed buildings are perceived as the best option for construction in the housing sector in terms of technical know-how, ease in construction, and cost. The construction practices are changing at a slower pace as the use of precast RCC construction can be observed in some of the projects located in urban areas. As per the current estimate of the housing shortage in Indian urban areas accounts for 10 million units and the supply intervention is significantly less than the actual demand of the sector. The demand-supply analysis indicated that about 0.6 million residential units are required annually in the top eight Indian cities versus a supply of 0.2 million units per year, which shows the vast supply gap for urban housing. Reflecting on this use of steel-framed construction is envisaged as a suitable option that is sustainable and can satisfy the urgent need for housing in a shorter time. Besides, research indicated that steel composite structures are more economical than that of RCC structure considering speedy construction, facilitating faster return on capital investment (Dabhade *et al.* 2009).

8 RESEARCH METHOD

The case study includes a two-storied building constructed with steel located in the city of Pune. The steel and RCC buildings, which are hereafter referred to as building A and building B, respectively, are further analyzed for quantitative parameters. The parameters considered for comparison include the quantity of material used, cost of materials, time for the complete execution of the structural system, and quantity of water used in construction. The data collected for analysis is acquired from an existing steel building, as shown in Figure 1. For realistic comparison, a hypothetical RCC building was devised with a similar footprint and architectural form, as shown in Figure 2.

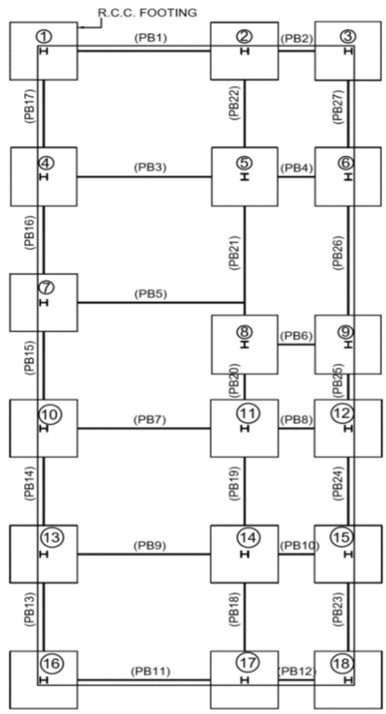


Figure 1. Building A

8.1 Building A

Building A, an existing steel composite building located in Pune, India, covering 110.92 m^2, is selected for the analysis. It is constructed with structural members made of steel with concrete decking used for floor slabs. The quantity of material used in construction is calculated for the two essential parts of the building, i.e., foundation and superstructure, as per detailed architectural drawings. For obtaining the quantities of steel consumed, the bill of quantities was referred, which included the quantity of steel for the structural members like stanchions, steel joists, decking sheets, etc. The analysis is based on the following assumptions:

(1) For steel composite building, the Fe 250 grade of steel is used.
(2) For the RCC building, the Fe 415 grade of steel is used.
(3) The density of mild steel is 7,850 kg/m^3.

The foundation of the steel building was made of RCC as a standard practice considering the threat of moisture penetration and rusting of the steel foundation if

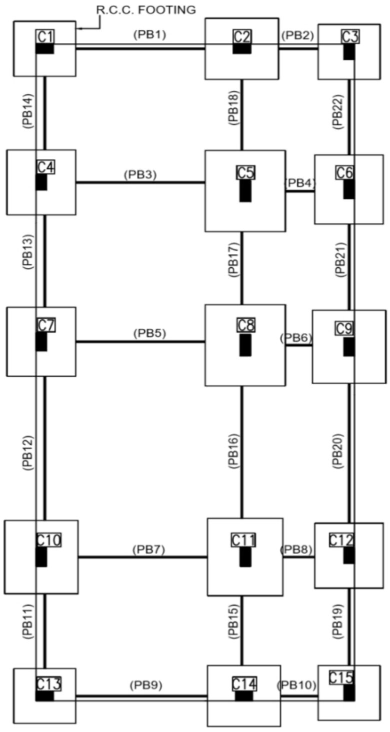


Figure 2. Building B

not covered by concrete. However, concrete is used in decking slab, plinth slab, and plinth beams. Steel is used in structural members such as steel stanchions, beams; in addition, it also includes the reinforcement bars used in RCC members. Table 1 summarises the total quantity of materials for building A.

Table 1. The total quantity of material in building A

Description	Concrete (m^3)	Steel (kg)
Substructure	31.32	48.67
Superstructure	47.41	22,011.52
Total	78.73	22,060.19

8.2 Building B

The architectural drawings were prepared for a similar building with an identical floor plan and floor area 110.92 m^2 with RCC as a structural material, which is referred to as Building B. The structural details provided by the structural engineer were considered for analysis. Table 2 summarises the total quantity of materials for building B. Detailed calculations are provided in Table B1 to Table B4 of Appendix A.

Table 2. The total quantity of material in building B

Description	Concrete (m^3)	Steel (kg)
Substructure	20.33	31.40
Superstructure	77.07	28,417.00
Total	97.40	28,448.40

Table 3 represents the overall results of the quantities for both the buildings, i.e., building A and building B, respectively.

Based on the material quantities, the cost incurred against these quantities is further explored, as shown in Table 4. The cost of steel 45 rupees per kg is considered, while the cost of 1 m^3 of concrete is considered Rs 4000 as an average cost based on the current market rates. It has been found that the cost of building B, which is constructed with RCC, is more against the material consumed as compared to building A constructed with steel as a primary structural material.

Considering the importance of time required for construction, which is a significant criterion in the present context, it is further explored for both the buildings. Based on data, it has been found that the structural part of building A was constructed in 9 weeks, the details of which are as shown in Table 5.

Literature established that buildings constructed with steel as primary structural material need less time for construction as compared to an RCC building. The time required for the construction of RCC structural members is shown in Table 6. The time required for the RCC building found more than that for a steel composite building by 9 weeks.

Literature established the importance of saving on the quantity of water in construction operations aimed at conserving natural resources. This aspect is examined in the

Table 3. Overall summary of material quantities for buildings A and B

Description	Building A steel composite building	Building B RCC building
Quantity of steel in kg	22,060.19	28,448.40
Quantity of concrete in m^3	78.73	97.40

Table 4. Cost of building materials

Building	Steel			Concrete			Total cost (rupees)
	Quantity (kg)	Rate (rupees/kg)	Cost (rupees)	Quantity (m^3)	Rate (rupees/m^3)	Cost (rupees)	
Building A	22,060.19	45	992,708.55	78.73	4,000	314,920	1,307,628.55
Building B	28,448.40	45	1,280,178.00	97.40	4,000	389,600	1,669,778.00

Table 5. Time for construction (steel building - A)

No.	Nature of work	Time (week)
1	Clearing the site centreline and excavation	1
2	Laying PCC curing	1
3	Laying steel and casting foundations	1
4	Curing	1
5	Column formwork and casting columns up to plinth	2
6	Erection of stanchions, decking slabs, and concreting	3
Total time consumed		9

Table 6. Time for construction (RCC building - B)

No.	Nature of work	Time (week)
1	Clearing the site centreline and excavation	1
2	Laying PCC curing	1
3	Laying steel and casting foundations	1
4	Curing	1
5	Column formwork and casting columns up to plinth	2
7	Centering and laying steel for plinth beams	1
8	Columns in plinth	1
9	Preparing plinth and laying PCC	2
10	Columns in the ground and first floor	2
11	First slab and beam centering, laying steel and casting slab	4
12	Curing of slab	2
Total time consumed		18

Table 7. Quantity of water required in the construction

Building	Quantity of concrete (m^3)	Quantity of water per m^3(litres)	Quantity of water consumed (litres)
Building A	78.73	180	14,171.40
Building B	94.70	180	17,532.00

context of building A and B, as shown in Table 7. Analysis indicated considerably less quantity of water required for the construction of building A as compared to building B.

9 RESULTS AND DISCUSSION

It has been found that although RCC is used as a principal structural building material for building B. It also uses steel in the form of steel reinforcement in considerable quantity. The quantity of steel used in building B was found 28,448.40 kg, which is about 22% more than that of steel in building A that accounts for 23,313.52 kg. Analysis indicated that the RCC building uses steel in large quantities in the form of reinforcement, which has resulted in significant cost implications, as steel is a comparatively cost-intensive material than concrete. As per analysis in RCC building, the total investment against steel was Rs 1,280,178.00, which is more than that of steel building that is Rs 1,051,298.55.

The quantity of concrete used for building A was marginally less than building B, which is 78.73 m^3 for steel building and 97.40 m^3 for concrete building. This is because of more quantity of concrete used in the foundation of the steel building. The concrete required for substructure in a steel building is 31.3 m^3, which is more than the quantity of concrete required for an RCC building, i.e., 20.33 m^3 due to structural requirements. Based on the quantity of concrete consumed, the cost for concrete was Rs 389,600 for building B and Rs 314,920 for building A, which is Rs 74,680 more for concrete building as compared to RCC building.

From an economic perspective, the steel building is found economical than the RCC building as the total cost of building B found Rs 1,669,778.00 against Rs 1,307,628.55 for building A. The 28% cost escalation for RCC construction indicates that the use of steel results in substantial savings.

From the environmental viewpoint, steel building was found more sustainable. The analysis indicated that the quantity of concrete in the RCC building is more than that used in the steel composite building. As concrete has less potential for recycling, it is likely to contribute to dumping subsequently, cause harm to the environment. On the other hand, the steel building uses comparatively less quantity of concrete, while a large share of material is in the form of steel that is significantly recyclable.

The water requirement for RCC structure was found17% more than that of steel composite structure, required for only deck slab, plinth slab, and foundations, which are made of concrete. This aspect suggests large saving on the water, which is a scarce resource, particularly in urban areas, in addition to saving on the cost incurred against it. Being predominantly in-situ construction, RCC construction found more time-consuming. The time required for construction for the RCC building was approx. 40% more than that required for steel building as this construction technology requires extended time for curing. The extended time may impose high costs on the initial expenditure estimates as well as delay in the occupation of the project.

Steel buildings are structurally stronger as axial forces and reactions are less in composite columns than RCC columns. Besides, steel buildings are earthquake resistant, durable, and easily reusable. One of the most significant aspects of any steel building than similar RCC buildings is a considerable saving in time. It is because the

RCC building always needs a predecessor activity completed to go further for successor activity. For example, the first floor can be constructed after the ground floor structure is completed; hence considerable time is consumed in waiting. Another is the time consumed in curing, a requirement of RCC construction to attain required structural strength. On the contrary, in a steel building, the whole structural framework can be constructed at one stretch of time, and there is no wastage of time for waiting. In the case of precast concrete slab used for decking, the time for curing is not needed.

10 CONCLUSION

This study presented a detailed account of steel construction, which is an emerging technology in the context of the Indian residential construction sector. The comparative analysis of steel building and conventional reinforced concrete buildings performed in this work revealed that steel construction possesses several benefits. It is evident that the use of steel structures results in lower negative environmental impact in energy use, consumption of raw material, and waste generation. One of the most significant features found is saving vast quantities of water, which is a valuable natural resource. This virtue of steel is valuable, considering the scarce water resources in India and global warming. Savings due to time efficiency can have a significant impact in terms of cost. It is observed that the steel-framed structures offer a comparatively shorter construction period compared to the reinforced concrete structural alternatives. This time difference can primarily be attributed to the reduction in the fabrication of components of the assembly of the steel frame for steel structure compared to an RCC building. Furthermore, its characteristics like strength, usability, durability, usability, flexibility, less weight renders steel structure more earthquake resistant. In terms of quality, it can be said that steel construction is significantly more stable as compared to reinforced concrete construction. In addition, it offers greater ease of installation of the plumbing and electrical works with more accuracy. Steel also offers architectural advantages as steel buildings can have good aesthetic appeal; besides, it is economical for mass construction. Given its recyclability and reusability, it is recognized as a sustainable material. The outcome of a comparative analysis of the cost factor is supposed to disprove the fallacy that steel construction technology is expensive. This research will help architects and designers to make rational decisions, leading to the appropriate diffusion and adoption of steel construction as an environmentally benign construction technology for residential buildings in the future.

REFERENCES

Akadiri, P., Chinyio, E., and Olomolaiye, P. (2012). Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings*, 2(2), 126–152. https://doi:10.3390/buildings2020126

Barlow, J., and Ozaki, R. (2005). Building mass customised housing through innovation in the production system: Lessons from Japan. *Environment and Planning A*, 37(1), 9–20. https://doi.org/10.1068/a3579

Barrett, J., Birch, R., Cherrett, N., and Wiedmann, T. (2005). Exploring the application of the ecological footprint to sustainable consumption policy. *Journal of Environmental Policy and Planning*, 7(4), 303–316. https://doi.org/10.1080/15239080500441095

Bowyer, J., Bratkovich, S., Fernholz, K., Frank, M., Groot, H., Howe, J., and Pepke, E. (2015). Understanding steel recovery and recycling rates and limits to recycling. Dovetail Partners Outlook.

Burgan, B. A., and Sansom, M. R. (2006). Sustainable steel construction. *Journal of Constructional Steel Research*, 62(11), 1178–1183. https://doi.org/10.1016/j.jcsr.2006.06.029

Chen, Y., Okudan, G., and Riley, D. (2010). Sustainable performance criteria for construction method selection in concrete buildings. *Automation in Construction*, 19(2), 235–244. https://doi.org/10.1016/j.autcon.2009.10.004

Dabhade, U., Hedaoo, N., Gupta, L., and Ronghe, G. (2009). Time and cost evaluation of construction of steel-framed composite floor with precast concrete floor structure. *The 26th International Symposium on Automation and Robotics in Construction*, Austin, U.S.A.

Ding, G. K. (2014). Life cycle assessment of sustainable building materials: An overview. *Eco-efficient construction and building materials*, 38–62. https://doi.org/10.1533/9780857097729.1.38

Dozzi, S., and AbouRizk, S. (1993). Productivity in construction. Institute for Research in Construction, National Research Council, Ontario, Canada.

Drennan, M. (2017). Comparative construction costs of typical low-rise office buildings in South Africa. M.E. thesis, Stellenbosch University, Stellenbosch, South Africa.

Du Plessis, C. (2002). Agenda 21 for sustainable construction in developing countries. CSIR, UNEP-IETC, Pretoria, South Africa.

Du Plessis, C. (2007). A strategic framework for sustainable construction in developing countries. *Construction Management and Economics*, 25(1), 67–76. https://doi.org/10.1080/01446190600601313

Durmisevic, E., and Noort, N. (2003). Reuse potential of steel in building construction. *The 11th Rinker International Conference: Deconstruction and materials*, Florida, United States.

Fujita, M., and Iwata, M. (2008). Reuse system of building steel structures. *Structure and Infrastructure Engineering*, 4(3), 207–220. https://doi.org/10.1080/15732470600720351

Gebrehiwet, T., and Luo, H. (2017). Analysis of delay impact on construction project based on R.I.I. and correlation coefficient. *Empirical study*, 196, 366–374. https://doi.org/10.1016/j.proeng.2017.07.212

Gibb, A., and Isaack, F. (2003). Re-engineering through preassembly: Client expectations and drivers. *Building Research and Information*, 31(2), 146–60. https://doi.org/10.1080/09613210302000

Gorgolewski, M., Straka, V., Edmonds, J., and Sergio, C. (2006). Facilitating greater reuse and recycling of structural steel in the construction and demolition process. Ryerson University, Canadian Institute of Steel Construction, Ontario, Canada.

Hallala, B. B. (2017). Cost-effectiveness of composite frames in condominium houses. Wolaita Sodo University, Wolaita Sodo, Ethiopia.

Holtzhausen, H. (2007). Embodied energy and its impact on architectural decisions. *W.I.T. Transactions on Ecology and the Environment*, 102, 377–385. https://doi.10.2495/SDP070361

Jaillon, L., and Poon, C. (2009). The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector. *Automation in Construction*, 18, 239–48. https://doi.org/10.1016/j.autcon.2008.09.002

Johnson, T. (2006). Comparison of environmental impacts of steel and concrete as building materials using the life cycle assessment method. Master's thesis, Massachusetts Institute of Technology, Massachusetts, United States.

Kadir, M., Lee, W., Jaafar, M., Sapuan, S., and Ali, A. (2006). Construction performance comparison between conventional and industrialised building systems in Malaysia. *Structural Survey*, 24(5), 412–24. https://doi.org/10.1108/02630800610712004

Kasim, N., Anumba, C., and Dainty, A. (2005). Improving materials management practices on fast-track construction projects. *Proceedings Twenty-First Annual Association of Researchers in Construction Management (ARCOM) Conference*, London, UK.

Khalfan, M., and Maqsood, T. (2014). Current state of off-site manufacturing in Australian and Chinese residential construction. *Journal of Construction Engineering*, 1–5. http://dx.doi.org/10.1155/2014/164863.

Kibert, C. (2012). *Sustainable Construction Green Building Design and Delivery.* 3rd Edition, John Wiley and Sons, New Jersey, United States.

Lombard, A. (2011). Decision making between hybrid and in-situ concrete construction in South Africa. Ph.D. thesis, Stellenbosch University, Stellenbosch, South Africa.

Ortiz, O., Castells, F., and Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, 23(1), 28–39. https://doi.org/10.1016/j.conbuildmat.2007.11.012

Pan, W., Dainty, A., and Gibb, A. (2012). Establishing and weighing decision criteria for building system selection in housing construction. *Proceedings of 11th joint C.I.B., ASCE Journal of Construction Engineering and Management, Prefabrication in Construction*, Helsinki, Finland.

Petkar, S. (2014). Environmental Impact of Construction Materials and Practices. Ph.D. thesis, National Institute of Construction Management and Research, Pune, India.

Saleem, M., and Qureshi, H. (2018). Design solutions for sustainable construction of pre-engineered steel buildings. *Sustainability*, 10(6), 1761. https://doi.org/10.3390/su10061761

Sattary, S., and Thorpe, D. (2016). Potential carbon emission reductions in Australian construction systems through bioclimatic principles. *Sustainable Cities and Society*. 23, 105–113. https://doi.org/10.1016/j.scs.2016.03.006

Sharma, A., Saxena, A., Sethi, M., Shree, V., and Varun (2011). Life cycle assessment of buildings: A review. *Renewable and Sustainable Energy Reviews*, 15(1), 871–875. https://doi.org/10.1016/j.rser.2010.09.008

Song, J., Fagerlund, W., Haas, C., Tatum, C., and Vanegas, J. (2005). Considering prework on industrial projects. *Journal of Construction Engineering and Management*, 131(6), 723–733. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:6(723)

Taha, S., Ibrahim, M., and Ali, A. (2016). Steel as a Sustainable Choice Towards the Green Building Concept. WIT Press, Southampton, U.K.

Teng, Y., and Pan, W. (2019). Systematic embodied carbon assessment and reduction of prefabricated high-rise public residential buildings in Hong Kong. *Journal of Cleaner Production*, 238, 117791. doi:https://doi.org/10.1016/j.jclepro.2019.117791

Usman, A. U., and Khamidi, M.F. (2012). Sustainable building material for green building construction, conservation, and refurbishing. *Conference on Management in Construction Research Association (MiCRA)*, Kuala Lumpur, Malaysia.

Veljkovic, M. (2016). *Sustainable Steel Buildings: A Practical Guide for Structures and Envelopes*. John Wiley and Sons, New Jersey, United States.

Vijayalaxmi, J. (2010). Towards sustainable architecture– a case with greentainer. Local environment, 15(3), 245–259. https://doi.org/10.1080/13549830903575596

Xue, X., Zhang, R., and Dai, J. (2014). Innovation in construction: A critical review and future research. *International Journal of Innovation Science*, 6(2), 111–126.https://doi.org/10.1260/1757-2223.6.2.111

Yitmen, I. (2007). The challenge of change for innovation in construction: A North Cyprus perspective. *Building and Environment*, 42(3), 1319–1328. https://doi.org/10.1016/j.buildenv.2005.10.032

Zaveri, B., Gadhiya, J., and Dhameliya, H. (2016). A review on the comparative study of steel, RCC and composite building. *International Journal of Innovative Research in Science, Engineering and Technology*, 5(1), 354–365. https://doi:10.15680/IJIRSET.2015.0501045

Zhang, X., and Skitmore, M. (2012). Industrialized housing in China: A coin with two sides. *International Journal of Strategic Property Management*, 16(2), 143–157. https://doi.org/10.3846/1648715X.2011.638945

APPENDIX A: DETAILED CALCULATIONS FOR BUILDINGS A AND B

A BUILDING A

A.1 Substructure

The quantity of concrete in the substructure included the lower part PCC bed and upper part column footing up to the plinth level (RCC Stubs). The quantity of concrete used in the lower and upper part of the foundation for 18 steel stanchions is calculated, as shown in Table A1 and Table A2.

The total quantity of concrete for substructure (A+B) is equal to 31.32 m^3. Since the foundation for a steel building is made of RCC, which includes cement concrete with steel bars used as reinforcement, the quantity of which is calculated as per the thumb rules used by RCC consultants concerning IS code 456 (plain and reinforced concrete), which is 0.02% of the volume of concrete. Therefore, the quantity of steel reinforcement @ 0.02% of 31.32 m^3 is equal to 0.0062 m^3. Upon converting it into kilograms by using the density of 7,850 kg/m^3, it comes out to be 48.67 kg.

A.2 Superstructure

A.2.1 Quantity of concrete and steel in slabs and plinth beams

The quantity of concrete used in the steel superstructure is calculated for concrete filling for decking slab, PCC for plinth slab, and plinth beams are explained as follows.

The quantity of steel includes steel reinforcement in two decking slabs. In contrast, steel reinforcement in the plinth slab is negligible and thus not considered for analysis, but the calculation includes steel reinforcement for the plinth beams. The area of the decking slab is 110.72 m^2 (6.86 × 16.14), and the steel reinforcement @ 6.10 kg/m^2 is calculated to be 684.252 kg; thus, for two decking slabs, the quantity of steel is 1,350.78 kg. For plinth beams, the quantity of concrete is 6.47 m^3, the quantity of steel @ 6% of the volume of concrete is 0.38 m^3, and the quantity of steel considering the density of steel @ 7,850 kg/m^3 is 2,983 kg.

A.2.2 Quantity of steel in stanchions

Universal columns (152 × 152 × 30) were used for providing 18 stanchions with 5.84 m length (height of two floors, i.e., G+1).

The total mass of steel required for stanchions is 5.844 × 30 × 18 = 3,156.00 Kg.

A.2.3 Quantity of steel in primary and secondary beams

Sixteen primary beams (narrow parallel flange beam) were used in both orthographic directions are used as primary beams with the following details:

Size = 250 mm × 150 mm.

Weight @ 34.08 kg/m.

Length in X-direction = 6.86 m.

Weight = 6.86 × 34.08 = 233.78 kg.

Weight of 16 beams = 233.78 × 16 = 3,740.48 kg.

Weight of beams at two floors = 3,740.48 × 2 = 7,480.96 kg.

Length in Y-direction = 32.28 m.

Weight = 32.28 × 34.08 = 1,100.102 kg.

Weight of beams at two floors = 1,100.102 × 2 = 2,200.20 kg.

Total weight = 7,480.96 + 2,200.20 = 9,681.16 kg.

Table A1. Quantity of concrete in the lower part (A) of the foundation

Column numbers	Size of PCC bed (L × B × D)	Number	Quantity (m^3)	Size of column footing (L × B × D)	Number	Quantity (m^3)	Total quantity (m^3)
C1, C2, C3, C4, C5, C6, C7, C8, C9 C10, C11, C12, C13, C14, C15, C16, C17, C18	1.75 × 1.75 × 0.15 = 0.45	18	8.10	1.40 × 1.48 × 0.45 = 0.96	18	17.28	8.10 + 17.28 = 25.38

Table A2. Quantity of concrete in the upper part (B) of the foundation

RCC stubs column numbers	Column size (L × B × D)	Numbers	Quantity (m^3)
C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18	0.55 × 0.58 × 1.05 = 0.33	18	5.94

For secondary beams, the weight is considered 50% of the primary beams, i.e., 9,681.16/2 = 4,840.58 kg. Therefore, the total steel in beams = 9,681.16 + 4,840.58 = 14,521.74 kg. Table A3 shows the total quantity of steel for the superstructure.

Table A3. The total quantity of steel for the superstructure

No.	Item	Quantity (kg)
1	Steel reinforcement in decking slabs	1,350.78
2	Steel reinforcement in plinth beams	2,983.00
3	Steel Stanchions	3,156.00
4	Primary and secondary beams	14,521.74
	Total	22,011.52

B BUILDING B

B.1 Substructure

It included PCC bed and column footing up to the plinth level in the lower part, while the upper part includes the stub column from the foundation up to the plinth level. Quantity for concrete in the lower part and upper part of the foundation is calculated for 15 number of RCC columns as per the structural plan, which is presented in Table B1 and Table B2, respectively.

The quantity of concrete in RCC substructure = 19.08+1.25 = 20.33 m^3.

The quantity of steel reinforcement in the RCC substructure @ 0.02% of concrete volume, i.e., 0.004 m^3 is 31.40 kg with the density of steel 7,850 kg/m^3.

B.2 Superstructure

The quantity of concrete and steel reinforcement for beams, slabs, columns are further obtained based on detailed drawings for building B. The quantity of concrete in beams per floor is obtained for 7 numbers of beams, the details of which are shown in Table B3.

The quantity of concrete for beams on three floors is 6.47 × 3 = 19.41 m^3.

The quantity of concrete for three 0.15 mm thick RCC slabs and 15 number of RCC columns is further calculated, as shown in Table B4.

Quantity of concrete for two lower and one roof slab = 16.60 × 3 = 49.80 m^3.

Quantity for columns in two floors = 3.93 × 2 = 7.86 m^3.

Table B1. Quantity for concrete in the lower part of the foundation

Column nos.	Size of PCC bed (L × B × D)	Numbers	Quantity (m^3)	Size of column footing (L × B × D)	Numbers	Quantity (m^3)	Total quantity (m^3)
C1, C13	1.35 × 1.35 × 0.15 = 0.27	2	0.54	1.50 × 1.50 × 0.55 = 0.61	2	1.21	1.75
C2, C12, C14	1.50 × 1.60 × 0.15 = 0.36	3	1.08	1.20 × 1.30 × 0.50 = 0.78	3	2.34	3.42
C3, C15	1.35 × 1.35 × 0.15 = 0.27	2	0.54	1.50 × 1.05 × 0.55 = 0.60	2	1.21	1.75
C4	1.50 × 1.60 × 0.15 = 0.36	1	0.36	1.20 × 1.30 × 0.55 = 0.85	1	0.85	1.21
C5, C8	1.75 × 2.00 × 0.15 = 0.52	2	1.05	1.45 × 1.70 × 0.55 = 1.35	2	2.71	3.76
C6, C7	1.50 × 1.70 × 0.15 = 0.38	2	0.76	1.20 × 1.40 × 0.55 = 0.92	2	1.84	2.60
C9, C10	1.60 × 1.80 × 0.15 = 0.43	2	0.86	1.30 × 1.50 × 0.55 = 1.07	2	2.14	3.00
C11	1.60 × 1.90 × 0.15 = 0.46	1	0.45	1.30 × 1.60 × 0.55	1	1.14	1.59
			5.64			13.44	19.08

Table B2. Quantity of concrete in the upper part of foundation B

Column nos.	Column size (L × B × D)	Numbers	Volume (m^3)
C1, C2, C3, C4, C9, C10, C11, C12, C13, C14, C15	0.23 × 0.38 × 1.05 = 0.09	11	0.99
C5, C8	0.23 × 0.53 × 1.05 = 0.12	2	0.24
C6, C7	0.23 × 0.45 × 1.05 = 0.10	2	0.20
Quantity of concrete for the upper part of foundation (B)			1.25

Table B3. Quantity of concrete in beams

Name	Size: (L × B × D)	Number	Total quantity (m^3)
B1	6.25 × 0.23 × 0.45 = 0.646	5	3.23
B2	15.68 × 0.23 × 0.45 = 1.62	2	3.24
	Total		6.47

Table B4. Quantity of concrete in RCC slab and column per floor

Name	Size (L × B × D)	Number	Quantity (m^3)
Slab	6.86 × 16.14 × 0.15 = 16.60	1	16.60
Column C1 to C15	0.23 × 0.38 × 3.0 = 0.26	15	3.93

Quantity of concrete for RCC superstructure = 19.41 m^3+ 49.80 m^3+ 7.86 m^3 = 77.07 m^3.

The total quantity of concrete in building B (Substructure and superstructure):

77.07 + 20.33 = 97.4 m^3.

Steel reinforcement is to be calculated based on the volume of concrete used, which is excluding plinth slab as reinforcement used for it is negligible.

The quantity of concrete for RCC slab = 77.07 - 16.60 = 60.47 m^3.

The quantity of steel reinforcement is 6% of the total volume = 3.62 m^3.

The quantity of steel @ 7,850 kg/m^3 = 28,417 kg.

International Journal of Architecture, Engineering and Construction
Vol 9, No 1, March 2020, 3202001, 1-14

Analytical Study of Construction Waste Generation and Management for Residential Building: A Case Study of Pune City

Dharati Sote Wankhade* and Vasudha Gokhale

MKSSS's Dr. B. N. College of Architecture, SPP University, Pune, Maharashtra, India

Abstract: Construction and Demolition (C&D) waste is a pressing issue all over the globe where the handling of waste remains a perpetual problem. Owing to increase volume of C&D waste, shortage of landfills in India and long term adverse environmental, economic impacts of the disposed C&D waste, adequate waste management become increasingly essential. It is evident that C&D waste has substantial residual value which could be reduced, reused or recycled. This research examines the potential of materials used in construction in light of adequate waste management. Evidence of the extent of material wastages is yet to ascertain in research in Indian context, while cost implication of C&D waste is scarcely explored. The status quo of construction waste generation and management based on the particular context of selected housing project in city of Pune, India is presented. Considering that hard data on the quantity, type of construction waste is essential to properly plan and control its disposal, this research endeavors to quantify the construction waste generated in selected housing project. The data for this inquiry are sourced from the field investigation and experts' interviews to quantify the waste generated as well as explore the potential for its adequate management. Actual waste generated is quantified with reference to material procured and material consumed in the project under investigation. The economic implications of wastage of different materials used in construction are analyzed. The major causes of waste generation found are improper planning, handling, misuse, and incorrect processing of material on buildings site. It is found that each type of waste has different environmental and economic implications the information of which can motivate building operatives to opt for prior quantification and planning. This study provides a tool for evaluating the quantity construction waste and its economic implications of hence help in its sustainable management.

Keywords: Construction material, construction waste, ideal handling, 3R practice

DOI: http://dx.doi.org/10.7492/IJAEC.2020.009

1 INTRODUCTION

The economic growth of a country depends on the way in which construction activities are promoted for building and infrastructure development (Adewuyi and Odesola 2015). In the wake of growth, construction industry needs to face numerous challenges coupled with huge quantity of construction and demolition (C&D) wastes generation as major challenge. This phenomenon results in increasing environmental impact that can cause significant damage not only to ecosystem but also to the health and well-being of work force as well as people living in vicinity (Kozlovská and Spišáková 2013). C&D waste generation from construction activity is also substantial in monetary terms and increases project cost. In current scenario management of C&D waste which is generated during new construction, demolition and renovation activity becomes one of the major area of concern worldwide (Sasidharani 2015). In conventional construction system, waste is generated by various activities both planned and un-planned in the form of virgin materials and its by-products (Ugochukwu *et al.* 2017). The C&D waste represents major quantity in Municipal Solid Waste (MSW) is heavy and bulky resulting in increased complexity in its management. This is major concern for town planners due to its increasing quantity, continuing shortage of dumping sites, increase in transportation and disposal cost and above all growing concern about pollution and environmental deterioration (Miranda *et al.* 2017).

C&D waste covers a broad range of waste generated in building industries which includes waste from partial or total demolition, waste generated from construction activity of buildings, civil infrastructure, vegetation arising from site clearing, excavations for foundations, earth moving etc. (Oyenuga and Bhamidiarri 2015). Construction waste is often classified as physical and nonphysi-

*Corresponding author. E-mail: dharati.sote@gmail.com

cal waste where physical waste refers to waste generated in the form of material loss while nonphysical construction wastes includes time and cost overrun for construction projects (Muhaidin and Chan 2018). C&D waste has been also categorized under two categories components where major components include cement concrete, bricks, cement plaster, steel, rubble, stone and timber. Minor component category include conduits, pipes, electrical fixtures, wooden laminated panels and other material like glazed tiles, glass panes, etc. (Shrivastava and Chini 2009; Patel *et al.* 2017). This research includes analysis of physical waste in terms of waste generated in construction activity where demolition waste is kept out of the scope of this research and nonphysical waste addressed in terms of implications in context of residential building project in city of Pune.

2 STANDARD WASTAGE CONSIDERATION FOR BUILDING MATERIALS

The phenomenon of waste generation cannot be divorced from construction activity (Adewuyi and Otali 2013). Wastage of material is inevitable therefore the quantity of material procured need to include estimated quantity of waste for each item. The wastage of materials which is generally expressed as percentage of required material is termed as standard or allowable wastage. The total quantity of materials procured on construction site of project is calculated by increasing the theoretical quantity with allowable waste, proportionately. Standard wastage of the construction material depends on various variables like nature of work, type of material, method of application, size of the projects; and construction technology employed (Foo and Kamaludin 2017).

The theoretical quantity of material obtained is based on very precise dimensions mentioned in the drawings (Adewuyi *et al.* 2014). Table 1 shows the typical standard wastage that can be considered while estimating some of the materials in a housing project.

3 ACTUAL OR MEASURABLE WASTAGE

Actual wastage is the difference between quantity of material procured and consumed in construction of various building component (Bandgar and Kumthekar 2016). Measuring actual waste generated on site is an important aspect that plays a crucial role in practice of construction waste management. The generation of actual C&D waste is influenced by a number of parameters like type (i.e. residential or commercial) and size of project, nature of construction activities, period and form of construction, materials used and techniques that are applied for the construction, demolition of a building, as well as historical, cultural, economic value and importance of a building (CPCB, 2017) (Masudi *et al.* 2010; Kourmpanis *et al.* 2008).

Despite 5% to 10% allowance made to take care of wastage of material while preparing the estimate for a project has been found inadequate because exact amount and type of waste remains largely unknown (Saidu and Shakantu 2015; Adewuyi and Otali 2013). It is approximated that 1% to 10% of materials procured would end up as waste where most of the waste generation attributed to leftover cut-off, design changes, and poor workmanships (Fadiya *et al.* 2014). One of the main hindrances of accurate determination of volume of waste is the lack of data, poor documentation of waste generation (Kozlovská and Spišáková 2013). In many instances the previous experience gained by the builder may modify the pattern and quantity of the same (Saidu and Shakantu 2015).

As per Saidu and Shakantu (2015) quantity of wastage generated in construction of 100 houses is sufficient to build another 10 houses. In Hong Kong quantity of construction waste is estimated as 0.125 m^3 to 0.25 m^3 per gross floor area (GFA) (Mokhtar *et al.* 2011). The generation of waste is often dictated by the construction tech-

Table 1. Standard wastage consideration for building materials (Chitkara 2011)

No.	Material	Standard wastage in %	No.	Material	Standard wastage in %
1	Cement	2	12	Marble lining	20
2	Sand	10	13	Floor tiling	2 to 5
3	Aggregate	5	14	Wall tiling	3
4	Concrete - structural	2	15	Tile roofing	5
5	Concrete - blinding	10	16	Sheet roofing	2.5
6	Reinforcement - steel bars	3	17	Wood for flooring/walling	5 to 10
7	Reinforcement - steel mesh	10	18	Wood for door frames	5 to 7.5
8	PVC sheeting	15	19	Wood for shutters	10
9	Steel for windows	7	20	Pigments	5
10	Timbering in trenches	5	21	Paints	5
11	Stone masonry	5			

nology employed. It has been observed that the average levels of wastage in conventional construction systems is much higher than that of pre-assembly systems (Kozlovská and Spišáková 2013). Use of pre-fabrication technology can result up to 84.70% reduction in generation of C&D waste against four major types of materials namely concrete, reinforcement, plastering and tiling (Li *et al.* 2014).

4 C&D WASTE MANAGEMENT - 3R CONCEPT

4.1 3R Concept

Prevention and minimization of C&D waste is a new and emerging area of research worldwide. Till 1945, no country has the history of active C&D waste minimization or prevention which is not a common phenomenon until the 1980's or later. Research established that the initial efforts taken by various countries are generally weak and are not having a monitoring mechanism to ensure compliance of waste management (Toby 2007). As per "G8 Action Plan" on Science and Technology for Sustainable Development: Reduce, Reuse and Recycle (3R) Action Plan and "Progress of Implementation" is adopted during the "G8 Sea Island Summit" in USA in 2004. In this summit its implementation is perceived as main pillar in dealing C&D waste management (Nitivattananon and Borongan 2007). The 3R approach refers to reduce, reuse and recycle, which are waste management strategies aimed at full utilization of waste before it is send to disposal (Ng *et al.* 2018).

The hierarchy of utilization of 3R is as below:

(1) Reduce – produce less waste i.e. eliminating the generation of waste, wherever possible
(2) Reuse – making use of materials in their original state on the same site or at other sites / off-site
(3) Recycle – recycle materials that have reached the end of their useful life wherever possible i.e. turning materials into new products for other purposes (Level 2016)

Many researchers have found that several types of construction waste can be predominantly reused or recycled (Ng *et al.* 2015). Reflecting on the importance of implementing the 3R concept for management of C&D waste it has been stressed to implement the 3R concept in the building project in both the phases of work progress i.e. design and construction stage. Research has established the potential of reduction of waste at all stages of design and construction including deconstruction projects.

4.2 3R Strategy in Construction Waste Management

Construction waste could be minimized through practice of reduce, reuse and recycle which referred as the 3R strategy (Turkyilmaz 2019). It is a three-fold grouping of waste management strategies that applies to reduction, reuse, and recycling, of construction waste before sending it for disposal (Mohammed 2020). The reduction of construction is possible at design and planning stage, while reuse of waste generated on site can be used in successive construction process. For recycling of waste, proper segregation needs to be taken care (Level 2016).

The first step is to reduce the amount of waste generated followed by ensuring the management of wastes adequately. Careful planning is very important for diverting waste from the landfill or clean-fill as the decisions taken in planning phase dictate waste generation throughout the project implementation process. At design stage, it includes strategies like modular design, logical sequence of work, use of local and recycled material, compact services with minimum run, planning for deconstruction that is incorporated for minimizing waste. The protection of material from adverse weather condition and returning surplus material is necessary to minimize waste from disposal. Materials with higher recycled content which are locally available are recommended in construction waste minimization strategies. During construction, effective quality control is suggested along with avoiding the repairing work due to changes in original plan (Level 2016).

At construction stage the waste generated can be used on the site itself during construction or after the completion of the project (Turkyilmaz 2019). Recycling is one of the commitments to the environment as the use of recycled materials is less expensive as compared materials obtained from primary sources (Level 2016). Materials such as asphalt, timber and metal have properties that support recycling which can be used in the same state in construction process (Turkyilmaz 2019).

The 3R practice of waste management for construction activities has been promoted with the aim of protecting the environment by effectively utilization of natural resources, with the view to reduce the quantity of waste and also utilizing the generated waste in the most effective manner. The economic advantages of waste minimization include lower project costs, increased business investment, lower risk of process regarding wastes amongst others (Yakkaluru and Naik 2016). This aspect needs more attention as far as adequate management of construction waste is concerned.

5 INDIAN CONSTRUCTION INDUSTRY

In India more than 377 million people are living in 7,935 cities which is about 31.20% of the total population of the country (Ahmed 2016). The conventional construction systems for building construction in the country includes load bearing construction, reinforced cement concrete (RCC) framed and structural steel (SS) framed (BMTPC 2018). Load bearing is traditional method of construction in which brick walls are structural members primarily cast-in-situ. In RCC framed system, structural components like column, beam and slab are of RCC with brick or concrete block infill walls. In this process on-site three major trades are involved viz. steel bending, form-work fabrication and concreting (Siti and Wan 2013). In steel framed system, RCC beams and columns are replaced by hot rolled steel sections which are mostly cast-in-situ. Each of these systems generates waste material differently in constructional operations.

Indian construction industry generates about 11.40 ton to 14.70 ton C&D waste per annum. Quantification of C&D waste done by different agencies in year 2008 exhibit different values which range from 0.30 ton to 0.53 ton per day (Miranda *et al.* 2017). Enormous increase in the year 2013 reported by CSE indicating 530 ton of C&D waste generation by building projects excluding the infrastructure projects such as roads and dams which is 44 times higher than the official estimates (CSE, 2014). Indian construction industry use large quantity of concrete and brick as principal building material where C&D waste is about 7 ton to 8 ton which is more than 50 % of the total C&D waste generated (Thomas and Wilson 2013; Rawat *et al.* 2014).

Currently, Indian building industry is observing a paradigm shift from slow-track systems to fast-track systems represented by pre-cast modular building components, hot and cold rolled form steel construction, large form-work system, sandwich panel construction, factory made fabricated system, etc. (BMTPC 2018). The fast-track construction system includes the manufacturing and assembly (usually off-site) of buildings or parts of buildings in manufacturing unit and recognized as pre-assembly system (Arashpour *et al.* 2018). It has been found that the average wastage generated in conventional construction systems in the process of concreting, masonry, plastering, tiling, etc. is much higher than that of pre-assembly systems (Kozlovská and Spišáková 2013).

It is a common practice that contractor executes medium to large construction projects on a labor contract basis or on turnkey basis. Small housing projects are executed by owners which are predominantly executed by them on labor contract basis. It has been found that in this construction process waste generation ranges between 5% to 7% while in larger projects, where execution is done on turnkey basis or through the team of contractor wastage of materials is less as it ranges upto 3% (Ponnada and Kameswari 2015).

6 C&D WASTE MANAGEMENT - INDIAN SCENARIO

6.1 Current Situation

The management of C&D waste include re-use of materials salvaged in good condition during construction and demolition where the metal items are sent for re-melting through scrap dealers and the disposal of other items to low lying sites (Ponnada and Kameswari 2015). In Indian construction sector initiatives taken by government or municipal bodies for construction waste management are minimal. It has been found that various items recovered during construction or demolition is sold in the market at a discounted rate. Items that cannot be re-used are consumed in land filling with ease as no landfill tax is imposed by the municipal authorities. The waste is largely disposed without segregation even when mandate is in place but no penal action is taken against violators. It is noticed that the feasibility of recycling is not considered seriously and the proposed methods for management of C&D waste by Technology Information, Forecasting and Assessment Council, Government of India (TIFAC 2001) are not practically implemented in most of the construction sites (Thomas and Wilson 2013). The Ministry of Environment and Forests introduced the waste management and handling rules which has limited compliance (Kumar *et al.* 2017).

As common practice, C&D waste is sold and transported to privately-owned low-lying sites or dumped in an unauthorized manner along roads or other public land. Such un-thoughtful and unscientific dumping is resulting in severe pressure on scarce urban land as well as reducing life spans of landfill (Miranda *et al.* 2017). Recycling of construction waste is difficult since its disposal needs large chunk of space that is scarcely available in Indian cities (Pitroda and Chanki 2018). The C&D waste dumped on landfill site, leads to soil pollution which affects soil fertility and also leads to sub-soil water pollution. Random dumping of these wastes have negative impact on environment due to addition of air pollution and degradation of the air quality (Sote *et al.* 2014; Ng *et al.* 2015).

6.2 Economic Implications of Construction Waste

Construction industry contribute 11% of the country's Gross Domestic Product (GDP) with 54% of total investment in infrastructure project, 36 % in industrial projects and 5% in residential and commercial project each (GOI 2019). The poor management of material and waste leads to an increase in the total cost of building projects. Cost overrun is a common issue in construction industries all over the world as most of the projects experience cost overruns exceeding the initial budget (Saidu and Shakantu 2016) where India is no exception.

It has been found that the component of material cost comprises about 50 % of the total cost of the project. This exhibit that generation of waste from construction operation is huge in monetary terms (Ajayi *et al.* 2017). Waste can be disposed of or reused to gain economic benefits (Agarwal *et al.* 2015). The recovered items during construction generally is sold at lower price and rest is transported to landfill site for which building owner or builders bear the cost of transportation (Miranda *et al.* 2017). The cost of transportation range between INR 250 to INR 500 per truckload depending on the type of waste and distance of site from landfill area (TIFAC 2001). Many a times high cost of transportation refrain contractors to identified landfill sites and they tend to dump waste in unauthorized locations nearby.

6.3 Case Study

The study is conducted in the city of Pune which is the second largest city in Maharashtra after Mumbai. Pune consist of maximum number of housing typology as apartment buildings which is 37% of the whole residential built stock, while rest include slums, row houses, bungalows and old low-rise housing typology referred as Wada. The average area ranges from 50 m^2 to 150 m^2 (Mahajan and Shirsath 2011).

The project selected for analysis is a residential complex representative of current apartment buildings in Pune city. It consists of two apartment buildings with 14 floors each accounting for 12,500.00 m^2 total built-up area. The residential units are of three different types having 3, 4 and 5 habitable rooms with built up area 60.00 m^2, 90.00 m^2, and 110.00 m^2 respectively.

7 METHODOLOGY

7.1 Research Objective

The objective of this research are two-fold, first is to find out the pattern of waste generation and the cost implications and second is to explore the potential of 3R practices for minimization of construction waste at the construction site under consideration. The data for this research is primarily collected from procurement inventories which are analyzed against design drawings and site investigation to determine material used and material purchased for the project under investigation.

The study focuses on construction waste generated on new residential building site during the construction phase only and not design phase of project. Within the scope only material wastage has been taken into account while demolition waste, labor and other wastages are not considered. This research uses quantitative method for data collection from the numeric measurement of the volume of the building elements on site to enumerate material consumption. The actual wastage is measured by calculating the difference between material procured and actual consumption in building component of selected project site. The cost of waste generated is calculated based on present market rates of materials.

The research further extends to explore the likely impact of implementation of 3R practice to understand its potential in waste management in the context of the project in hand. For this, semi-structured interviews are carried out with experts having working experience ranging from 10 years to 15 years on the residential construction projects. The interview is audio taped and the data was processed with verbatim transcription.

7.2 Method for Quantification of Actual Waste

For obtaining details about construction material, the bill of quantities which contained list of materials and measured quantities of the items needed for the constructional operations is referred. This includes estimation of standard material wastage that is quantity of projected waste generation during the construction process. Out of major construction materials involved in construction process soil, cement, sand-crushed, sand-river, aggregate, reinforcement steel bars, fly ash brick, electrical conduit, plumbing pipes, tiles and paint (external and internal) are considered for analysis in this research. The materials like electrical, plumbing accessories, door & window frames, safety grills, etc. are either procured in required numbers or sizes. The quantity of wastage for such material is not considered as the waste generated of these materials is minimal.

The materials selected for analysis are classified as per the basic categories of civil, services, finishes and by-product:

(1) Civil - soil, cement, sand-crushed, sand-river, aggregate, reinforcement steel bars, fly ash brick
(2) Services - electrical and plumbing services
(3) Finishes - tiles and paint (external and internal)
(4) By-product - concrete and mortar

Material reconciliation is carried out by comparing the difference between the materials procured and the actual consumption of the material in building component. Quantity of material procured is explored based on records maintained in material store room of the construction site while quantity of material consumed is obtained by calculating the volume of building component by measuring its actual size on site. The value of all materials which conventionally is in different units is converted in tons by multiplying its density for better understanding and reasonable comparison. The waste which is found as a mixture or compound of different virgin materials is calculated separately.

8 ANALYSIS AND RESULTS

8.1 Actual Waste for Composite Materials

Waste from cement, crushed sand and aggregate is found in the form of concrete (PCC) and mortar which is combination of ingredient materials in specified proportion. Table 2 shows the quantity of waste generated on site in the form of concrete and mortar (which is composed of cement, sand and aggregate) waste generated on site.

Table 2. Wastage of composite materials - concrete and mortar

No.	Construction material	Quantity mixed	Quantity consumed	Quantity waste	Waste % against quantity mixed
		ton	ton	ton	%
1	Concrete	10,862.40	10,332.00	530.40	4.88
2	Mortar	2,443.46	2,204.00	239.46	9.80

Table 3. Material procured, consumed and waste generated in terms of quantity and percentage

No.	Construction material	Quantity procured	Quantity consumed	Quantity wastage	Wastage % within quantity procured
		ton	ton	ton	%
1	Soil	3,116.00	2,400.00	716.00	23.00
2	Cement	2,436.45	2,265.04	171.41	7.00
3	Sand - crushed	6,451.20	4,856.09	1,595.11	24.73
4	Sand - river	4,817.40	3,649.15	1,168.25	24.25
5	Aggregate	5,665.25	5,052.93	612.32	10.81
6	Reinforcement steel bar	570.37	521.20	49.17	8.62
7	Fly ash brick	1,923.35	1,696.00	227.35	11.82
8	Tiles	201.60	168.00	33.60	16.67
9	Paint - External	7.58	6.56	1.02	13.43
10	Paint - Internal	3.26	2.70	0.56	17.20
11	Electrical conduit	18.90	17.64	1.26	6.67
12	Plumbing pipes	17.94	16.38	1.56	8.70
	Total	25,230.44	20,652.53	4,577.91	18.15

Based on quantities of concrete and mortar shown in Table 2, the waste generated is further analyzed to find out the quantity of ingredient materials i.e. cement, sand-crushed, sand-river and aggregate based on their presence as per specified proportion. As the volume of ingredients of concrete and mortar is reduced after adding water to certain extent as compared to dry volume (Liton 2018). Equation (1) and Equation (2) is used to calculate the quantity for dry concrete and mortar considering presence of air voids in ingredients that is sand and aggregate.

$$D_c = 1.54 \times W_c \tag{1}$$

$$D_m = 1.25 \times W_m \tag{2}$$

D_c – Dry volume of concrete
W_c – Wet volume of concrete
D_m – Dry volume of mortar
W_m – Wet volume of mortar

8.2 Percentage of Actual Waste

Quantity of waste is computed which is later used to estimate the total wastage of each material. This is further analyzed by calculating the percentage of wastage of material with reference to the material procured as per the Equation (3).

$$P_m = \left(\frac{Q_w}{Qp}\right) \times 100\% \tag{3}$$

Pm – Percentage of material wastage
Qw – Quantity of material wastage
Qp – Quantity of material procured

Table 3 presents material procured, consumed and waste generated in terms of quantity and percentage for each material.

9 DISCUSSION

9.1 General Discussion

Analysis indicates that materials like aggregate, river and crush sand, cement, steel and fly ash bricks are purchased in bulk quantity considering standard allowance for wastage. The actual wastage of these materials is predominantly in the form of a mixture or by-product of two or more materials having different physical as well as chemical properties (Figure 1). This aspect makes the reuse or recycling operation difficult to certain extent. On the other hand, the actual wastage of material like reinforcement steel bar, sanitary pipes and fittings, bricks, etc. is in its virgin state having same chemical properties.

The soil as excavated from the site for foundation is stored and reused for backfilling for the same. It has been observed that out of total soil excavated about 23.00% soil is wasted after using in backfilling and landscaping because of improper handling and stacking.

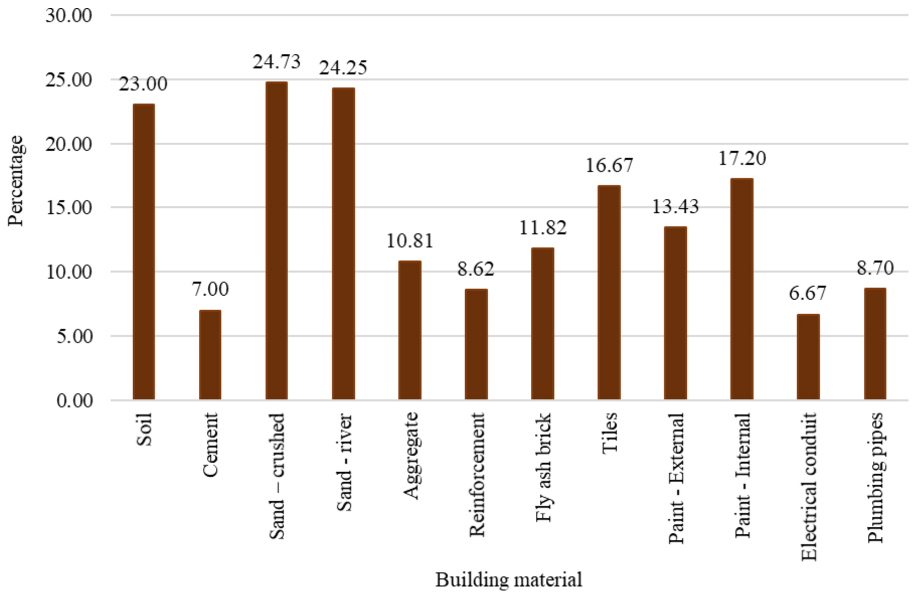


Figure 1. Wastage of material generated in percentage

Large quantity of wastage of reinforcement steel bar which is largely used in RCC construction attributed to inadequate cutting. The quantity of left out small pieces is huge which result in about 8.62% of wastage and consecutive monetary losses.

Largest volume of material procured is for aggregate, crush and river sand which are used for different purposes in different forms. Commonly used forms include concrete and mortar for plain cement concrete (PCC), reinforced cement concrete (RCC) component, masonry, plaster and screed where these materials are used in different proportions. The crush sand, river sand and aggregate wastage are 24.73%, 24.25% and 10.81% respectively. The reason for wastage of these materials as found is contamination of both sand and aggregate due to mixing with soil. This is because of common practice that these materials are unloaded on ground directly. In addition to this, wastage of sand also seen in form of by-product like mortar used for masonry, plaster and screed. Wastage of aggregate is found in the form of by-product like concrete.

Cement is another material used in large quantity for various purposes that include concrete and mortar for masonry, plaster, bedding of tile. In addition, inadequate storage of cement bags results in the penetration of moisture which form cement lumps. Cement waste is found 7.00% which is more than standard wastage considered and being an expensive material that is used in large quantity. Its wastage has considerable impact on overall cost of the project.

The fly-ash bricks are used for masonry of external façade and interior partition walls. Wastage of these bricks is 11.82% because of cutting of bricks, improper handling and stacking. Wastage of vitrified tiles used for floor finishing of habitable rooms as well as antiskid tiles for toilet floor and glazed wall tiles used in toilets and kitchens is 16.67% which is much more than the standard wastage. This is because of cutting of tiles to fit to the room sizes, for skirting etc. In addition, inadequate stacking and handling of tiles is noticed on selected project site.

The waste of paint material used for wall finishes is 13.43% and 17.20 % from external and internal painting operations respectively. This is because of material stickled to storage canes, brushes and roller used in painting process in addition to improper handling. The waste of electrical conduits and plumbing pipes as observed is 6.67% and 8.70% respectively which is in form of unusable small pieces.

9.2 Contribution of Materials in Total Waste

Next step of study is to find out the contribution of each material in percentage among total wastage of material. For this, the quantity of waste generated is further ana-

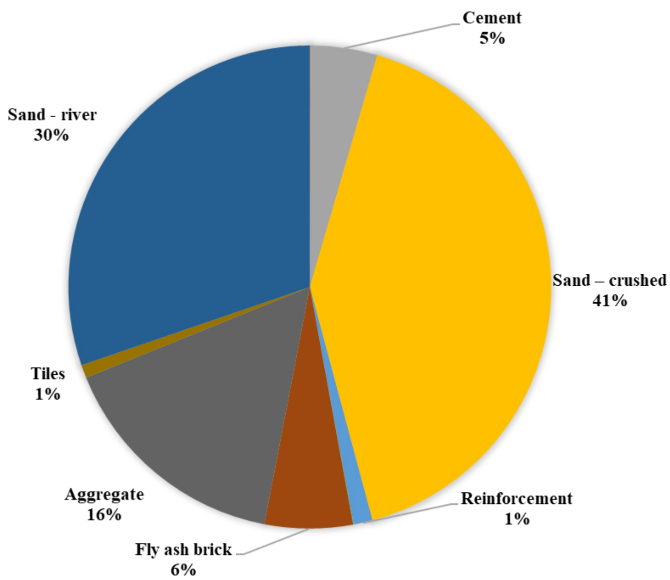


Figure 2. Contribution of wastage of material in total wastage

lyzed based on Equation (4).

$$C_m = \left(\frac{Q_w}{Q_t}\right) \times 100\% \tag{4}$$

C_m – Contribution of material wastage in percentage
Q_w – Quantity of material wastage
Q_t – Quantity of total material wastage

Figure 2 and Table 4 indicate that wastage of sand-crushed, sand-river and aggregate is 41.31%, 30.25% and 15.86% respectively which is maximum and as compare to rest all materials. The wastage of cement and fly-ash brick is 4.44% and 5.89% among the total wastage of materials on site. While wastage of reinforcement is 1.27% and of tiles is 0.87% only which is less as far as quantity of material is concerned.

The share of wastage of plumbing pipes, electrical conduits, internal and external paint is minimal in total quantity wastage generated.

9.3 Comparison of Standard and Actual Wastage

The actual quantity of waste generated on site is compared against the standard wastage which is considered while procuring the material as d presented in Figure 3.

The largest quantity of waste is found in floor and wall a tile which is more than five times the allowable wastage followed by wastage of reinforcement steel bars which is three times more than the standard wastage. The wastage of paint material both external and internal is nearly three times more than the standard wastage. Wastage of sand and cement is found 2.50 times more while quantity of wastage of fly-ash bricks which is used for infill walls is 2.25 times more than the allowable wastage. Quantity of waste for aggregate which is used in bulk quantity is found two times more while wastage against material used for building services like electrical conduit and plumbing pipe is less as it is 1.50 times of standard wastage.

Table 4. Contribution of wastage of material in total wastage

No.	Construction material	Quantity wastage	Contribution
		ton	%
1	Soil	716.00	
2	Cement	171.41	4.44%
3	Sand - crushed	1595.11	41.31%
4	Sand - river	1168.25	30.25%
5	Aggregate	612.32	15.86%
6	Reinforcement steel bar	49.17	1.27%
7	Fly ash brick	227.35	5.89%
8	Tiles	33.60	0.87%
9	Paint - internal	1.02	0.03%
	Paint - external	0.56	0.01%
10	Electrical conduit	1.26	0.03%
11	Plumbing pipes	1.56	0.04%
	Total	3861.61	

9.4 Impact on Cost

Research established that the poor management of materials leads to generation of waste which in turn results in an increase in the total cost of building projects. Reflecting on this, the waste generation is further analyzed in terms of cost incurred. The cost of each material waste is computed based on quantity market rate per unit of a

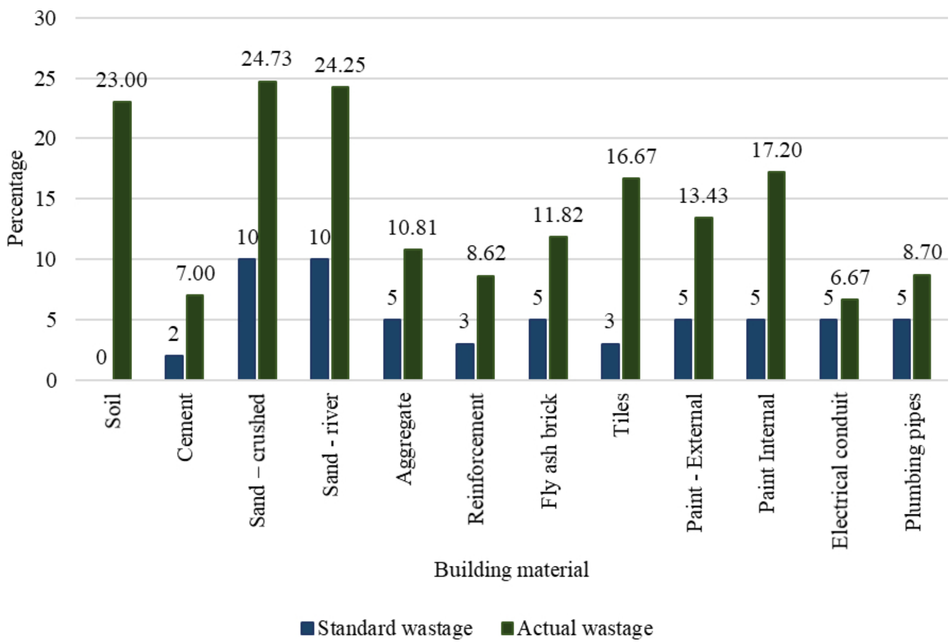


Figure 3. Comparison of standard and actual wastage

Table 5. Contribution of cost involved in wastage of material

No	Construction material	Unit	Rate INR	Quantity	Amount INR	Contribution
1	Soil	m^3		1,558.00		
2	Cement	Bags	350.00	3,428.19	1,199,866.50	10.59%
3	Sand - crushed	m^3	1,000.00	996.94	996,943.75	8.80%
4	Sand - river	m^3	2,500.00	631.49	1,578,719.59	13.94%
5	Aggregate	m^3	950.00	395.05	375,292.90	3.31%
6	Reinforcement steel bar	kg	48.00	49,170.00	2,360,160.00	20.84%
7	Fly ash brick	Nos	7.50	90,940.00	682,050.00	6.02%
8	Tiles	m^2	400.00	2,800.00	1,120,000.00	9.89%
9	Paint - internal	m^2	400.00	4,980.00	1,992,000.00	17.59%
	Paint - external	m^2	300.00	2,542.00	762,600.00	6.73%
10	Electrical conduit	m	20.00	3,000.00	60,000.00	0.53%
11	Plumbing pipes	m	100.00	2,000.00	200,000.00	1.77%
	Total				1,132,757.50	

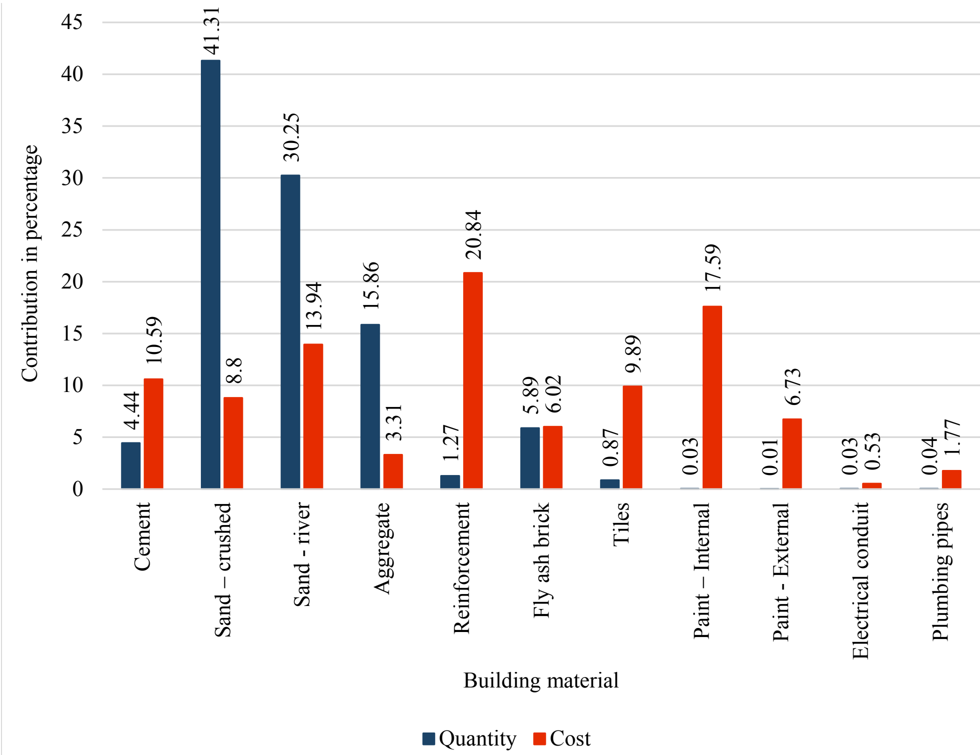


Figure 4. Contribution of wastage in terms of quantity and cost

particular material.

The economic implication due to wastage of materials generated is further examined. The cost involved in wastage of each material and their respective contribution in percentage is calculated by using Equation (5) and the output of which is presented in Table 5.

$$C_c = \left(\frac{C_w}{C_t}\right) \times 100\% \quad (5)$$

C_c – Contribution of cost of material wastage in percentage;

C_w – Cost of material wastage;

C_t – Cost of total material wastage;

As soil is excavated from construction site and not procured from other sources hence it is not considered for analysis.

The contribution of each material in terms of quantity of waste generated as well as corresponding cost is computed and presented in Figure 4.

As shown in Figure 4, the highest impact found in terms of cost is for steel which was 1.27% in quantity but the cost of wastage accounted for 20.84 % given the high cost of virgin material. This is followed by wastage of cement the quantity of which is 4.44% while it resulted in 10.59% increase in cost which is about 2.50 times. The quantity of wastage of materials viz. sand-crushed, sand-river and aggregate are much more, while economic implications of these waste materials are less. In case of fly ash brick, the quantity of wastage and cost is nearly similar. Material used for painting are less in quantity however their wastage resulted in high cost implications. It is found approximately 6.73% to 17.59% in terms of cost for external and internal paint respectively. The cost from wastage of tile is 9.89% while its wastage is only 0.87%. The material wastage along with cost of conduits and pipes is less as compare to all other materials.

10 POTENTIAL OF IDEAL HANDLING BY ADOPTING 3R PRACTICES

Semi-structured interview with experts is conducted to examine the prevailing trend of waste generation and establish potential of each material for an efficient waste management based on 3R practices. The experts selected are included twelve architect, site manager, site engineer, project management consultant and structural engineer who are directly or indirectly involved in the activities on construction sites.

The interviews are audio recorded and the interview data is processed with verbatim transcription. The statements regarding each material and practices are further analyzed under the three thematic categories reduce, reuse and recycle. The possible 3R practices based on experts' opinion are presented in table.

Table 6 indicates that wastage of material like soil, cement, sand (crushed and river), aggregate, fly ash brick and tiles could be reused to maximum extent. Similarly, wastage of material like reinforcement, paint, plumbing pipes and electrical conduits could be recycled to large quantity. The practices recommended by the experts help to minimize material wastage in residential building construction projects and enhance the efficiency of construction industry for material consumption. Waste management and minimization are important strategies that need to be applied increasingly across construction projects.

11 CONCLUSIONS AND RECOMMENDATIONS

This research addressed waste management in Indian building industry which has become a major environmental issue considering the increasing amount of construction and demolition (C&D) waste being dumped at landfill sites. The causes and consequences of construction waste generated on building sites are analyzed in context of housing sector in city of Pune. It has been found that the cost is considered as one of the key determinants for choices and decisions for waste management technologies and practices. Expert's discussion indicated that the fi-

Table 6. Potential of ideal handling of material

No	Material waste	Potential of 3R practices for ideal handling	
1	Soil	Reduce	Generated from excavation of ground for required volume for construction of foundation
		Reuse	Reusing topsoil (up to 150 mm deep) for landscape area
			Reusing boulder and murum in backfilling and road filling
			Reusing of black cotton soil in farms
		Recycle	Difficult as it is natural material to be utilised in its original form
2	Cement	Reduce	Reducing by stacking methods like dry area, hard platform, etc.
		Reuse	Reusing in form of concrete and mortar
		Recycle	Recycling in form of concrete to manufacture aggregate
3	Sand – crushed and river	Reduce	Reduction by stacking of material on hard platform and designated area
		Reuse	Reusing as tile and paver block bedding material after screening in required size
			Reusing for construction of internal roads of the project
			Reusing for site development activity like chamber construction
			Reusing for off-site activities
		Recycle	Spread throughout the premises of project site, so difficult to collect and not possible as contaminated due to addition of soil
4	Aggregate	Reduce	Reduction by stacking of material on hard platform
		Reuse	Reusing for internal road construction
			Reusing for site development activity like chamber construction
			Reusing for off-site activities
		Recycle	Recycling by crushing to manufacture crushed sand

Table 6. Potential of ideal handling of material (continued)

No	Material waste	Potential of 3R practices for ideal handling	
5	Fly ash brick	Reduce	Reduction by careful stacking and transportation
		Reuse	Reusing for development of off-site labor camp
			Reusing for construction of outdoor hardscape
		Recycle	Recycling at manufacturing unit
6	Reinforcement steel bar	Reduce	Reduction by preparing of Bar Bending Schedule at the beginning of construction and cutting of reinforcement bars by shearing machine before starting the work
		Reuse	Reusing steel bar of diameter 8 mm, 10 mm, 12 mm for making chairs, pins in beam
			Reusing 16 mm and above dia bars by coupler binding instead of lapping the length of bars
		Recycle	Recycling at manufacturing unit
7	Tiles	Reduce	Reduction by adopting standard handling and stacking methods
		Reuse	Reusing for skirting of room
			Reusing for abstract design in entrance lobbies and on open terraces, the mosaic flooring
			Reusing for development of off-site labor camp
		Recycle	Lose properties in first place manufacturing process
8	Paint	Reduce	Reduction by adopting practices like • complete use of paint material in the cane • tightening of lid when the work is not in progress • proper cleaning of brushes by solvent after completion of work should be adopted by the workforce
		Reuse	Reusing remaining paint in cane for labor camp
		Recycle	Recycling at manufacturing unit
9	Plumbing pipes	Reduce	Reduction by considering material dimension coordination with the layout of services
		Reuse	Reusing small cut pieces of pipes
		Recycle	Recycling at manufacturing unit
10	Electrical conduits	Reduce	Reduction by considering material dimension coordination with the layout of services
		Reuse	Reusing small cut pieces of pipes
		Recycle	Recycling at manufacturing unit
11	Concrete	Reduce	Reduction by using design mix proportions
		Reuse	Reusing as bedding material for paver block
			Reusing for backfilling, site development, etc.
		Recycle	Recycling by manufacturing crushed sand
12	Mortar	Reduce	Reduction by using design mix proportions
			Reduction by adopting standard methods of mixing, transportation, etc
		Reuse	Reusing proportionately in immediate batch of mortar mix
			Reusing in bedding of flooring
			Reusing in filling at various works on site
		Recycle	Mixed mortar loose properties

nancial constraints result in low priority for construction waste management. It is noticed that in project management, the benefits offered by adequate waste handling are largely ignored as compared to the cost of implementing waste management practices. The analysis based on empirical study indicated that in construction activity, the generated waste extended beyond the allowable limit in terms of quantity. The major reasons for waste generation identified were inadequate planning and procurement of material. Another reason was improper handling of materials, carelessness and negligence on the part of building operatives. The analysis of economic implication of wastage of material in the project under investigation indicated loss of about INR 1.132 million as which is considerable. Considering the potential of various building material for reuse and recycling it is evident that such economic losses could be avoided.

This research argued that the quantification of construction waste in terms of volume as well as type is essential from the project design and planning stage for the building operatives to properly plan and control its disposal. It will enable contractors to readily forecast the type and quantity of waste that is likely to generate and their required handling to reduce the cost of disposal facilitating adequate waste management. The analysis presented in this study regarding cost and quantity of waste is supposed to prove instrumental for project managers, site engineers and contractors to identify materials, wastage of which result in greater economic losses so they can take appropriate action for saving cost and check adverse impact on environment.

This research recommends standardization of design, use of prefabricated materials, stock control as well as training for proper handling and environmental awareness of the workforce. Design and specification of materials based on size and dimensions available in market is stressed as it supposed to eliminate cutting and reshaping of various materials which in turn save on wastage to considerable extent. The study established that the 3R practices are practically possible and advantageous in minimizing the construction waste at its source while rest could be reused and recycled to maximum extent. For an efficient waste management, effort for wastage minimization should be planned at the initial design and planning stage, construction stage and integrated into the construction processes. It is established that concise efforts at these stages of construction lead to minimization of waste generation. The construction waste management can be successfully achieved with consent, coordination, and cooperation from all the stakeholders. The benefits to be gained from 3R practices adoption for waste minimization are enormous as it saves control cost of project as well as environment as a whole.

REFERENCES

Adewuyi, T. O., Idoro G. I., and Ikpo, I. J. (2014). Empirical evaluation of construction material waste generated on sites in Nigeria. *Journal of Civil Engineering Science and Application*, 16(2), 96–103. https://doi.org/10.9744/ced.16.2.96-103

Adewuyi, T. O., and Odesola, I. A. (2015). Factors affecting material waste on construction sites in Nigeria. *Journal of Engineering and Technology*, 6(1), 82–99. Available at: http://journal.utem.edu.my/index.php/jet/article/view/237

Adewuyi, T. O., and Otali, M. (2013). Evaluation of causes of construction material waste - Case of Rivers state, Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 6(6), 746–753. https://doi.org/10.4314/ejesm.v6i6.5S

Agarwal, R., Chaudhary, M., and Singh, J. (2015). Waste management initiatives in India for human well being. *European Scientific Journal*, 11(10), 105–128. Available at: https://smartnet.niua.org/sites/default/files/resources/h16.pdf

Ahmed, S. J. R. (2016). Status and challenges of municipal solid waste management in India: A review. *Cogent Environmental Science*, 2(1), 1–18. https://doi.org/10.1080/23311843.2016.1139434

Ajayi, S. O., Oyedele L. O., Akinadé O. O., Bilal M., Owolabi H. O., and Alaka H. A. (2017). Optimising material procurement for construction waste minimization: an exploration of success factors. *Sustainable materials and technologies*, 11, 38–46. https://doi.org/10.1016/ j.susmat.2017.01.001

Arashpour, M., Miletic, M., Williams, N., and Fang, Y. (2018). Design for manufacture and assembly in off-site construction: Advanced production of modular façade systems. *35th International Symposium on Automation and Robotics in Construction*, Australia.

Bandgar, G. S., and Kumthekar M. B. (2016). A Study on Feasibility of Rapid Wall Panel for Building Construction. *International Research Journal of Engineering and Technology*, 3(6), 1026–1031.

BMTPC, I. (2018). *Compendium of Prospective Emerging Technologies for Mass Housing* (Third Edition ed.). Building Materials and Technology Promotion Council, Ministry of Housing and Urban Affairs, Government of India, New Delhi, India.

Fadiya, O. O., Georgakis, P., and Chinyio, E. (2014). Quantitative Analysis of the Sources of Construction Waste. *Journal of construction engineering and management*, 2014, 9. https://doi.org/10.1155/2014/651060

Foo, C. H., and Kamaludin, N. (2017). Professional' views on material wastage level and causes of construction waste generation in Malaysia. *An International Journal of Organization, Technology and Management in Construction*, 21(1), 33–54. https://doi.org/10.5592/otmcj.2013.1.11

GOI (2019). http://www.makeinindia.com/sector/construction. Available at: http://www.makeinindia.com/sector/construction

Kourmpanis, B., Papadopoulos A., Moustakas K., Stylianou M., Haralambous K. J., and Loizidou M. (2008). Preliminary study for the management of construction and demolition waste. *Waste management and Resource*, 26(3), 267–275. https://doi.org/10.1177/0734242X07083344

Kozlovská, M., and Spišáková M. (2013). Contruction waste generation across construction project life-cycle. *Organization, technology & management in construction : an international journal*, 5(1), 687–695. https://doi.org/10.5592/otmcj.2013.1.5

Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S J., Arya, S., Rena, K., Cheeseman R., and C.

(2017). Challenges and opportunities associated with waste management in India. *Royal society open science*, 4(3), 1–11. https://doi.org/10.1098/rsos.160764

Level, B., Ltd. (2016). *The three Rs of waste minimisation are: reduce, reuse, and recycle*. Judgeford, Porirua, New Zealand. Available at:

Li, Z., Shen, G. Q., and Alshawi, M. (2014). Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. *Resources, conservation and recycling*, 91, 27–39. https://doi.org/10.1016/j.resconrec.2014.07.013

Liton, B. (2018). What is The Dry Volume of Concrete and How to Calculate It? Available at: https://www.acivilengineer.com/dry-volume-of-concrete

Mahajan, S., and Shirsath, M. (2011). Housing study for Pune Municipal Corporation 2009–2010. Pune, India.

Masudi, A. F., Hassan C. R. C., Mahmood N. Z., and Mokhtar S. N. (2010). Quantification Methods for Construction Waste Generation at Construction Sites: A Review. *Advanced Material research*, 163–167, 4564–4569. https://doi.org/10.4028/www.scientific.net/AMR.163-167.4564

Miranda, R., Tike C., and Vadake K. (2017). Study of Construction and Demolition Waste Management in India. *International Journal of Scientific Engineering and Science*, 1(11), 50–52.

Mohammed, M. S. (2020). A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach. *IOP Conference Series Earth and Environmental*, Bristol, UK.

Mokhtar, S. N., Mahmood N. Z., Che Hassan C. R., Masudi A. F., and Sulaiman N. M. (2011). Factors that contribute to the generation of construction waste at sites. *Advanced Materials Research*, 163, 4501–4507. https://doi.org/10.4028/www.scientific.net/AMR.163-167.4501

Muhaidin, N. H. M., and Chan, H. B. (2018). The comparison of construction waste produced by conventional method against IBS: A case study in Pulau Pinang. *Advances in Civil Engineering and Science Technology*, Penang, Malaysia.

Ng, L. S., Seow, T. W., and Goh, K. C. (2015). Implementation on solid waste reduction through 3R (NSWM Policy) and elements to close gap between policy and contractors in construction industry in Penang. *International Journal of Environmental Science and Development*, 6(9), 668–675. https://doi.org/10.7763/IJESD.2015.V6.678

Ng, L. S., Seow, T. W., and Tan, L. W. (2017). Current practices of construction waste reduction through 3R practice among contractors in malaysia: Case study in penang. *Materials Science and Engineering*. 271(1): 012039. https://doi.org/10.1088/1757-899X/271/1/012039

Ng, L. S., Seow T. W., and Tan, L. W. (2018). Constraints to 3R construction waste reduction among contractors in Penang. *Earth and Environmental Science*. 140(1), 012103. https://doi.org/10.1088/1755-1315/140/1/012103

Nitivattananon, V., and Borongan, G. (2007). Construction and demolition waste management: current practices in Asia. *the Proceedings of the International Conference on Sustainable Solid Waste Management*, Chennai, India.

Oyenuga, A. A., and Bhamidiarri, R. (2015). Sustainable Approach to Managing Construction and Demolition Waste: An Opportunity or a New Challenge? *International Journal of Innovative Research in Science, Engineering and Technology*, 4(11), 10368–10378. https://doi.org/10.15680/IJIRSET.2015.0411007

Patel, V. B., Pitroda, J., and Bhagat, S. S. (2017). Organizing and Reducing Construction and Demolition waste: A review. *the International Conference on Technology and Management (ICTM 2017)*, Gujarat, India.

Pitroda, J. R., and Chanki, N. M. (2018). A Critical Literature Review on Construction Waste Management. *International Journal of Advance Engineering and Research Development*, 5(3), 434–439.

Ponnada, M., and Kameswari, P. (2015). Construction and demolition waste management—a review. *International Journal of Advanced Science and Technology*, 84, 19–46. https:// doi.org/10.14257/ijast.2015.84.03

Rawat, A., Sachan, A. K., and Ramashanker (2014). Management of Construction and Demolition Waste Materials. *International Conference on Sustainable Civil Infrastructure(ASCE India)*, IIIT, Hyderabad, India.

Saidu, I., and Shakantu, W. (2016). The contributions of construction material waste to project cost overruns in Abuja, Nigeria. *Acta Structilia*, 23(1), 99–113. https://doi.org/10.18820/1023-0564/ as23i1.4

Saidu, I., and Shakantu, W. M. W. (2015). A relationship between quality-of estimating, construction material waste generation and cost overrun in Abuja, Nigeria. *the Fourth Construction Management Conference*, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa.

Sasidharani, B., and Jayanthi, R. (2015). Material Waste Management In Construction Industries. *International Journal of Science and Engineering Research (IJ0SER)*, 3(5), 1–12.

Shrivastava, S., and Chini, A. (2009). Construction materials and C&D waste in India. *Lifecycle Design of Buildings, System and Materials*, Enschede, Netherlands.

Mahayuddin, S. A., and Zaharuddin, W. A. Z. W. (2013). Quantification of waste in conventional construction. *International Journal of Environmental Science and Development*, 4(3), 296–299. https://doi.org/10.7763/IJESD.2013.V4.357

Sote, D., Bhonde, D., Nawle, R., and Anagal, V. (2014). Optimizing energy through on-site reuse and recycle construction waste in residential project–A Case Study of Pune. *30th International PLEA Conference: Sustainable Habitat for Developing Societies – Choosing The Way Forward*, Ahmedabad, India.

Thomas, J., and Wilson, P. M. (2013). Construction waste management in India. *American Journal of Engineering Research (AJER)*, 2, 6–9.

TIFAC (2001). Utilisation of Waste from Construction Industry. Available at: https://tifac.org.in/index.php/8-publication/184-utilisation-of-waste-from-construction-industry

Toby, G. (2007). A review of international approaches to waste prevention, and minimisation, *AEA Technology PLC*, Oxfordshire, UK.

Turkyilmaz, A. G. (2019). A comprehensive construction and demolition waste management model using PESTEL and 3R for construction companies operating in central Asia. *Sustainability*, 16.

Ugochukwu, S., Agugoesi S., Mbakwe C., and Abazuonu L. (2017). An on-site Quantification of Building Material Wastage on Construction Projects in Anambra State, Nigeria: A comparison with the Literature. *Journal of Architecture and Civil Engineering*, 3(6), 12–23.

IndiaMART (2019). Construction Material Rates. Available at: www.indiamart.com

Yakkaluru, P., and Naik, B. H. (2016). Waste Minimisation in Construction Industry. *International Journal of Innovative Research in Science, Engineering and Technology*, 5(10), 18023–18030. https://doi.org/10.15680/IJIRSET.2016.0510108


Electronic Journal of STRUCTURAL ENGINEERING

Login

ABOUT CURRENT ARCHIVES EDITORIAL TEAM SUBMISSIONS CONTACT ANNOUNCEMENTS SEARCH

ISSN: 1443-9255

OPEN ACCESS JOURNAL

Electronic Journal of Structural Engineering is an open access journal, so articles are freely available to the readers.

OPEN ACCESS

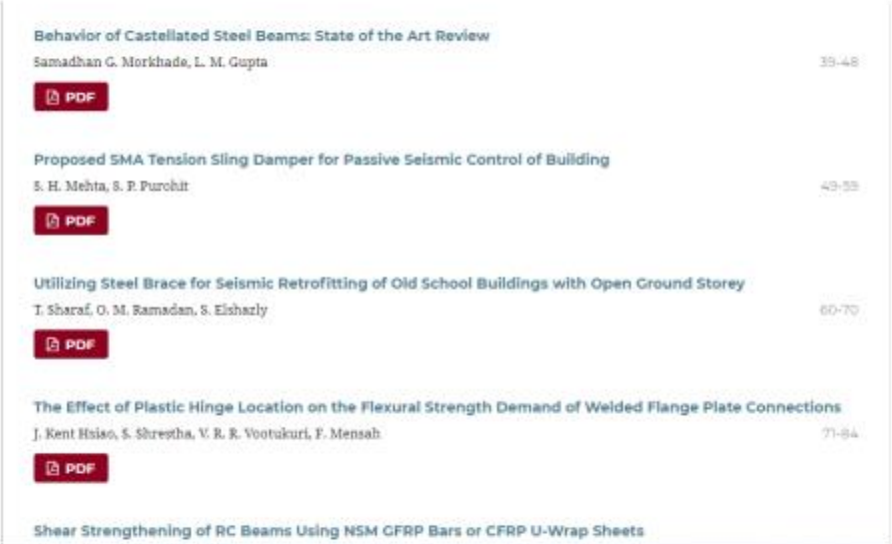
MAKE A SUBMISSION

INFORMATION

About the Journal

Electronic Journal of Structural Engineering

Electronic Journal of Structural Engineering is an **open access**, peer-reviewed journal that presents scientific research in various fields within structural engineering. Being one of the first digital journals around the world, the Electronic Journal of Structural Engineering (EJSE) is an international forum for the dissemination and discussion of leading-edge



eJSE International

Electronic Journal of Structural Engineering 19(1) 2019

Proposed SMA Tension Sling Damper for Passive Seismic Control of Building

S. H. Mehta & S. P. Purohit
Department of Civil Engineering, School of Engineering, Institute of Technology, Nirma University, Ahmedabad, Gujarat, India - 382481

ABSTRACT: Passive Shape Memory Alloy (SMA) based Tension Sling Damper (TSD) is proposed to control seismic response of building represented as dynamic SDOF system. Non-linear hysteretic behavior of SMA is characterized by Tanaka model with seismic excitations as input. It is converted to equivalent piece-wise linear elastic viscous damping model described by stiffness constant 'k_{eff}' and damping constant 'c_{eff}' to implement it with linear dynamic system. Damping constant 'c_{eff}' is evaluated for TSD for given seismic excitation at each instance of time defined as instantaneous damping, unlike constant damping used in other studies, to derive accurate seismic response of the dynamic system. Seismic response control parameters – peak and rms performance indices (PI) for displacement and acceleration, peak damper force, maximum damping ratio are evaluated for flexible, moderately stiff and stiff dynamic systems fitted with TSD under pulse and strong ground motion type seismic excitations with varied PGA. Substantial reduction in PI is observed for controlled systems through varying design parameters of TSD – cross-sectional area and length of SMA sling. TSD yields better seismic response control for moderately stiff and flexible system due to super-elastic properties of SMA. Further, it works efficiently for seismic excitations with low to moderate PGA.

1 INTRODUCTION

Seismic response control of structure has been extremely important to safeguard it from excessive damage. Passive energy dissipation systems for seismic application have received much attention since mid-1990s as these require no external power to attenuate damage to the framing system. Passive damping devices include viscous fluid damper, viscoelastic damper, metallic damper, friction damper etc. (Symans et al. 2008). It has been realized that such devices yield limited structural response control due to inability of the damper to respond in real time. This leads to development of semi-active dampers capable of modifying its mechanical properties with real time (Soong et al. 2002, Spencer et al. 2003). Most common among semi-active dampers are Electrorheological and Magnetorheological dampers (Xu et al. 2000) that are used to produce actuation force estimated through Optimal Control Theories (Jansen & Dyke 1999, Purohit & Chandiramani 2010). Following the success of semi-active dampers, post 2000 have seen many active dampers and dampers with combination of active and passive elements (hybrid dampers) developed to control seismic response of the structure. Since, both, semi-active and active dampers use damping materials with unique controllable properties in real time, there has been a surge in active research to explore such materials in last decade. Recently, Shape Memory Alloys (SMA) have drawn significant attention for potential seismic application in structures due to their unique and superior properties of phase transformations. Typical SMA exists in two different phases - martensite & austenite with their reversible transformation being stress or temperature dependent (Buehler & Wiley, 1961).

The unique characteristics of Cu-Zn and Cu-Al alloys to undergo reversible thermo-elastic martensitic transformation had been demonstrated first by Kurdjumov & Khandros (1949). In 1963, Buehler and co-workers discovered NiTi SMA at Naval Ordinance Laboratory (NOL) undergoing phase transformations offering potential to commercialize SMA applications. NitiNOL has been used in diversified fields like Automobile, Aerospace, Robotics and Biomedical (Jani et al. 2014). Song et al. (2006) have studied potential application of SMA based passive control device for seismic response control of the structure. Bertrand et al. (2013) have shown increased damping due to phase transformation from austenite to martensite when used as damper in structures. SMA based passive dampers have been developed and implemented with Reinforced Concrete frames (Dolce et al. 2005, McCormick et al. 2006); with steel frames (Mortazavi et al. 2013) and as Buckling Restrained Braces with steel frames (Miller et al. 2012). Zhang & Zhu (2007), Morais et al. (2017), in their studies, established that damping offered by SMA damper is a function of SMA wire diameter, strain rate & amplitude and pre-straining of SMA wire.

Many researchers have carried out experimental studies to understand the hysteretic behavior of SMA material in the form of wire/rod. Caughey (1960) has represented hysteretic behavior of SMA observed under cyclic sinusoidal loading as a bilinear curve. Tanaka (1986) represented one dimensional hysteretic model for SMA which is versatile and simpler to use. Graesser & Cozzareli (1991) have included macroscopic characteristics of SMA to the existing one dimensional hysteresis model. However, prediction using G-C model drifts from experimental results of hysteretic behavior due to use of identical parameters for loading and unloading path of the model. Ren et al. (2007) have improved classical G-C model setting model parameters different for loading and unloading path to match prediction and experimental results of hysteretic behavior of SMA. Further, effect of strain rate and strain amplitude on hysteretic behavior of SMA under cyclic loading also have been studied. Experimental studies conducted by DesRoches et al. (2004) have found that damping potential of super-elastic SMA wire/bar is low and of the order less than 7% equivalent viscous damping. It has been observed that damping of SMA degrades with cyclic strain exceeding 6%. Increment in seismic loading rate observes reduction in equivalent damping in SMA, also reported by Ren et al., (2007). Energy dissipation in each cycle (Iterative Response Spectrum) of SMA has been modelled as equivalent viscous damping for sinusoidal loading (Parulekar et al. 2014). SMA wire based damper and re-centering devices for seismic response control of structures have been explored by Han et al. (2003), Zhang & Zhu (2007) and Lobo et al. (2015). Ghodke & Jangid (2016) have used SMA wire with base isolators for seismic response control of irregular building. Equivalent linear elastic viscous damping model for SMA wire has been proposed for nonlinear force deformation behavior of the isolator following AASHTO guidelines. Two model parameters, i.e. effective elastic stiffness and effective viscous damping have been derived, to map hysteretic parameters used for classical G-C model and model proposed by Ren et al. (2007).

Present paper aims to control seismic response of building modelled as SDOF dynamic system, passively, through proposed SMA based Tension Sling Damper (TSD). SDOF system fitted with TSD is subjected to various seismic excitations ranging between with low to high PGA representing pulse type and strong ground motion type. Design parameters for SMA based TSD include cross-sectional area and length of SMA sling. Maximum strain induced in SMA sling of TSD is restricted (< 6%) to eliminate non-recoverable drift of the dynamic system. Nonlinear hysteretic behavior of SMA represented by Tanaka model (Tanaka 1986) is characterized under seismic inputs. It is modelled as equivalent piece-wise linear elastic viscous damping model to implement with linear dynamic system.

The present study has two distinct objectives to be met with; (i) to develop a reusable super-elastic SMA wire based passive damper, inducing tension forces only, to control seismic response of the building. (ii) to propose equivalent piece-wise linear elastic viscous damping model that allows evaluation of damping at each instant leading to realistic seismic control of the building. Seismic response control of the dynamic system is quantified with peak and RMS Performance Indices (PI) for displacement and acceleration under different type of seismic excitations. Damper force and damping offered by TSD at each instant are evaluated to assess efficacy for seismic response control of dynamic system.

2 SYSTEM MODEL

2.1 *Tension Sling Damper (TSD)*

The proposed Tension Sling Damper (TSD) uses SMA wires, bearing only tensile strain, when subjected to seismic excitations. It can be fitted at the centre/off-centre in principal diagonal member of a building frame. Figure 1a, b show schematic diagram of elevation & plan and isometric view of the damper. TSD has a rigid core box that can move freely inside the slit provided in plates connected with flanges of designated I section forming bottom bracing element. Connecting plates also house rigid rod, each at above and below rigid core box at a distance that satisfies length requirement of SMA sling as shown in Figure 1a, b. SMA slings, number as per design, are firmly attached to the rigid core box and the same are wound around rigid rod. Rigid core box receives an input motion from top bracing element (I section) as it is connected to connecting plate at the central shaft of rigid core box. It is followed that, at any instant of seismic excitation input, only one set of SMA slings wound around rigid rod is strained due to tension. At the same time, the other set of SMA slings disengages itself from the rigid rod until the direction of input changes. Smooth relative motion of the rigid core box inside the slits of connecting plates with bottom bracing element is ensured through tolerances and friction reducing agents.

Proposed TSD distinguishes itself from conventional X-bracing elements as former eliminates compression diagonal member likely to undergo buckling due to seismic excitation. Proposed passive TSD offers flexibility in design, at par, with other well established passive damping devices as: i) damper force of TSD can be tuned to input seismic excitations as designer can vary cross-sectional area and/or nos. of

SMA sling; ii) length of SMA sling can be designed without overshooting non-recoverable tensile strain limit of 0.06 strain (DesRoches et al. 2004); and iii) elimination of compressive force of the TSD prevents buckling possibility.

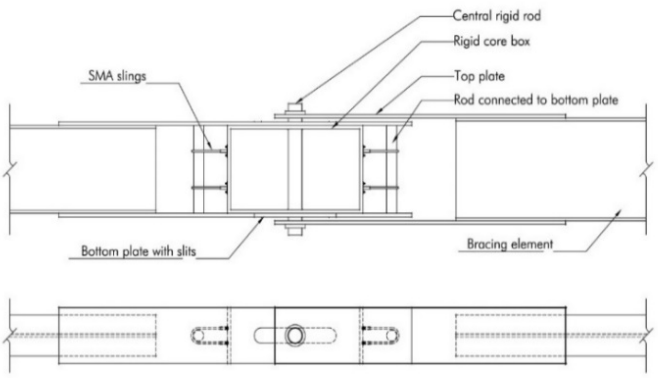


Figure 1 (a) Plan and elevation of proposed Tension Sling Damper

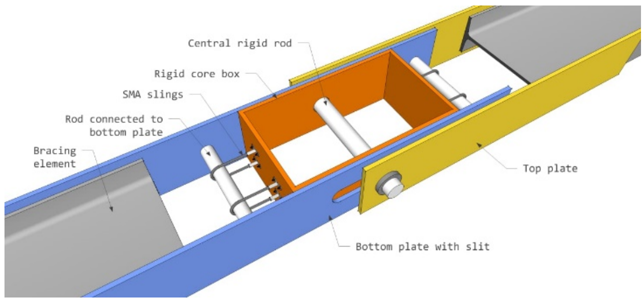


Figure 1 (b) Isometric view of proposed Tension Sling Damper

2.2 *SMA Slings*

SMA slings of the present study are characterized by unified Tanaka Model under cyclic loading leading to hysteretic stress-strain relationship. Mechanical properties (Hardtl & Lagoudas, 2008) used are : Modulus of Elasticity in Martensite (E_M) and Austenite (E_A) : 46 GPa and 55 GPa; Martensite Start Temperature (M_s) and Finish Temperature (M_f): -28°C and -43°C; Austenite Start Temperature (A_s) and Finish Temperature (A_f) : -3°C and 7°C; Stiffness influence coefficients for Martensite (C_M) and Austenite (C_A) : 7.4 Mpa/°C; Maximum transformation strain ($H^{cur}(\sigma) = H_{max}$): 0.06. A good agreement between experimental investigation and simulated response using above properties of SMA wire has been established by Hardtl & Lagoudas (2008). The total strain in SMA sling by unified Tanaka model is expressed through Equation (1) to Equation (3).

$$\varepsilon = \varepsilon_{Elastic} + \varepsilon_{Transformation} + \varepsilon_{Thermodynamic} \qquad (1)$$

$$\varepsilon_{thermodynamic} = \alpha(T - T_0) \qquad (2)$$

where α = co-efficient of thermal expansion, T=Temperature of SMA element at that instant and T_0=Initial temperature

$$\varepsilon_{Transformation} = \xi H^{cur}(\sigma) \qquad (3)$$

where ξ = % of martensite by volume and $H^{cur}(\sigma)$ = maximum transformation strain.

Loading/unloading or heating/cooling of SMA slings induce phase transformation which is represented by parameter 'ξ', i.e., % martensite volume fraction which is a function of temperature and stress influence co-efficient. Details can be referred from Hardtl & Lagoudas (2008). Martensite volume fraction (ξ) during phase transformation of SMA sling subjected to loading/unloading or temperature variation can be evaluated through Equation (4) to Equation (7).

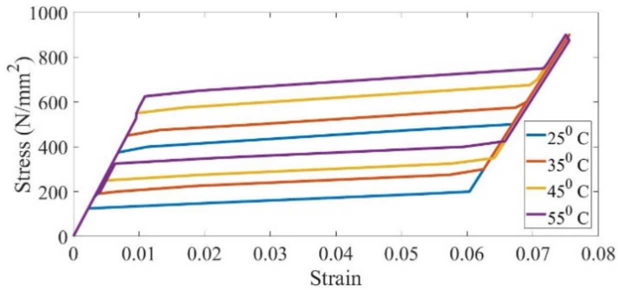


Figure 2 Variation of stress vs strain for SMA wire subjected to stress cycle at various ambient temperatures

$$\xi = 0;\ \text{if } T \geq M_s^{\sigma} \text{ or } T \geq A_f^{\sigma} \qquad (4)$$

$$\xi = \frac{(M_s^{\sigma} - T)}{(Ms - Mf)};\ \text{if } M_f^{\sigma} < T < M_s^{\sigma} \qquad (5)$$

$$\xi = \frac{(A_f^{\sigma} - T)}{(A_f - A_s)};\ \text{if } A_s^{\sigma} < T < A_f^{\sigma} \qquad (6)$$

$$\xi = 1;\ \text{if } T \leq M_f^{\sigma} \text{ or } T \leq A_s^{\sigma} \qquad (7)$$

where

$$A_s^{\sigma} = A_s + \frac{\sigma}{C_A}; \qquad A_f^{\sigma} = A_f + \frac{\sigma}{C_M};$$

$$M_s^{\sigma} = M_s + \frac{\sigma}{C_M}; \qquad M_f^{\sigma} = M_f + \frac{\sigma}{C_M}$$

Here A_s, A_f and M_s, M_f are start and finish temperatures while C_A and C_M are stress influence coefficients for austenite and martensite, respectively.

The elastic strain for SMA sling, thus, can be derived from Equation (1), using Equation (2) and Equation (3), given as

$$\varepsilon_{elastic} = \varepsilon - \xi H^{cur}(\sigma) - \alpha(T - T_0) \qquad (8)$$

The elastic stress in SMA sling can be computed using modulus of elasticity of SMA at any instant as defined by

$$E = E_A + \xi\,(E_M - E_A) \qquad (9)$$

where, E_A = Elastic modulus of austenite and E_M = Elastic modulus of martensite

Thus, stress in the SMA sling corresponding to given strain level for isothermal process is as follows,

$$\sigma = [E_A + \xi(E_M - E_A)]\,[\varepsilon - \xi H^{cur}(\sigma)] \qquad (10)$$

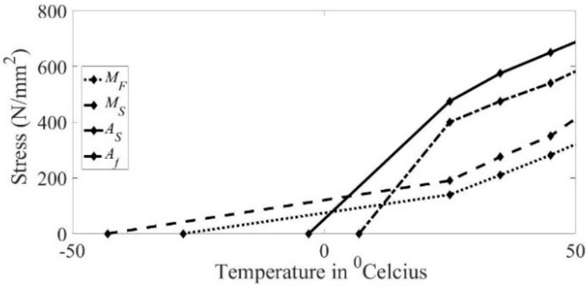


Figure 3 Stress vs transformation temperature for SMA slings

Stress-strain relationship for SMA sling given by Equation (10) is plotted in Figure 2, considering an isothermal process, for realizable ambient temperatures. Experimental studies by Hardtl & Lagoudas (2008) revealed that stress- strain relationship is well depicted by Tanaka model. Figure 3 shows relationship between stress vs transformation temperature. It is evident that increment in applied stress brings transformation temperature within the vicinity of ambient temperature range and thus SMA sling is effectively utilized as damping. This may be one of the reasons for advocating pre-strain in SMA wires by some researchers (Zhang & Zhu, 2007). Low stress levels applied to SMA sling see phase transformation at lower temperature. However, effectiveness of SMA for seismic response control at low ambient temperature is relatively less explored in literature.

2.3 *Proposed Equivalent Piece-wise Linear Elastic Viscous Damping Model of SMA*

SMA characterization studies of Tanaka, Graessar & Cozzaerelli and Ren et al establishes that hysteretic behavior comprises of nonlinear force deformation relationship. Such models find difficulties in implementation with linear dynamic system and warrants stochastic linearization method to obtain equivalent stiffness and damping (Gur et al. 2016). Further, application of SMA in base isolator for irregular building by Ghodke & Jangid (2016), following AASHTO guidelines, proposes nonlinear force deformation behavior to be modelled as equivalent linear model. The proposed model has two parameters; i) effective equivalent linear elastic stiffness and ii) effective equivalent linear viscous damping. Therefore, characteristic linear force in the SMA wire can be represented as Equation (11).

$$F_{SMA} = k_{eff}\, x(t) + c_{eff}\, \dot{x}(t) \qquad (11)$$

where x, $\dot{x}$ are displacement and velocity of the SMA wire respectively. Referring Fig. 3 k_{eff} is given as Equation (12)

$$k_{eff} = \frac{(F_{max} - F_{\min})}{(x_{max} - x_{min})} \qquad (12)$$

F_{max} and F_{min} are maximum and minimum forces observed by the SMA wire, where as x_{max} and x_{min} are corresponding maximum and minimum displacements.

Effective damping ratio ξ_{eff} can be determined using Figure 4 as,

$$\xi_{eff} = \frac{2\,\lambda F_{ys}\,(x_{max} - x_y)}{2\pi k_{eff} x_{max}^2} \qquad (13)$$

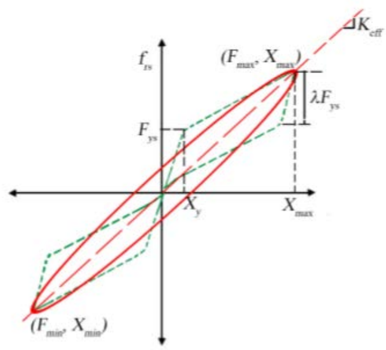


Figure 4 Equivalent stiffness for SMA wire as per AASHTO guidelines, Ghodke & Jangid (2016)

where λF_{ys} is the shear force difference between the two transformation related to loading and unloading, $\lambda = (1 - \alpha_s)$, α_s is the ratio of transformation stiffness to austenite stiffness, x_y is the displacement corresponding to yield force of SMA wire and effective damping co-efficient c_{eff} = 2*ξ_{eff}*sqrt (k_{eff}*m) with usual notations.

It is evident that, SMA wire subjected to random excitations like earthquake imposes varied damping demand on SMA, unlike constant damping demand defined in Equation (13) by Ghodke & Jangid (2016).

In the present study, SMA wire represented by Tanaka model is excited under Kobe (N-S component 1964) ground motion. Nonlinear force deformation behavior of SMA wire is determined and is shown in Figure 5. Equivalent stiffness, k_{eff} as defined by Equation (12) and given by Figure 4 is evaluated for Figure 5. However, varied seismic demand of SMA wire as defined by instantaneous damping is evaluated replacing maximum displacement x_{max} of Figure 4 by instantaneous displacement x_i in Equation (13). The instantaneous damping ratio can be expressed as Equation (14)

$$\xi_{eff}(i) = \frac{2\,\lambda F_{ys}\,(x_i - x_y)}{2\pi * k_{eff} * x_{max}^2} \qquad (14)$$

Instantaneous damping co-efficient is evaluated as,

$$c_{eff}\,(i) = 2\,\xi_{eff}(i)\sqrt{k_{eff} * m} \qquad (15)$$

SMA force generated at each instance of time due to equivalent linear constant stiffness and instantaneous damping can be expressed as

$$F_{SMA}(i) = k_{eff}x(i) + c_{eff}(i)\dot{x}(i) \qquad (16)$$

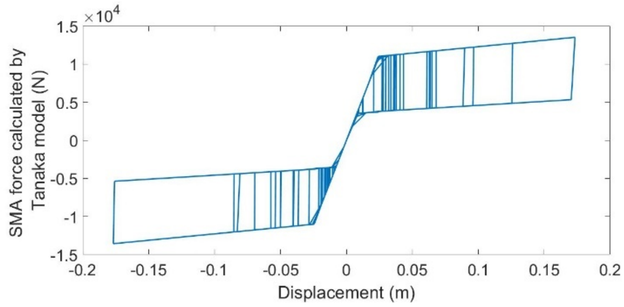


Figure 5 SMA damper force for Kobe ground displacement by unified Tanaka model

Figure 6 shows equivalent linear force deformation behavior of SMA wire under Kobe ground motion following piecewise linear equivalent elastic viscous damping based on Equation (12), Equation (14) and Equation (15).

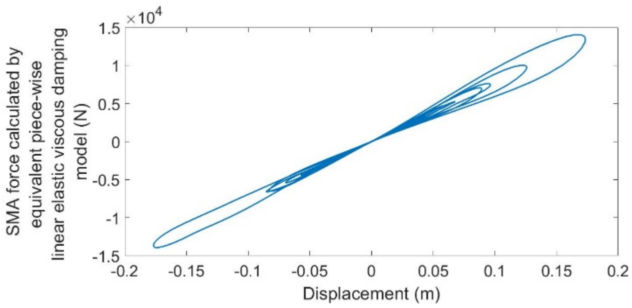


Figure 6 SMA damper force vs Kobe ground displacement represented by equivalent piece-wise linear elastic viscous damping model

Above results indicate good agreement between peak damper force derived by Tanaka model and equivalent piece-wise linear elastic viscous damping model proposed in present study. Damping component evaluated by equivalent linear elastic viscous damping model (Ghodke & Jangid, 2016) and equivalent piece-wise linear elastic viscous damping model under Kobe seismic excitations are as shown in Figure 7 and Figure 8. The apparent difference in force vs displacement relationship is due to the fact that the former (Fig. 7) uses constant stiffness and damping irrespective of seismic input received by SMA while the later (Fig. 8) evaluates damping co-efficient 'c_{eff}' at each instance of time for each seismic input. This approach of SMA modelling will allow one to use compatible semi-active or active control device to further improve seismic response control of the dynamic system which is not in the scope of present study.

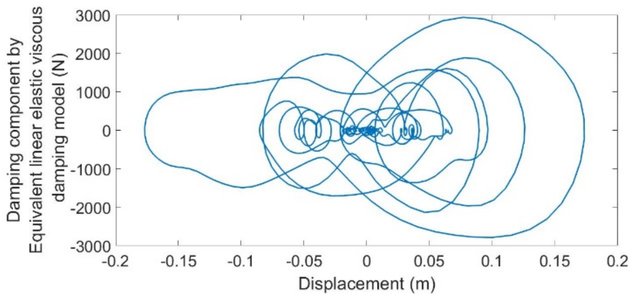


Figure 7 Force vs displacement relationship for equivalent linear elastic viscous damping model of SMA to Kobe seismic excitation

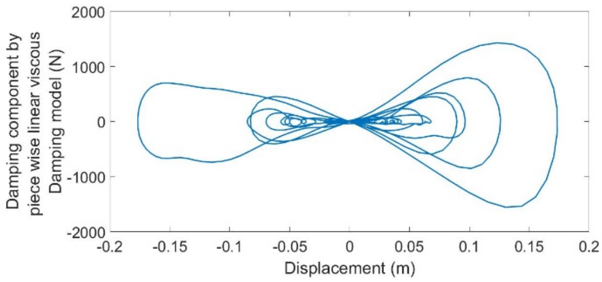


Figure 8 Force vs displacement relationship for equivalent piece-wise linear elastic viscous damping model of SMA to Kobe seismic excitation

2.4 *Structural Model*

A building modelled as discrete linear Single Degree of Freedom (SDOF) system with dominant flexural mode of vibration is considered as shown in Figure 9. Dynamic properties of the system considered are k/m = 17.55 /s^2; c/m = 0.084 /s and ξ = 0.01 (Seelecke et al. 2002). Seismic excitations representing pulse type earthquake – Loma Prieta 1989 (PGA-0.64g, E-W component) & Kobe 1964 (PGA-0.829g, N-S component) and strong motion earthquakes – Taft 1952 (PGA-0.179g, E-W component) & El Centro 1945 (PGA-0.29g, N-S component) are used in the present study. These excitations are padded with zero acceleration data appropriately to ensure decaying seismic response of the SDOF system.

Passive TSD, developed in Section 2.1, is attached to the SDOF system and schematically shown in Figure 9. Design parameters of TSD – cross-sectional area (diameter) and length of SMA slings are evolved to achieve desirable seismic response control. These design parameters are determined imposing constraint on strain limit to negate residual strain of TSD.

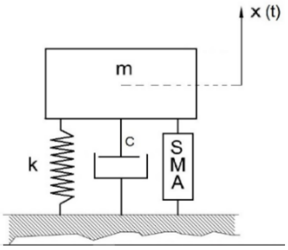


Figure 9 Discrete mathematical model of SDOF system with Tension Sling Damper

Dynamic equilibrium equation of motion for the linear SDOF system with TSD subjected to seismic excitation is expressed as

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) + F_{SMA}(t) = -m\ddot{x}_g(t) \quad (17)$$

where m, k and c are mass, stiffness and damping coefficient; $\ddot{x}_g$ is seismic ground acceleration and F_{SMA} is the passive damping force exerted by the TSD. As non-linear passive damper force F_{SMA} given by Tanaka model is represented by equivalent piecewise linear elastic viscous damping model, defined by Equation (16) introduced in Section 2.3, dynamic equation of motion (Equation (17)) is modified to

$$m\ddot{x}(t) + (c+c_{eff}(i))\,\dot{x}(t) + (k+k_{eff})\,x(t) = -\,m\ddot{x}_g(t) \quad (18)$$

3 RESULTS AND DISCUSSION

Uncontrolled displacement response of SDOF system under Taft seismic excitation is extracted as shown in Figure 10a to validate it with results by Seelecke et al (2002) reproduced in Figure 10b. Comparison of response shows good agreement to miniscule extent.

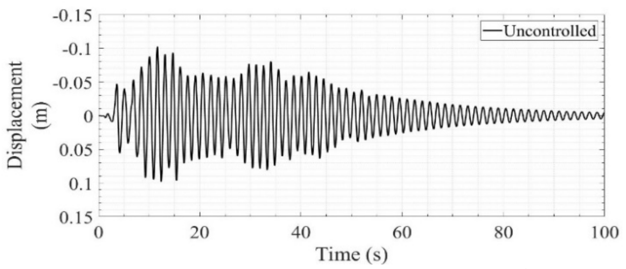


Figure 10a Uncontrolled displacement response of SDOF System subjected to Taft seismic excitation (present study)
Figure 10 b Uncontrolled displacement response of SDOF system subjected to Taft seismic excitation (Seelecke et al. 2002)

Seismic response parameters of controlled SDOF system with TSD are defined through peak and rms Performance Indices (PI) (Ohtori et al. 2004), with usual notations in Table 1.

Peak and rms PI for displacement and acceleration responses, peak damper force, maximum strain and peak instantaneous damping ratio are evaluated for three types of dynamic systems - flexible system (T_n=1.5s); moderately stiff system (T_n=0.7s); stiff system (T_n=0.3s) fitted with TSD subjected to seismic excitations.

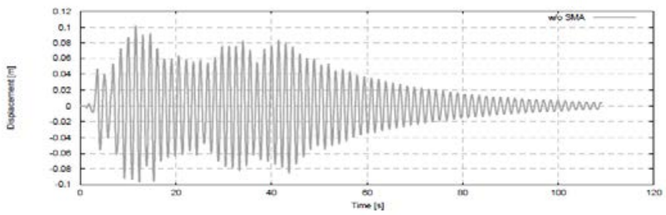


Table 1. Peak and rms performance indices (PI) for Controlled SDOF System

Peak Displacement	RMS Displacement
$J_1 = \frac{\max \mid x_{controlled} \mid}{\max \mid x_{uncontrolled} \mid}$	$J_2 = \frac{\text{rms} \mid x_{controlled} \mid}{\text{rms} \mid x_{uncontrolled} \mid}$
Peak Acceleration	**RMS Acceleration**
$J_3 = \frac{\max \mid \ddot{x}_{controlled} \mid}{\max \mid \ddot{x}_{uncontrolled} \mid}$	$J_4 = \frac{\text{rms} \mid \ddot{x}_{controlled} \mid}{\text{rms} \mid \ddot{x}_{uncontrolled} \mid}$

Design parameters – cross-sectional area (diameter and nos of SMA slings) and sling length are evaluated to control seismic response of the dynamic system. Iterative simulations to derive unified design parameters are attempted for three dynamic systems under each seismic excitation. Seismic response parameters reported in Table 2 show mostly considerable reduction for peak and rms displacement and acceleration response. As flexible dynamic system undergoes large displacement relative to other two dynamic systems, such system warrants relatively higher sling length to keep strain within 6% of limiting for superelastic SMA. It is seen that unified design parameters for each seismic excitation yields much lower maximum strain then limiting strain of 6% for moderately stiff and stiff dynamic systems.

It is evident from Table 2 that controlled SDOF system with TSD yields substantial reduction in peak and rms PI for pulse type seismic excitation with strain values of about 4 to 4.5%. On similar lines, controlled SDOF system with TSD yields considerable reduction in peak and rms PI for strong motion type seismic excitations – El Centro, however, such results for peak and rms PI under Taft excitation are achieved when maximum strain in SMA wire is of the order of 6% .

Revised Table 2. Seismic response parameters- peak and rms PI, peak damper force and maximum damper force of controlled SDOF systems under seismic excitation

Time Histories	Time Period, T_n (s)	TSD Design Parameters		Performance Indices (PI)				Maximum Strain	Peak Damper Force (kN)	Peak Instantaneous Damping Ratio (%)
		Nos. of Tension Slings (6 mm dia)	Sling length (m)	J_1	J_2	J_3	J_4			
Taft (0.173g)	1.5	1	1.125	0.692	0.495	0.886	0.566	0.058	104.30	22.08
	0.7	1	1.125	0.920	0.861	0.986	0.835	0.030	45.951	10.08
	0.3	1	1.125	0.833	0.747	0.825	0.739	0.011	7.848	1.98
Kobe (0.829g)	1.5	6	7.6	0.784	0.580	0.829	0.651	0.060	701.811	8.98
	0.7	6	7.6	0.728	0.588	0.798	0.593	0.042	552.190	6.00
	0.3	6	7.6	0.976	0.872	0.964	0.839	0.005	42.701	0.00
Loma Prieta (0.64g)	1.5	1	4.4	0.900	0.644	1.000	0.761	0.028	53.529	3.26
	0.7	1	4.4	0.752	0.608	0.798	0.610	0.041	126.26	5.28
	0.3	1	4.4	0.913	0.798	0.939	0.794	0.013	24.734	1.00
El Centro (0.289g)	1.5	1	2.2	0.855	0.565	0.996	0.665	0.047	85.717	6.57
	0.7	1	2.2	0.805	0.703	0.886	0.726	0.034	70.363	4.51
	0.3	1	2.2	0.912	0.688	0.995	0.684	0.008	11.197	0.28

It has been found that seismic excitations bearing relatively low PGA (Taft, Loma Prieta and El Centro), are well resisted by SMA based TSD comprising of 6 mm diameter single tension sling of varied sling length. However, nos. of tension slings increases to 6 with higher length of sling for TSD to resist seismic excitation of high PGA (Kobe). It is realized that both design parameters such as diameter and length of tension sling play an important role in controlling seismic response of the dynamic system and their combination for TSD braced at a specified angle, may lead to optimal seismic response control for given seismic excitation. This condition forms basis for developing optimization problem formulation. Requirement of relatively higher sling length for TSD may offer practical difficulties and can be seen as a constraint for the proposed TSD. However, this can be negated using TSD in combination with other compatible passive control devices which is beyond the scope of present study.

It is observed that TSD efficiently controls seismic response across all categories of dynamic systems considered in the present study. Flexible - and while moderately stiff systems utilize damping component stiff systems exploit stiffness component of TSD to yield seismic response control of the dynamic system. The said results can be followed from Equation (11) as cross-sectional area of SMA slings contribute stiffness component and sling length contributes damping component of the passive damper force.

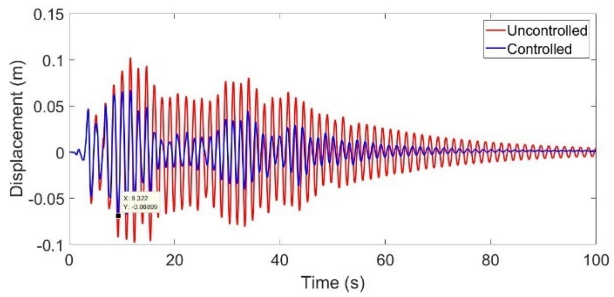


Figure 11a

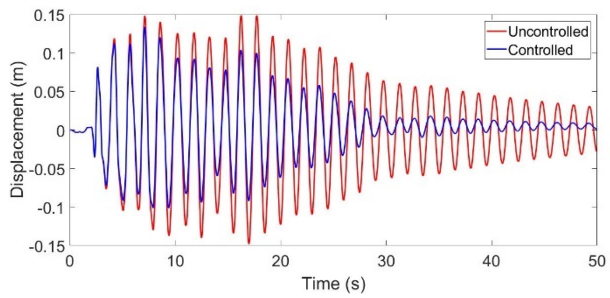


Figure 11c

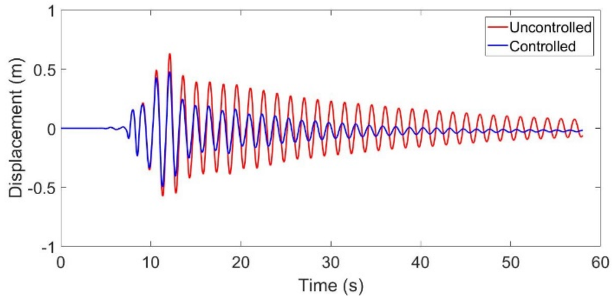


Figure 11b

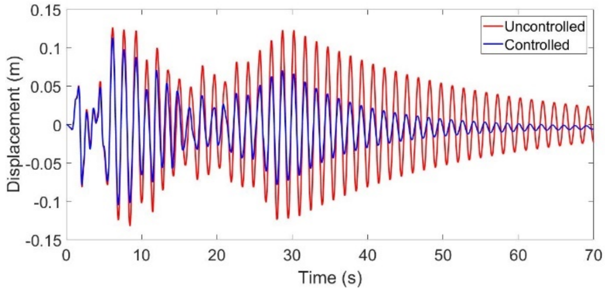


Figure 11d

Figure 11 Comparison of uncontrolled and controlled displacement response of flexible dynamic system (Tn=1.5s) subjected to (a) Taft (b) Kobe (c) Loma Prieta and (d) El Centro seismic excitation

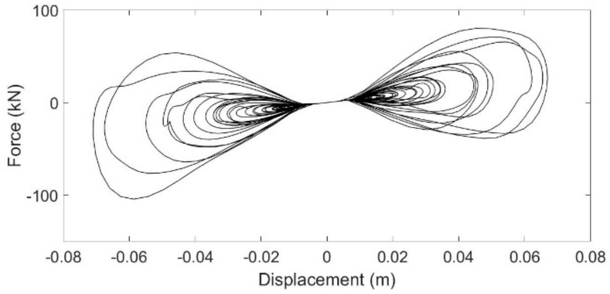


Figure 12a

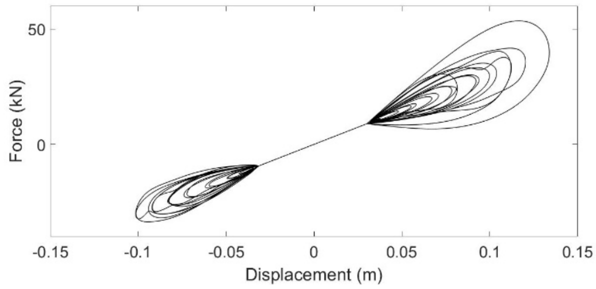


Figure 12c

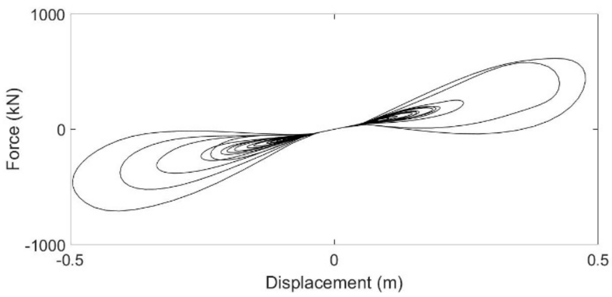


Figure 12b

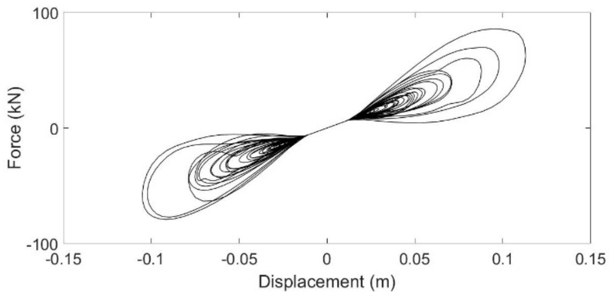


Figure 12d

Figure 12 Passive damper force vs displacement of flexible dynamic system (T_n=1.5s) subjected to (a) Taft (b) Kobe (c) Loma Prieta and (d) El Centro seismic excitations

Uncontrolled and controlled displacement response of the system is shown in Figure 11a to Figure 11d for each seismic excitation considered in the study for dynamic system with T_n=1.5s. It is seen that peak displacements occur at 11.62s and 9.32s for Taft excitation; 12.12s and 11.24s for Kobe excitation; 16.24s and 7.01s for Loma Prieta excitation and 8.42s and 6.16s for El Centro excitation, respectively. Early occurrence of peak displacement for controlled system vis-a-vis uncontrolled system falls in line with the results reported by similar studies in the literature.

It is seen that TSD fitted controlled system (T_n=1.5s) shows reduction in displacement time history across all seismic excitations considered for the present study. Reduction in displacement time histories for other two dynamic systems are also observed.

Damper force vs displacement relation for TSD fitted with the above-mentioned system subjected to various seismic excitations is shown in Figure 12a to Figure 12d. Damper force shows hysteretic nature ensuring energy dissipation and is realized mostly in first and third quadrant. It is evident that TSD is mostly driven by damping component under strong ground motion and thus results into broader hysteretic loop. Hysteretic loop of TSD flattens for strain, in SMA tension slings, below transformation strain of super-elastic SMA wire.

Variation in Martensite Volume Fraction (MVF) and damping ratio (ζ) at each instant for Taft seismic excitation are represented in Figure 13, where MVF is determined through Tanaka model of SMA. Instantaneous damping ratio is evaluated following Equation (14) considering area of hysteresis loop at each instant for TSD fitted to flexible dynamic system.

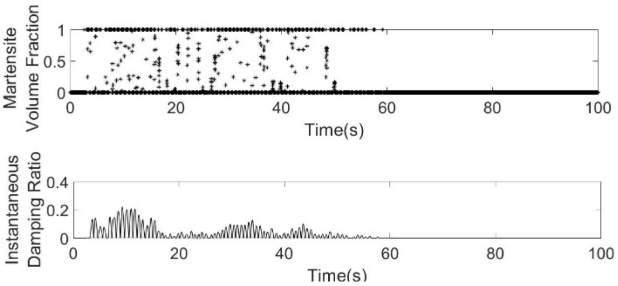


Figure 13 Variation of Instantaneous Damping Ratio and martensite volume fraction for Taft seismic excitations flexible dynamic system

MVF assumes lower bound value of '0' indicating austenite phase and upper bound value representing transformation phase – martensite of SMA wire. Figure 13 also depicts instantaneous damping offered by passive TSD, due to frequent phase transformation in super-elastic SMA wire, contributing to supplemental damping than inherent damping possessed by the system. Evidently, damping ratio of the system will not increase if phase transformation does not take place in SMA sling and thus contribution of SMA be limited to offer stiffness to the system resembling bracing component of structural system. Other research studies have introduced concept of pre-straining of SMA to ensure phase transformation of SMA so that super-elastic properties of SMA are utilized.

Instantaneous damping ratio realized by TSD under Kobe, Loma Prieta and El Centro excitation are evaluated in Figure 14 a, b & c, respectively where maximum instantaneous damping ratio ranges between 22.08% to 0.28% of the critical damping.

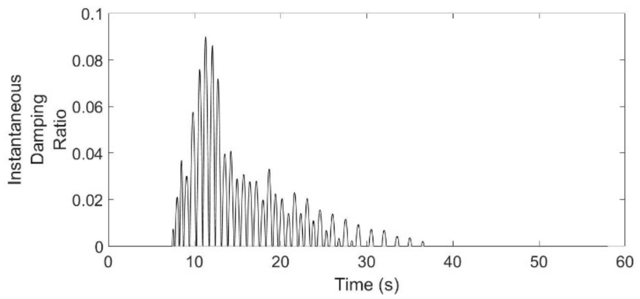


Figure 14 a

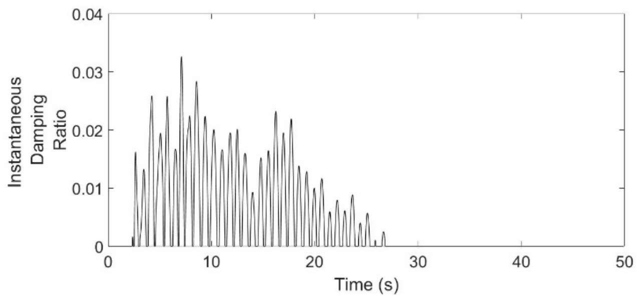


Figure 14 b

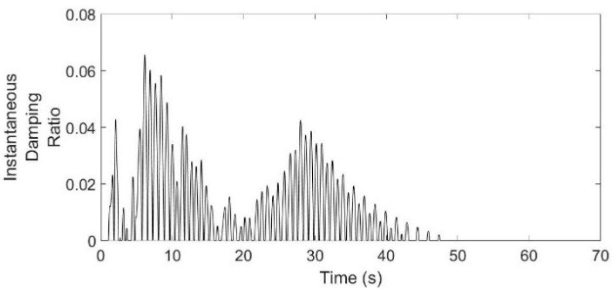


Figure 14 c

Figure 14 Variation of instantaneous damping ratio for flexible system subjected to a) Kobe b) Loma Prieta and c) El Centro seismic excitation

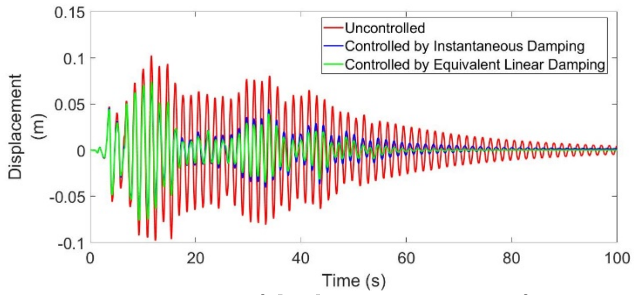


Figure 15 comparison of displacement response for uncontrolled system, controlled system with instantaneous damping model and controlled system by equivalent linear elastic viscous damping model (Ghodke & Jangid, 2016)

Figure 15 shows comparison between displacement response of controlled SDOF system with equivalent piece-wise linear elastic viscous model (proposed in the study) and equivalent linear elastic viscous model of Ghodke and Jangid (2016) vis-à-vis uncontrolled dynamic system for Taft seismic excitations. It indicates that equivalent linear viscous damping model of Ghodke and Jangid yields better results as compared to present study as model implements constant and maximum damping offered by SMA.

4 CONCLUSIONS

Present paper proposes a SMA based Tension Sling Damper (TSD) for passive seismic response control of the dynamic system. Mechanism and features of proposed TSD are summarized. SMA sling is modelled as equivalent piece-wise linear elastic viscous damping model to map non-linear stress-strain behaviour of SMA characterized by unified Tanaka model. A building structure represented as discrete SDOF dynamic system is simulated for pulse type and strong ground motion type seismic excitations. Response parameters – peak and rms performance indices, peak damper force and maximum damping ratio are evaluated for controlled system fitted with TSD. Substantial reduction in peak and rms displacement response of the dynamic system is achieved by varying design parameters – cross-sectional area and SMA sling length for each seismic excitation. Peak and rms acceleration, of the system are found to reduce moderately. Dynamic system yields better seismic response control, when the strain induced in super-elastic SMA wire ranges between 3 to 4.5% for all seismic excitations except Taft excitation where effective control is seen for strain of the order 6% due to higher frequency content. Out of three dynamic systems, moderately stiff system (T_n=0.7s) yields best seismic response control with TSD. For stiff systems, instantaneous ratio realized by TSD is quite low and seismic control is achieved due to stiffness component of the damper force, leading to ineffective seismic response control. Thus, one might have to apply pre-strain to SMA sling to derive desirable seismic response.

Present study suggests that proposed TSD works effectively with flexible and moderately stiff system due to super-elastic properties of SMA undergoing substantial strain under seismic excitations. Requirement of relatively higher sling length for seismic excitations like Kobe reveals that such solution may be practically difficult and imposes a limitation for the use of TSD. However, proposed TSD may be used with other compatible passive device to control the seismic response effectively. Optimization techniques may be employed to derive diameter and sling length for TSD with objective function on displacement and/or acceleration response.

5 REFERENCES

Bertrand, E., Castany P., and Glorient, T., “Investigation of the martensitic transformation and the damping behavior of a superelastic Ti-Ta-Nb alloy”, Acta Materialia, 2013, Vol. 61, No. 2, 511-518.

Buehler, W., and Wiley, R., “Nickel based alloys”, 1961; patent US3174851A

Caughey, T., “Sinusoidal excitation of a system with bilinear hysteresis”, ASME Journal of Applied Mechanics, 1960, Vol. 27, No. 4, 1-4.

DesRoches, R., McCormick, J. and Delemont, M., “Cyclic properties of super elastic shape memory alloys wire and bars”, Journal of Structural Engineering, 2004, Vol. 1, No. 38, 39-46.

Dolce, M., Cardone, D., Ponzo, F., and Valente, C., “Shaking table tests on reinforced concrete frames without and with passive control systems”, Earthquake Engineering and Structural Dynamics, 2005, Vol. 34, 1687-1717.

Ghodke, S., and Jangid, S., “Equivalent linear elastic-viscous model of shape memory alloy for isolated structures”, Advances in Engineering Software, 2016, Vol. 99, No. 22, 1-8.

Graesser, E. and Cozzarelli, F., “Shape-Memory Alloys as new materials for sseismic isolation”, Journal of Engineering Mechanics, 1991, Vol. 117, No. 11, 2590-608.

Gur, S., Mishra S. and Roy K. “Stochastic seismic response of building with super-elastic damper”, Mechanical Signal Processing, 2016, Vol 72-73, 642-659.

Han, Y., Li, Q. S., Li, A. Q., Leung, A. Y. T., and Lin, P., “Structural vibration control by shape memory alloy damper”, Earthquake Engineering and Structural Dynamics, 2003, Vol. 32, 483–494.

Hartl, D. J., and Lagoudas, D. C., “Thermomechanical characterization of shape memory alloy material, Shape Memory Alloys: modelling and engineering Applications”, Springer Science, 2008; 53-119.

Jani, J. M., Leroy, M., Subik, A., and Gibson, M., “A review of shape memory alloy research, applications and opportunities”, Materials and Design, 2014, Vol. 56, 1078-1114.

Jansen, L. M., and Dyke, S. J., “Semi-active control strategies for MR dampers: A Comparative Study, Journal of Engineering Mechanics”, 1999, vol 126, No. 8, 795–803.

Kumar, P. K., Lagoudas, D. C. (ed), “Introduction to shape memory alloys, Shape Memory Alloys: Modelling and Engineering Applications”, Springer Science, 2008, 1-15.

Kurdjumov, G. V., and Khandros, L. G., “The thermoelastic behaviour of the martensitic phase of Au-Cd alloys”, Doklady Akacemii Nauk, 1949, Report SSSR 66, 211-213

Lobo, P., Almeida, J., and Guerreiro, L., “Semi-active damping device based on superelastic shape memory alloys”, Structures, 2015, Vol. 3, 1-12

McCormik, J., DesRoches, R., Fugazza, D., and Auriccchio, F., “Seismic vibration control using superelastic shape memory alloys”, Journal of Engineering Materials and Technology, 2006, Vol. 128, 294-301.

Miller, D. J., Fahnestock, L., and Eatherton, M., “Development and experimental validation of a Nickel - Titanium shape memory alloy self centering and buckling restrained braces”, Engineering Structures, 2012, Vol. 40, 288-298.

Morais, J., Morais, P., Santos, C., Campos Costa, A., and Candeias, P., “Shape memory alloy based dampers for earthquake response mitigation”, Structural Integrity Procedia, 2017; Vol. 5, 705-712.

Mortazavi, S. M. R., Ghassemieh, M., and Motahari, S.A., “Seismic control of steel structures with shape memory alloys”, International Journal of Automation and Control Engineering, 2013, Vol. 2, No. 1, 28-34.

Ohtori, Y., Christensen, R. E., Spencer, B. F. Jr., and Dyke, S. J., “Benchmark problems for seismically excited nonlinear buildings”, Journal of Engineering Mechanics, 2004, Vol. 103, No. 4, 366-385.

Parulekar, Y. M., Ravi Kiran, A., Reddy, G. R., Singh, R. K., and Vaze, K. K., "Shake table tests and analytical simulations of a steel structure with shape memory alloy dampers", Smart Materials and Structures, 2014, Vol. 23, 1-12.

Purohit, S. P., and Chandiramani, N. K., "Optimal static output feedback control of a building using an MR Damper", Structural Control and Health Monitoring, 2010, Vol. 18, No. 8, 852-868.

Seelecke, S., Heintze, O., and Masuda, A., "Simulation of earthquake-induced structural vibrations in systems with SMA damping element", Proceedings of the SPIE Smart Structures & Materials, 2002, 4697, 1-8.

Sherif, M., and Ozbulut, O., "Tensile And super-elastic fatigue characterization Of NiTi shape memory cables", Smart Materials and Structures, 2018, Vol. 27, 1-13.

Song, G., Ma, N., and Li, H. N., "Applications of shape memory alloys in civil structures", Engineering Structures, 2006, Vol. 28, 1266-1274.

Soong, T. T., and Spencer B. F., "Supplementary energy dissipation: state-of-the-art and state-of-the-practice", Engineering Structures, 2002, Vol. 24**,** 243– 259.

Spencer, B. F., and Nagarajaiah, S., "State of the art structural control", Journal of Structural Engineering, 2003, Vol. 129, 845-856.-

Symans, M. D., Charney, F. A., Whittaker, A. S., Constantinou, M. C., Kircher, C. A., Johnson, M. W., and McNamara, R. J., "Energy dissipation systems for seismic applications: current practice and recent developments", Journal of Structural Engineering, 2008, Vol. 134, No. 1, 4-21.

Tanaka, K., "A thermomechanical sketch of shape memory effect: one-dimensional tensile behaviour", Research Mechanical, 1986, Vol. 18, 251-263

Xu Y.L., Qu W.L., and Ko J. M., "Seismic response control of frame structures using magnetorheological/electrorheological dampers", Earthquake Engineering Structural Dynamics, 2000, Vol. 29-5, 557-575.

Zhang, Y., and Zhu, S., "A shape memory alloy-based reusable hysteretic damper for seismic hazard Mitigation", Smart Materials and Structures, 2007, Vol.16, 1603-1613.

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for **"shodh sarita"**. Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	Shodh Sarita (print only)	Shodh Sanchar Educational and Research Foundation	2348-2397	NA	from September-2019 to April- 2021	Discontinued from April 2021

Showing 1 to 1 of 1 entries

Previous 1 Next

GOVT. OF INDIA- RNI NO. UPBIL/2014/56766
UGC Approved Care Listed Journal

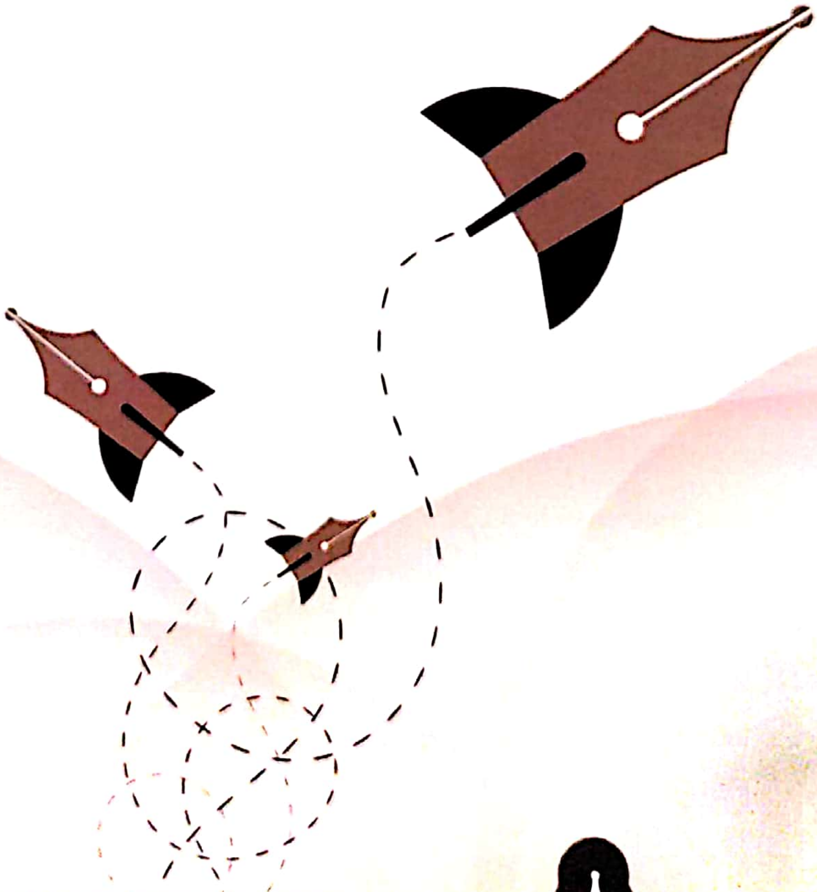
ISSN 2348-2397

SIJ

Shodh Sarita

An International Multidisciplinary Quarterly
Bilingual Peer Reviewed Refereed Research Journal

• Vol. 8 • Issue 29 • January to March 2021



Editor in Chief
Dr. Vinay Kumar Sharma
D. Litt. - Gold Medalist

sancHar
Educational & Research Foundation

Scanned with Oken Scanner

UGC APPROVED
CARE LISTED JOURNAL
GOVT. OF INDIA - RNI No. UPBIL/2014/56766

ISSN No. 2348-2397

SIJ

Shodh Sarita

AN INTERNATIONAL MULTIDISCIPLINARY QUARTERLY BILINGUAL
PEER REVIEWED REFEREED RESEARCH JOURNAL

• Vol. 8 • Issue 29 • January - March 2021

EDITORIAL BOARD

Prof. Sudheer Pratap singh
Jawahar Lal Nehru University, New Delhi

Prof. Kumud Sharma
Delhi University, Delhi

Prof. S. K Sharma
Mizoram University, Mizoram

Prof. S. Chelliah
Madurai Kamraj University, Madurai

Prof. Pavitar Parkash Singh
Lovely Professional Universiy, Punjab

Prof. Parmeshwari Sharma
University of Jammu, Jammu

Prof. Ram Prasad Bhatt
Hamburg University, Germany

Prof. Girish Pant
Jamia Millia Islamia University, New Delhi

Prof. Ajay Kumar Bhatt
Amity University, Haryana

Prof. M.P. Sharma
Jamia Millia Islamia University, New Delhi

EDITOR IN CHIEF

Dr. Vinay Kumar Sharma
Chairman
Sanchar Educational & Research Foundation, Lucknow

PUBLISHED BY

sanchar
Educational & Research Foundation

Scanned with Oken Scanner

Scanned with Oken Scanner

ISSN - 2348-2397
UGC CARE LISTED JOURNAL
SIJ
Shodh Sarita
January-March, 2021
Vol. 8, Issue 29
Page Nos. 182-186
AN INTERNATIONAL BILINGUAL PEER REVIEWED REFEREED RESEARCH JOURNAL

FIRE HAZARDS IN HEALTHCARE BUILDINGS: INVESTIGATING ROLE OF HEALTH-CARE PROVIDERS

Meera Pankaj Shirolkar*
Vasudha Ashutosh Gokhale**

ABSTRACT

The country has witnessed a series of devastating fires in healthcare facilities in the last few years which have caused high rate casualty and extensive misery. In case of fire occurrence healthcare necessitate the occupants' evacuation which include healthcare providers, patients as well as visitors. The complexity in evacuation stems from the diversity of patients which include ambulatory outpatients, wheel chair bound patients who need assistance for evacuation. In such circumstances healthcare providers need to play an important role. This research is aimed to examine perception and preparedness of healthcare providers on occurrence of a fire. Based on a questionnaire survey in the state of Maharashtra various aspects that affect evacuation of patients on occurrence of fire hazard are presented. The findings are useful to understand the significance of role of human resources in evacuation process in a healthcare facility. This may motivate healthcare providers to be proactive and take necessary measures to handle emergency situation on occurrence of a fire.

Keywords: *Healthcare, Evacuation, Preparedness, Fire, Emergency*

INTRODUCTION

Accidental fire is one of the main reasons that cause most unnatural deaths in India after road accidents and drowning. On an average, in India, every year, about 25,000 persons died due to fires occurred in both in industrial and non-industrial buildings (Fire and Security Association of India).Healthcare buildings are the facility offering the quality healthcare and creating an affirmative setting for rapid patient recovery and a place of immediate care for a larger population during emergencies (FEMA, 2007). They are considered as one of the essential facilities because the community rest on them for care and/or resources. However they are liable to face a disaster, which may necessitate the occupants' evacuation which includehealthcare providers, patients as well as visitors.The dependence of a healthcare facility's occupants on its staff in case of prevalence of a disaster results in a second classification as a susceptible facility which calls for unique concerns for evacuation decisions (Sternberg, 1998)

Healthcare unit evacuation planning includes several complex, organized steps assisting evacuation procedure. (Childers, 2010). Research indicated that an understanding of evacuation behaviour can prove instrumental for finding out appropriate solution for efficient evacuation and consequent safety of the occupants (Chizari, et al., 2013).

ROLE OF HEALTH-CARE PROVIDERS

Role of staff needs to be organized in healthcare buildings where role of attendants

*Professor, Dr. Bhanuben Nanavati College of Architecture for Women, Pune
**Professor, Dr. Bhanuben Nanavati College of Architecture for Women, Pune

(nurses and ward attendants) has to be as main performers along with emergency support staff (Iserson et al. 2008). Evacuation is found extremely reliant on staff's involvement and teamwork and past research stresses the significance of ensuring evacuation plans in place as well as the importance of training the staff to understand the plan is stressed. As per (Lach, Langan, & James, 2005) it is of utmost importance that nurses should be aware and knowledgeable about the different kinds of disasters and their probable consequences. (Bovender & Carey, 2006)

THE BUILDING ENVIRONMENT

Non-familiarity with the building layout adds to stress and adversely affect the evacuation process (Sagun, Bouchlaghem, & Anumba, 2008). Presence of staff in terms of number significantly affects the capability to quickly move patients out of the hospital in an urgent evacuation on fire occurrence. Many healthcare facilities have temporary or visiting staff which may not be as readily available during an emergency, as employees who are in full-time job (Zane, Biddinger, Hassol, Rich, Gerber, & DeAngelis, 2010).

TRAINING AND KNOWLEDGE

Nurses and attendants comprise the major labour forces that are the immediate respondents and supposed to take immediate action for safety of patients in emergency situation (Gwynne, Galea, Lawrence, & Filippidis, 2001). This phenomenon calls for imparting knowledge about disaster management and train nurses and other supporting staff for disaster preparedness (Achora & Kamanyire, 2016; Chapman & Arbon, 2008).

1) *THE METHODOLOGY*

The responses of health-care providers' viz. administration personnel, doctors, ward attendants, nurses, security and others except patients were taken in the form of a questionnaire survey, with an objective to

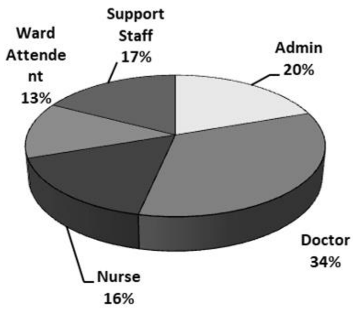


Figure-1:Composition of Sample. (Sample size was 426)

identify their awareness and perception of role in case of fire. The questionnaire survey was carried out in cities of Maharashtra state viz. Pune, Sangli, Kolhapur, Solapurand Mumbai.

Various factors that affect response of healthcare providers is examined and presented as below.

DESIGNATED ROLE, TYPE OF WORK, WORKING PATTERN, LOCATION WITHIN BUILDING:

A health care provider's job profile defines their area of work and role to play in a healthcare unit during an emergency situation. It has been noticed that healthcare providers work for different period in a week as shown in **Figure-2.**

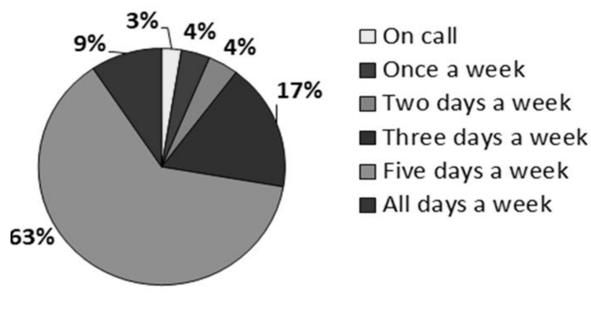


Figure-2: Weekly working period

Survey results indicated that 3% of total healthcare providers' visit as 'on-call', out of which 80% is doctor consultants. Total 63% respondents have contact period of 5 days in a week, which comprises of 90% of total nurses and 87% of total admin staff. 9% of healthcare providers work for all seven days in a week which comprise of 30% of total support staff, interns and security depending on their specific job profiles.

Figure-3shows the duration of working period on daily basis of individual healthcare provider, which explains that 38% healthcare providers' work between 8 to 12 hrs daily,which majorly comprise of 53% of total support staff, 28% of total doctors (interns and

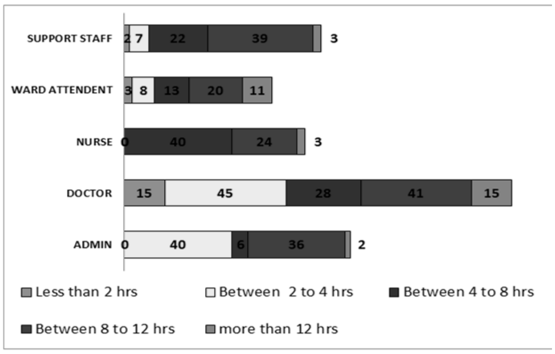


Figure-3: Duration of contact period per day

assistant doctors), 43% of total admin, 34% of total nurses and 36% of total attendants.

It is observed that only 5% have contact period of work for less than 2 hours which majorly comprise of on-call doctors and consultants in emergency (75%).

2) *EDUCATION AND TRAINING OBTAINED:*

Knowledge and awareness about help agencies during emergency advantages in immediate action without delay in evacuation process. Thus aspect of information and attentiveness about help agencies was tested for responses.

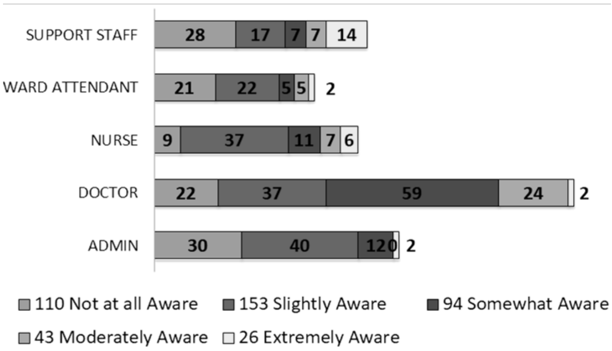


Figure-4Respondents level of awareness about help agencies.

Figure-4shows respondents level of awareness about help agencies, which explains that mere 6% of respondents were extremely aware about help agencies, which majorly included 52% support staff, 23% nurses and 8% each of doctors, attendants and admin. 36% respondents were slightly aware which comprised of 26% admin, 24% each nurse and doctor category, 14% attendants and 11% support staff.

ACQUAINTANCE WITH THE BUILDING, INFRASTRUCTURE.

Respondent's knowledge and awareness about the building with reference to exits, lifts, staircases available safety systems and their familiarity with the building/premise is explored. From the total responses 6.5% were not aware about total number of exits in the premises they work , 5% were not aware about number of lifts existing in the building premise, 13% were unaware about number of staircases in the building they work, 9.6% didn't know and 3.5% not sure about availability of safety systems present in the building. Familiarity of premise of work plays an important role in safe evacuation process thereby avoiding initial delay in pre-evacuation time.

Figure-5: shows respondents level of familiarity with the premises, which explains

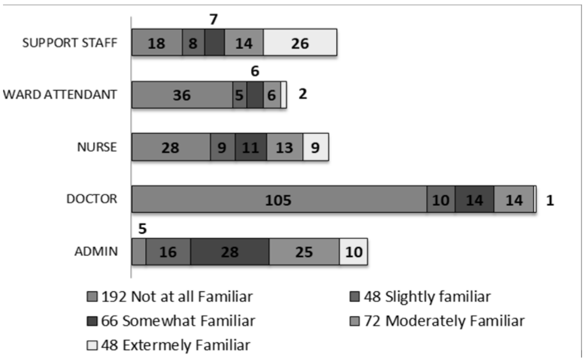


Figure-5: Respondents level of familiarity

that 45% are not at all familiar which comprised of 55% doctors, 18.75% attendants, 14.5% nurses and 9.3% support staff and 2.5% admin.

In all 11% respondents, which consist of 54% of support staff, 21% of admin, 18.75% of nurses and 4% attendants are extremely familiar with the premises.

Figure-6 shows percentage distribution about awareness level about emergency evacuation procedures which explains that 63% of healthcare providers' are not at all aware about any emergency procedures, out of which 47% aredoctors, 20% admin, 14.5% attendants,10% nurses and 8.5% support staff.In all 7% healthcare providers are totally aware of the emergency evacuation procedures, out of which 48% support staff,

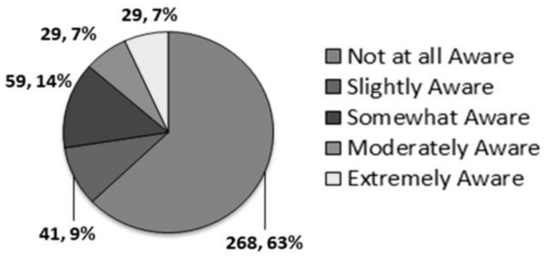


***Figure-6:** Awareness percentage about emergency evacuation procedures.*

27.5% admin and 17% nurses; but 0% doctors have any knowledge about it.

Figure-7 shows percentage distribution about Awareness of healthcare providers' about use of safety systems in building which explains that 10% healthcare providers' are extremely aware about the useof safety systems , out of which major part of 46.5% is admin, 28% nurses, 21% admin and 4.5% attendants: 0% doctors are aware/knowledgeable about use of safety systems.

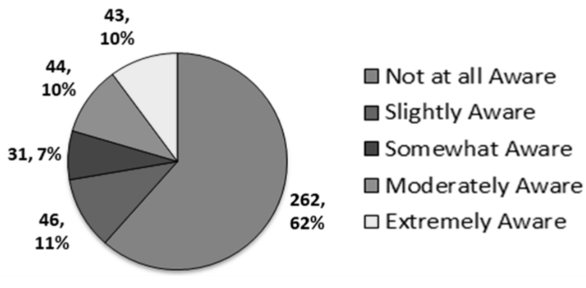


Figure-7: Awareness about use of safety systems

3) *RESPONSIBILITY AND ACCOUNTABILITY TOWARDS THEIR ASSIGNED ROLE ON OCCURRENCE OF FIRE:*

In an emergency actions are performed immediately if one's role and responsibilities are clearly known. One's role and responsibility is carried out to its best if one feels accountable for it. This aspect about healthcare providers' that up to what extent they are accountable in the present context is explored.

From **Figure-8**it is observed that more number of nurses and admin consider themselves to be completely responsible for patients' evacuation as against doctors and admin who accept it as mostly responsible and somewhat responsible. Least number of ward attendants (14.5%) consider themselves completely responsible.

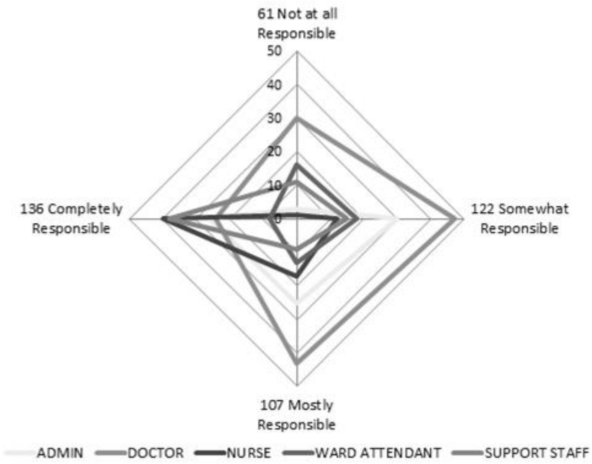


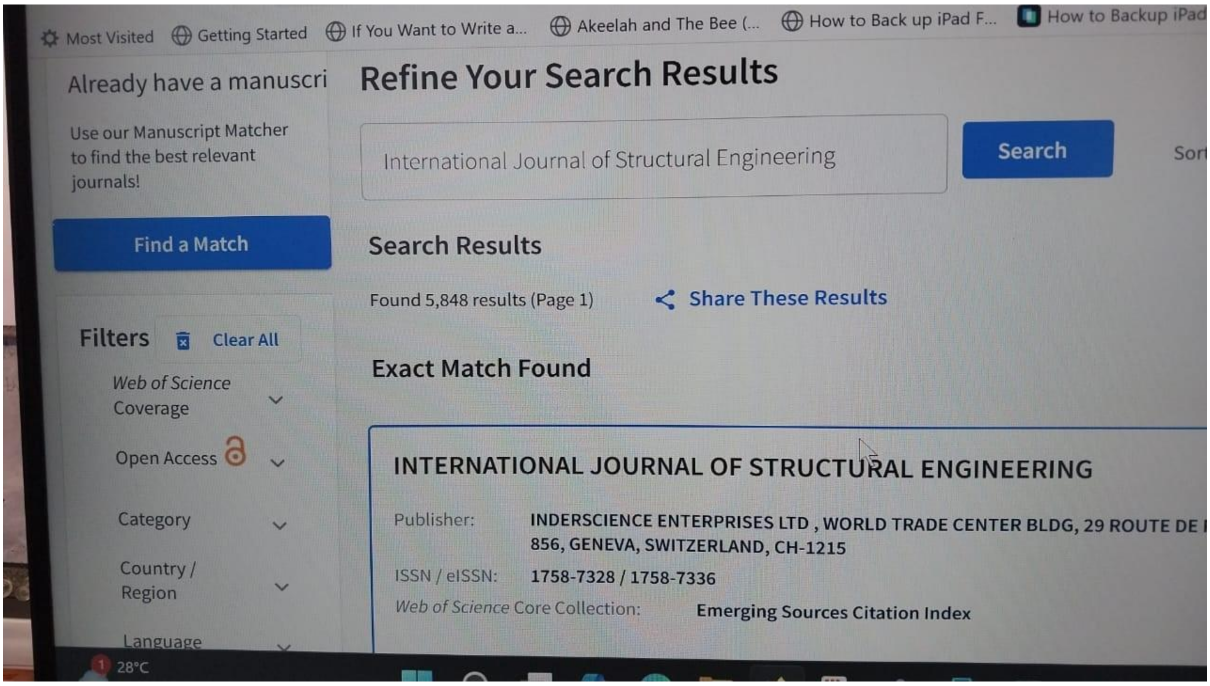
Figure-8: Self-accountability factor.

CONCLUSION

Evacuation process is largely dependent on perception of occupants about their surroundings and setting where they work. The perceptions of major occupants were found different with respect to their job profile, contact period, awareness about the premises and role to play in case of fire. Awareness about the premises and the building is of prime importance to direct/help out patients during emergency. Doctors who visited as on-call/visiting doctors were not well acquainted with the premises due to less contact period at work. Marked lack of training at education level identified which was reported important by the respondents. Awareness about available immediate support and services during an emergency in the form of help agencies can assure speedy and right help for evacuation of occupants. Less knowledge and awareness about these aspects identified largely which is a matter of concern. This research indicated the need for training and imparting knowledge to the healthcare providers about occurrence of fire hazard so they can attend patients as early as possible .Health care environment are generally very stressful environment for staff particularly for nurses and doctors both physically and mentally, with tight deadlines and patient's well-being at risk. These factors are to be addressed at top most priority to make healthcare environment safer from a potential fire hazard.

References

1. Achora, S., & Kamanyire, J. K. (2016). Disaster Preparedness: Need for inclusion in undergraduate nursing education. . *Sultan Qaboos University Medical Journal*, 16(1), e15.
2. Bovender, J., & Carey, B. (2006). A week we Don't want to forget: lessons learned from Tulane. . *Frontiers of health services management*, , 23(1), 3.
3. Chapman, K., & Arbon, P. (2008). Are nurses ready?: Disaster preparedness in the acute setting. *Australasian Emergency Nursing Journal*, 11(3), 135-144.
4. Childers, A. K. (2010). *Prioritizing patients for emergency evacuation from a healthcare facility.*
5. Chizari, H., Malekinezhad, F., Embi, M., Yatim, Y., Razak, S., bin Haji Ahmad, M., et al. (2013). Agent-based approach for modeling evacuee uncertainty behavior using game theory model. *Life Science Journal*,, 10(3), 1350-1355.
6. FEMA, A. (2007). *461/Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components.* Redwood City, CA: Applied Technology Council, 113.
7. *Fire and Security Association of India*. (n.d.). Retrieved August Monday, 2017, from www.fsai.in
8. Gwynne, S., Galea, E. R., Lawrence, P. J., & Filippidis, L. (2001). Modelling occupant interaction with fire conditions using the building EXODUS evacuation model. *Fire safety Journal*, 36:327-57.
9. Lach, H., Langan, J., & James, D. (2005). Disaster planning: Are gerontological nurses prepared? *Journal of Gerontological Nursing*, , 31(11), 21-27.
10. Sagun, A., Bouchlaghem, D., & Anumba, C. J. (2008). Building Design Information and Requirements for Crowd Safety During Disasters. . *Resilient Organisations.*
11. Sternberg, R. (1998). *In Search of the Human Mind*, . Harcourt Brace & Company 2nd Edition, .
12. Taaffe, K., Kohl, R., & Kimbler, D. (2005). Hospital evacuation: issues and complexities. *Proceedings of the 37th conference on Winter simulation .Winter Simulation Conference*, (pp. pp. 943-950).
13. Thompson, A. K., Faith, K., Gibson, J. L., & Upshur, R. E. (2006). (2006). Pandemic influenza preparedness: an ethical framework to guide decision-making. . *BMC medical ethics*,, 7(1), 12.


Most Visited
Getting Started
If You Want to Write a...
Akeelah and The Bee (...
How to Back up iPad F...
How to Backup iPad
Already have a manuscri
Use our Manuscript Matcher to find the best relevant journals!
Find a Match
Filters
Clear All
Web of Science Coverage
Open Access
Category
Country / Region
Language
Refine Your Search Results
International Journal of Structural Engineering
Search
Sort
Search Results
Found 5,848 results (Page 1)
Share These Results
Exact Match Found
INTERNATIONAL JOURNAL OF STRUCTURAL ENGINEERING
Publisher:
INDERSCIENCE ENTERPRISES LTD , WORLD TRADE CENTER BLDG, 29 ROUTE DE
856, GENEVA, SWITZERLAND, CH-1215
ISSN / eISSN:
1758-7328 / 1758-7336
Web of Science Core Collection:
Emerging Sources Citation Index
28°C

Passive Seismic Protection of Shear Building Using Shape Memory Alloy-Based Tension Sling Damper

Sujata H Mehta* amd Sharadkumar Purohit**

Passive control force is obtained from Shape Memory Alloy-based Tension Sling Damper (SMA-TSD) fitted to a seismically excited 10 storeyed shear building. One-dimensional Tanaka model is considered to represent the hysteresis behavior of SMA-TSD. This exhibits a nonlinear relationship between damper force and input states; hence, its implementation with linear system is a non-trivial task. In the paper, SMA-TSD is represented by Voigt model comprising equivalent stiffness and damping components derived by mapping it with flag-shaped hysteresis loop defined by Tanaka model. The results for controlled response of the buildings are obtained in terms of peak response quantities, i.e., interstorey drift, displacement and acceleration. One SMA-TSD fitted at ground storey of the building yields moderate control (4└ 29%) in peak response quantities. However, peak response quantities reduce substantially (4└ 53%) for different levels of El Centro seismic excitations and moderately (4└ 19%) for 50% Kobe seismic excitation when two SMA-TSDs are used in the building. The efficacy of SMA-TSD implemented in the study is a function of design parameters, diameter of SMA wire and length of SMA wire, and can be optimized.

Author pls chk: symbols are missing

Keywords: Shape Memory Alloy (SMA), Tension Sling Damper (TSD), Voigt model, Passive control

Introduction

Seismic response of buildings has been a matter of utmost concern in order to save lives and minimize damages amid fast paced growth of vertical cities. Some design strategies, including base isolation and supplemental damping devices, are frequently practiced in seismic-prone areas. Base isolation increases the natural period of the overall structure, which reduces its acceleration response under seismic excitation, and thus it works efficiently for stiff structures (Housner *et al.,* 1997). For other types of structures, primary damping mechanisms are activated through passive energy dissipation devices like viscous fluid dampers, viscoelastic solid dampers, metallic dampers and friction dampers (Soong and Spencer, 2002). These

Author pls confirm information

* Research Scholar, Department of Civil Engineering, School of Engineering, Institute of Technology, Nirma University, Ahmedabad 382481, Gujarat, India; and is the corresponding author. E-mail: 13extphde106@nirmauni.ac.in

** Professor, Department of Civil Engineering, School of Engineering, Institute of Technology, Nirma University, Ahmedabad 382481, Gujarat, India. E-mail: sharad.purohit@nirmauni.ac.in

© 2021 IUP. All Rights Reserved.

devices dissipate energy resulted due to seismic excitation of the system in the form of heat due to viscous friction in viscous fluid damper, yielding of metal in metallic damper, shearing of viscoelastic material in viscoelastic damper and sliding friction between two surfaces in friction damper (Pall and Marsh, 1982; Aiken and Kelly, 1992; and Symans and Constantinou, 1998). The aim of such devices in a structure is to limit damaging deformations, but the extent to which a particular device accomplishes the aim depends on the inherent properties of the structure, properties of damping device and characteristics of seismic excitations (Symans *et al*., 2008).

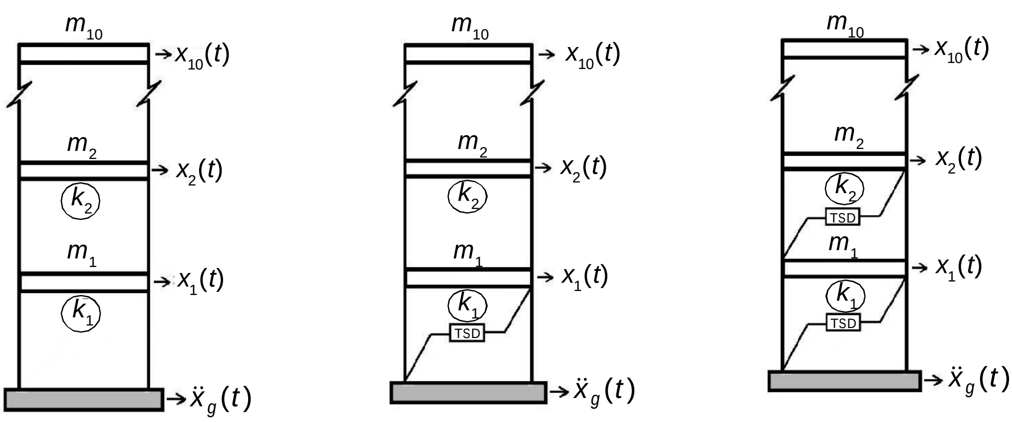
Advent of smart materials with controllable inherent properties paves the way for the development of structure with real-time control. Various classes of dampers known as semi-active, active and hybrid dampers have been developed and implemented with structures to control structural response due to wind or seismic excitation. First ever application of active control of structure was presented by Sae-Ung and Yao (1978). However, due to requirement of capital energy and long-term reliability concerns, a class of dampers, known as semi-active dampers, have become increasingly popular. These dampers are regarded as controllable passive devices as relative motion between their ends are resisted passively but with controllable mechanical properties (Spencer and Nagarajaiah, 2003). Viscous-orifice dampers, electrorheological dampers and magnetorheological dampers are a few examples of controllable passive devices (Jansen and Dyke, 1999; and Chen *et al.*, 2004). Despite the presence of semi-active dampers and active dampers as design strategy for existing and new structures, passive energy dissipation devices are being used due to their robustness and cheaper cost.

Shape Memory Alloys (SMA) are relatively new class of materials, having unique controllable characteristics of shape memory effect and super-elasticity, qualifying it as smart materials. Superelasticity property of SMA material enables it to undergo stress induced hysteretic phase transformation from parent austenite phase to martensite phase and vice versa without inducing any residual strain (Buehler and Wiley, 1961). Super-elastic SMA materials are capable of repeatedly absorbing large amounts of energy under loading cycles without exhibiting permanent deformation (Ozbulut *et al.*, 2011). Jani *et al.* (2014) presented an exhaustive review on SMA material focused on research and application of SMA. Various forms or types of SMA include NiTi SMA, High Temperature SMAs (HTSMA), Magnetic SMAs (MSMAs), SMA thin film and Shape Memory Alloy Polymers (SMPs). However, the present research mostly concentrates on application of NiTi SMAs to seismic control of buildings. Various researchers performed experimental investigations to characterize nonlinear hysteresis behavior or NiTi SMAs and provided constitutive relationships (Tanaka, 1986; Graesser and Cozzarelli, 1991; Schmidt, 2006; and Ren *et al*., 2007).

Improved damping characteristics and added stiffnesses offered by SMA when strained due to input motion make it a potential contender for developing passive, semi-active and hybrid control devices to control the structural response of a variety of problems (Jani *et al.*, 2014). Recently, many applications of SMA-based passive and hybrid control devices to control seismic response of various structures have been found in the literature. Dolce *et al.* (2005) and McCormik *et al.* (2006) developed passive dampers using SMA wires and implemented them with Reinforced Concrete (RC) frames. Similar application of SMA-based passive damping devices with steel frame was studied by Mortazavi *et al.* (2013) and as Buckling Restrained Braces (BRBs) with steel frame was studied by Miller *et al.* (2012). Zhang and Zhu (2007) implemented passive SMA wire-based damper with benchmark nonlinear problem and demonstrated that SMA damper is a function of wire diameter, strain rate, amplitude and pre-straining of SMA wire.

The paper implements passive SMA wire-based Tension Sling Damper (TSD) with 10 storey shear building of Yuen *et al.* (2007) subjected to seismic excitations. The efficacy of SMA-TSD used in the study is established through seismic response quantities, i.e., peak displacement, peak acceleration, peak inter storey drift and peak damper force. Nonlinear hysteretic behavior of SMA-TSD is modeled with simplified Tanaka model without considering its strain rate dependency. Viscoelastic material-based linear Kelvin-Voigt model is used to represent nonlinear hysteresis behavior of SMA-TSD and is characterized as equivalent linear model with equivalent stiffness and damping under seismic excitation (Sun and Lu., 1995). Seismic response control for model based 10 storey building is determined employing one SMA-TSD device at ground floor and two SMA-TSD devices and ground floor and first floor/ second floor of the building (Figure 1).

Figure 1: Ten-Storey Building



(a) Uncontrolled

(b) Controlled with one TSD

(c) Controlled with two TSD

2. Methodology

2.1 Ten-Storey Building

A ten-storey building represented as plane frame with rigid floors is modeled as lumped mass system with one degree of freedom at each storey level, as shown in Figure 1a. The same building controlled by one damper at ground floor and two dampers at ground and first floor are shown in Figure 1b and Figure 1c, respectively, under seismic excitations (Yuen *et al*., 2007). The equation of motion for the building is expressed as:

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = Gf - ML\ddot{x}_g(t) \qquad ...(1)$$

where M is the mass matrix given as diag $[m_i]$ of nominal mass of each storey m_i = 50 kg, K is tridiagonal stiffness matrix with $K_{ii} = k_i + k_{i+1}$, $k_{i,\, i+1} = -k_{i+1}$, $k_{i,\, i-1} = k_{i-1}$, where k_i is interstorey stiffnesses given as 948.70, 836.99, 886.11, 889.33, 925.77, 881.83, 833.79, 824.03, 872.11 and 829.86 N/cm for i = 1,2,…10, first to tenth storey, respectively. Damping coefficient matrix C is derived from proportional (Rayleigh) damping coefficients $\alpha_m = 0.1\ s^{-1}$ and $\alpha_k = 7.36 \times 10^{-4}\ s$ as $C = \alpha_m M + \alpha_k K$ with 1% damping ratio for first two modes [23]. The effect of seismic excitations at each storey is given as influence matrix L, which is a unit column matrix. Seismic ground acceleration is denoted as $\ddot{x}_g$ and $x = [x_1\ \ x_2..x_{10}]^T$ is the displacement vector for 10 storeys measured relative to the ground. G is the location matrix indicating damper/s location and f is the control force vector. For uncontrolled system G is null matrix, for one damper G is $[-1\ \ 0\ \ 0\ ...0]^T$ and $f = f_1$. For the two-damper case: G is a two-column matrix with $G_{ij} = 0$ except $G_{11} = G_{22} = -G_{12} = -1$, and $f = [f_1\ f_2]^T$, where each damper is at ground and first floor. For two-damper case, where one damper is at ground and the other damper at third floor, G is a two-column matrix with $G_{ij} = 0$ except $G_{11} = G_{32} = -G_{22} = -1$. If the building is modeled as a plant with states defined as $z = [x\ \dot{x}]^T$ and the output vector $y = [\ddot{x}_1\ \ddot{x}_2 \cdots \ddot{x}_{10}\ \ \ x_1\ x_2 \cdots x_{10}]$ the state and output equations are described in Equations (2) and (3), respectively.

Author pls chk and confirm [23]

$$\dot{z} = Az + Bf + Ex\, g \qquad ...(2)$$

Author pl. check symbol is missing

$$y = Cz + Df \qquad ...(3)$$

where A is system matrix, B is input matrix, C is output matrix, D is direct transmission matrix and E is location matrix for seismic excitations, and f is control force vector.

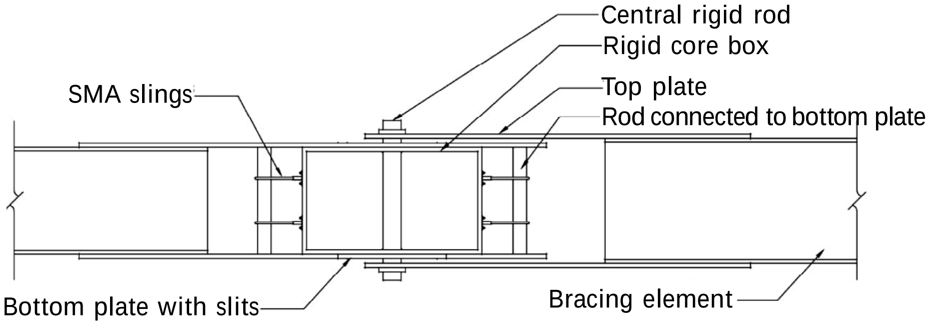
$$A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix};\ B = \begin{bmatrix} 0 \\ M^{-1}G \end{bmatrix};\ E = -\begin{bmatrix} 0 \\ L \end{bmatrix}$$

$$C = \begin{bmatrix} -M^{-1}K & -M^{-1}C \\ I & 0 \end{bmatrix};\ D = \begin{bmatrix} -M^{-1}G \\ 0 \end{bmatrix}$$

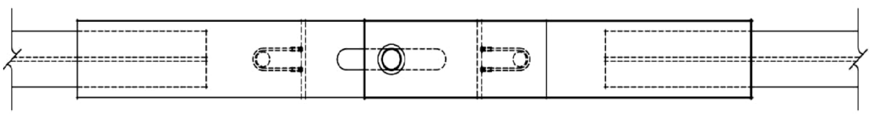
2.2 Tension Sling Damper

TSD comprises SMA slings of NiTinol wires developed to induce passive damping force. Figure 2a shows the plan of the TSD prototype with its components and Figure 2b provides side elevation of the TSD for completeness. TSD design includes proportioning of SMA wire diameter, total area represented by number of SMA slings and length of SMA sling. These parameters in the study are determined through a number of iterations corresponding to seismic excitation. The making principle of TSD is represented in Figure 2c and Figure 2d for back and forth motion induced due to input motion resulted into tensile strain only in one of the sets of SMA slings that remain engaged, while other set is disengaged. Design parameters of TSD are

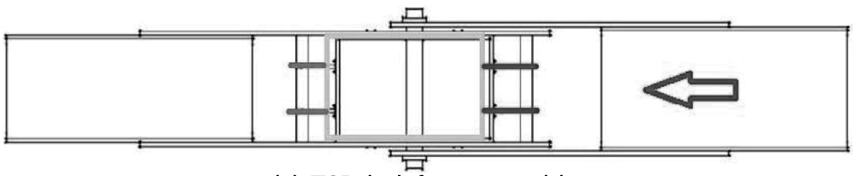
Figure 2: Details of Tension Sling Damper



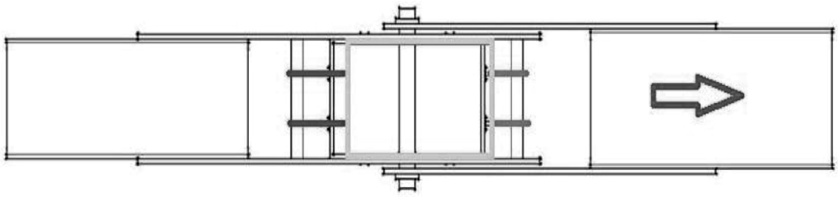
(a) Plan of TSD with nomenclature



(b) Side elevation of TSD



(c) TSD in left sway position



(d) TSD in right sway position

identified to limit operating strain level within 6 to 8% and thus TSD will not show any permanent offset. It can be fairly assumed that TSD will be recentered when velocity changes its sign.

Mechanical properties of NiTinol considered for SMA slings are modulus of elasticity for martensite (E_M) and austenite (E_A)—46 GPa and 55 GPa, austenite start and finish temperature –3 °C and 7 °C, martensite start and finish temperature –28 °C and –43 °C. Stress influence coefficients for martensite and austenite are C_M and C_A are 7.4 MPa/°C (Hartl and Lagoudas, 2008). Design parameter identification process reveals that smaller diameter of SMA wire is most likely to undergo phase transition from austenite to martensite due to presence of large magnitude of strain, inducing energy dissipation leading to increased damping. On the other hand, larger diameter SMA wire limit its contribution to stiffness. The design diameter for SMA wires used for SMA-TSD derived for the study is of the order 0.58 mm and lower. Such SMA wires, when rolled against rigid rod to form SMA sling, as shown in Figure 2a, bears finite contact and likely to offer negligible friction force in low velocity regime.

However, if strap of SMA wire is considered instead of small diameter SMA wire-based sling, frictional force may be generated at point of contact when velocity of input motion tends to zero. This shall be accounted for in the modeling of SMA-TSD. Additional damping supplemented by SMA-TSD is found within the range of 13 to 21% due to seismic excitation for the design parameters considered in the study which is comparable with other supplemental passive damping devices. The passive TSD is fitted in position within the principal diagonal in the ten-storeyed shear building at ground floor and first floor. The other possible configuration of TSD placement is horizontal position with chevron bracing.

2.3 Characterization of SMA-Based TSD

Passive control force of TSD can be evaluated from constitutive relationship between stress, strain and temperature developed by various researchers. Tanaka (1986) proposed one-dimensional stress-strain-temperature dependent model with exponential equation for kinematic phase transformations for SMA wires which was modified by Liang and Rogers through cosine function (Liang and Rogers, 1997). These models were strain-rate independent and thus other models such as Boyd and Lagoudas's thermodynamic model and Schmidt's plasticity model focused on strain-rate dependence that resulted into complex expressions and were practically non-implementable (Boyd and Lagoudas, 1996; and Schmidt, 2006). Graesser and Cozzaraelli developed strain-rate dependent one-dimensional model, more commonly known as G-C model, which is a modified form of Bouc-wen model given by Ozdemir to characterize nonlinear hysteresis behavior of SMA wires. Ren *et al.* (2007)further modified G-C model with different model parameters for different loading branches (Ozdemir, 1976; and Graesser and Cozzaraelli, 1991).

Owing to simplicity and versatility, the study considers one-dimensional Tanaka model for SMA-based TSD with constitutive relationship as:

$$\sigma = [E_A + \xi(E_M - E_A)]\,[\varepsilon - \xi H^{cur}(\sigma)] \qquad ...(4)$$

where martensitic volume fraction is evaluated as:

$$\xi = 0 \text{ if } T \geq M_s^{\sigma} \text{ or } T \geq A_f^{\sigma};\ \xi = \frac{(M_s^{\sigma} - T)}{(M_s - M_f)} \text{ if } M_s^{\sigma} < T < M_s^{\sigma};$$

$$\xi = \frac{(A_f^{\sigma} - T)}{(A_f - A_s)} \text{ if } A_s^{\sigma} < T < A_f^{\sigma};\ \xi = 1 \text{ if } T \leq M_f^{\sigma} \text{ or } T \leq A_s^{\sigma}$$

where $H^{cur}(\sigma)$ = maximum transformation strain, E_A=Elastic modulus of austenite and E_M= Elastic modulus of martensite, σ = mechanical stress and ε = total strain in SMA wire, A_s, M_s, A_s and A_f are austenite and martensite start and finish temperatures respectively, which modifies in the presence of stress as:

$$A_s^{\sigma} = A_s + \frac{\sigma}{C_A};\ M_s^{\sigma} = M_s + \frac{\sigma}{C_M};\ A_f^{\sigma} = A_f + \frac{\sigma}{C_A};\ M_f^{\sigma} = M_f + \frac{\sigma}{C_M}.$$

SMA-based damper device with nonlinear hysteresis behavior when fitted with a discrete linear dynamic system warrants nonlinear dynamic analysis to be performed to evaluate response quantities. Since nonlinear dynamic analysis is computationally intensive and time-consuming due to its iterative nature, day-to-day design strategies prefer linear dynamic analysis instead. Various seismic codes recommend use of equivalent linear model for SMA-based control devices mapping accurately its nonlinear hysteretic behavior (AASHTO, 1991). One such example of equivalent linear damping model is given by Ghodke and Jangid (2016) wherein stiffness and damping components of SMA-based energy dissipation devices were determined through energy equivalence.

In the paper, TSD mechanism is cyclic tensile stress that resembles well with experimental investigations carried out on SMA wire and thus its behavior depends on loading history (Tanaka, 1986; Zhang and Zhu, 2007; and Hartl and Lagoudas, 2008). Therefore, SMA wire with hysteretic behavior can be termed as a viscoelastic material and falls within the scope of linear theory. Hysteretic behavior of such material can be represented by the Voigt model which comprises stiffness and damping components, parallelly (Sun and Lu, 1995). The force displacement relationship for Voigt model for SMA-based TSD is given in Equation (5) as:

$$F_{SMA} = k_{eq}\,x(t) + C_{eq}\dot{x}(t) \qquad ...(5)$$

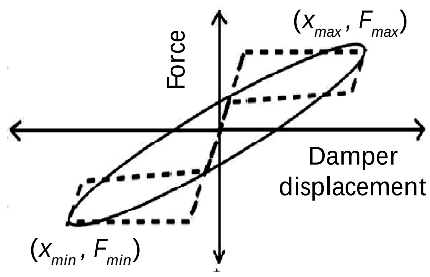
where F_{SMA} = force produced by SMA-based TSD; k_{eq}= equivalent stiffness of SMA wire and C_{eq} = equivalent damping of SMA wire.

Equivalent linear stiffness and damping parameters derived in Equation (5) for SMA-based TSD are determined following AASHTO guidelines for SMA material used for base isolation. Figure 3a shows force-displacement schematic diagram of flag-shaped one-dimensional Tanaka model for SMA-TSD and its conversion to viscoelastic Voigt model with co-ordinates of maximum, minimum—force and—displacement. Equivalent stiffness parameter of Voigt model, derived in Equation (5), can be evaluated as:

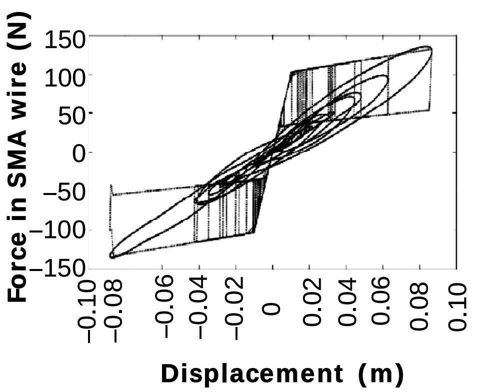
$$k_{eq} = \frac{(F_{max} - F_{min})}{(x_{max} - x_{min})} \quad ...(6)$$

where F_{max} and F_{min} are maximum and minimum force induced by TSD, x_{max} and x_{min} are maximum and minimum displacement observed by TSD under the input motion.

Figure 3: Characterization of SMA Based Passive TSD



(a) Schematic diagram for flag-shaped SMA conversion to viscoelastic Voigt model



(b) Equivalent linear Voigt model for Kobe (50%) seismic excitation

The equivalent viscous damping, c_{eq} expresses energy dissipation capacity of the super-elastic SMA wire due to cyclic inelastic deformation is given as:

$$c_{eq} = 2\xi_{eq}\sqrt{k_{eq}\,m} \quad ...(7)$$

where ξ_{eq} is the equivalent viscous damping ratio and m is mass of the storey when SMA-based TSD is fitted. Equivalent viscous damping ratio ξ_{eq} can be expressed as work done by damper force per cycle as:

$$\xi_{eq} = \frac{W_D}{2\Pi\, k_{eq}\, x_{max}^2} \quad ...(8)$$

where W_D is energy dissipated by the damper force per cycle of hysteretic SMA-based TSD. Energy dissipated by the damper force per cycle within the flag-shaped hysteresis loop of SMA wire is determined from known co-ordinates of SMA NiTinol wire at ambient temperature, as shown in Figure 3b. Representation of SMA-based TSD by the Voigt model of two components is validated by comparing energy dissipated by the flag-shaped hysteresis loop with the viscoelastic hysteresis loop.

Energy dissipated by the damper force for both types of hysteresis loops (refer Figure 3b) is found to be about 10.85 J for design parameters of SMA wire; 0.58 mm diameter, 1.45 m length and 50 kg mass of the system under Kobe displacement time history excitation. Figure 3b shows comparison of flag-shaped hysteresis loop of SMA wire with viscoelastic Voigt model hysteresis loop. The maximum strain rate of SMA-based TSD considered is found to be 14.08 mm/min under Kobe seismic excitation. It has been established from experimental investigations on SMA wire subjected to reverse cyclic loading that within the range of strain rate of 10 mm/min to 15 mm/min, the damping capability of SMA wire does not reduce but marginally increases (Ren *et al*., 2007; and Fan *et al*., 2019). In the study, lower bound value of damping for a given strain rate is considered and thus the damping capability estimated for SMA-TSD is slightly conservative.

3. Results and Discussion

The efficacy of SMA-based TSD towards controlling seismic response of a ten-storey shear building is studied under different magnitudes of classical seismic excitations, for e.g., strong motion type El Centro seismic excitations record (1940) of levels 50%, 100% and 150% and pulse type Kobe seismic excitation (1995) of 50% record are considered in the study. The Kobe seismic excitation is considered with half of its original acceleration amplitude to avoid unreasonably high response of the building if subjected to unscaled time history since PGA (Peak Ground Acceleration) of unscaled Kobe seismic excitation is about 2.4 times larger than that of unscaled El Centro seismic excitation. Two cases are considered, in which ten-storey shear building is fitted with single SMA-based TSD at ground floor and in second case, same building is fitted with two identical SMA-based TSD at ground and first floor and at ground floor and third floor. Location of SMA-based TSD is determined based on interstorey drift response of uncontrolled case, i.e., ten-storey shear building without SMA-based TSD which is similar to other studies (Yuen et al., 2007, Purohit and Chandiramani, 2012). Uncontrolled response of ten-storey building without SMA-based TSD is evaluated from Equation (2) with null matrix G under different seismic excitations. The results of uncontrolled response for ten-storey shear building are compared with the reported results of Yuen *et al.* (2007) for validation (Table 1).

Table 1: Comparison of Uncontrolled Response of Ten-Storey Shear Building

Seismic Response Quantities	Seismic Excitations							
	El Centro				Kobe			
	50%		100%		150%		50%	
	Yuen *et al.*	Present Study	Yuen *et al.*	Present Study	Yuen *et al.*	Present Study	Yuen *et al.*	Present Study
peak displacement (cm)	11.830	11.810 (–0.17)	23.66	23.620 (–0.17)	35.495	35.430 (–0.18)	29.180	29.120 (–0.21)
peak interstorey drift (cm)	1.816	1.810 (–0.33)	3.632	3.620 (–0.33)	5.447	5.430 (–0.31)	5.443	5.420 (–0.42)
peak acceleration (g)	0.566	0.562 (–0.71)	1.133	1.123 (–0.89)	1.699	1.685 (–0.83)	1.909	1.892 (–0.90)

Controlled responses of ten-storey shear building fitted with—one and two—SMA-TSD are evaluated utilizing Equation (2) to Equation (8). Note that control damper force of SMA-TSD FSMA in Equation (6) is denoted as force vector *f* in Equation (2). Control damper force by SMA-TSD is determined from mechanical properties, as mentioned in section 2.2 and one-dimensional Tanaka model at ambient temperature of 25° C. SMA-TSD is fitted in the principal diagonal connecting ground storey and first-storey for one-damper case. For two-damper case, SMA-TSD connects ground storey and first-storey; as well as first and second storey when ten-storey building is subjected to El Centro seismic excitations. SMA-TSD in two-damper case of the building subjected to Kobe seismic excitation connects ground storey and first storey and second storey and third storey to achieve reasonably controlled seismic response.

3.1 Controlled Building with One SMA-TSD

Controlled seismic response of the ten-storey shear building fitted with one SMA-TSD, as shown in Figure 1b, is represented in terms of seismic response parameters, peak displacement, peak interstorey drift, peak acceleration and peak damper force. Design parameters: length, diameter and number of SMA wire sling are determined through iterative search method. Table 2 shows seismic response parameters of ten-storey shear building fitted with SMA-TSD/s. Bracketed quantity denotes percentage difference between uncontrolled and controlled response where –ve indicates reduction. It has been found that one SMA-TSD yields moderate peak displacement reduction (up to 27%) for ten-storey building for all levels for El Centro seismic excitations. However, peak displacement response remains marginally higher (up to 6%) for the ten-storey building with one TSD under Kobe seismic excitation. Peak interstorey drift shows uniform reduction up to 4└ 19% for ten-storey building with one SMA-TSD as compared to its uncontrolled response for all seismic excitations. One SMA-TSD is found to be effective in reducing peak acceleration up to 4└ 11% for all

Author pl. check: symbols are missing

Table 2: Seismic Response Parameters of Controlled Ten-Storey Building with One and Two SMA-TSD

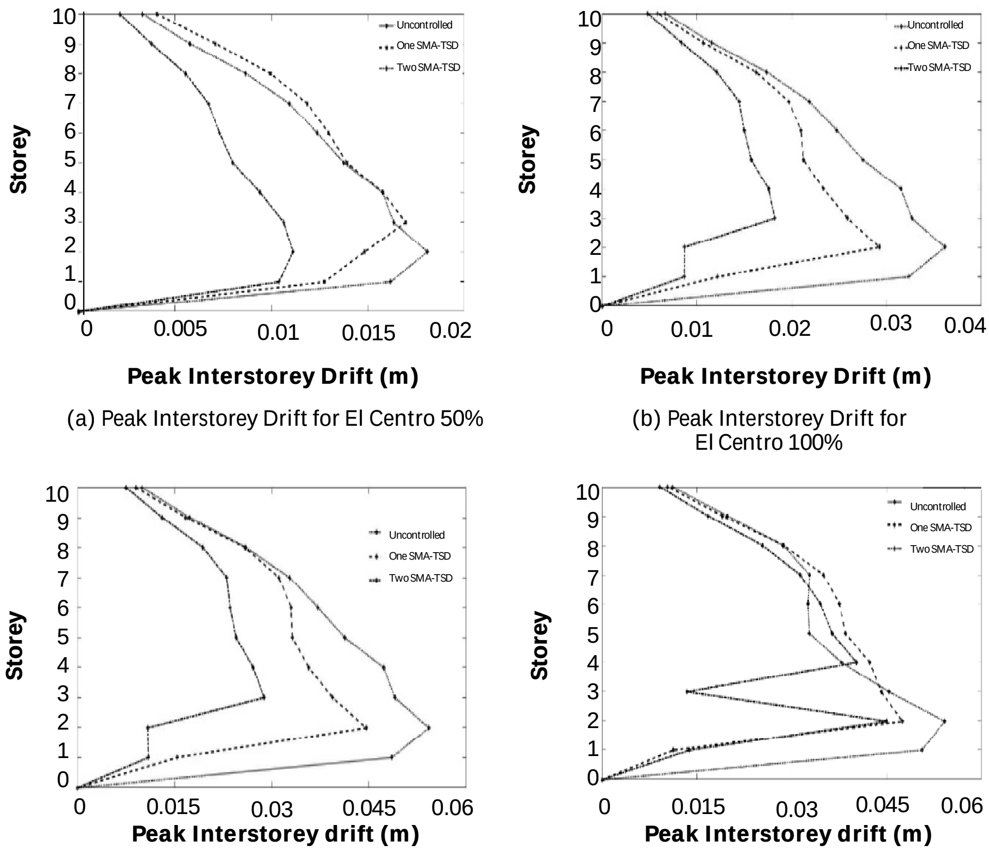
Seismic Excitations	Ten-Storey Building	TSD Design Parameters[1]	Peak Displace-ment (m)	Peak Interstorey Drift (m)	Peak Accele-ration (m/s^2)	Peak Damper Force (N)
El Centro (50%)	Uncontrolled	-	0.118	0.018	5.513	–
	One SMA-TSD	n = 40; Φ = 0.1 mm; L = 0.22 m	0.107 (–9.32)	0.017 (–5.56)	6.720 (21.89)	341.41
	Two SMA-TSD	n = 40; Φ = 0.1 mm; L(GS) = 0.14 m; L(FS) = 0.29 m	0.070 (–40.68)	0.010 (–44.44)	3.571 (–35.23)	78.95 (GS) 279.23 (FS)
El Centro (100%)	Uncontrolled	–	0.236	0.036	11.017	–
	One SMA-TSD	n = 50; Φ = 0.58 mm; L = 0.2 m	0.167 (–29.24)	0.029 (–19.44)	9.741 (–11.58)	1746.20
	Two SMA-TSD	n = 50; Φ = 0.58 mm; L(GS) = 0.14 m; L(FS) = 0.29 m;	0.110 (–53.39)	0.018 (–50.00)	7.976 (–27.61)	157.80 (GS) 1338.40 (FS)
El Centro (150%)	Uncontrolled	–	0.354	0.054	16.530	–
	One SMA-TSD	n = 70; Φ = 0.58 mm; L = 0.25 m	0.258 (–27.12)	0.045 (–16.67)	15.107 (–8.61)	2946.70
	Two SMA-TSD	n = 70; Φ = 0.58 mm; L(GS) = 0.18 m; L(FS) = 0.36 m	0.168 (–52.54)	0.029 (–46.67)	12.459 (–24.63)	238.86 (GS) 2377.80 (FS)
Kobe (50%)	Uncontrolled	–	0.291	0.054	18.561	-
	One SMA-TSD	n = 16; Φ = 0.58 mm; L(GS) = 0.18 m	0.308 (5.84)	0.048 (–11.11)	17.168 (–7.51)	2977.00
	Two SMA-TSD	n = 15; Φ = 0.58 mm; L(GS) = 0.97 m; L(SS) = 0.23 m	0.264 (–9.28)	0.045 (–16.67)	15.058 (–18.87)	8878.00(GS) 6295.60 (SS)

Note: [1] TSD design parameters: n = nos. of SMA slings, Φ = diameter of SMA slings, L = length of SMA slings, GS = ground storey, FS = first storey and SS = second storey

Author pl. check symbol is missing

seismic excitations except El Centro seismic excitation with 50% level, where peak acceleration is found to be shot up by 4└ 22%. Figure 4 shows peak interstorey drift response of uncontrolled and controlled ten-storey building. It is evident that control is most recently achieved across each storey for El Centro seismic excitations of 100% and 150% level but not 50% El Centro excitation and 50% Kobe seismic excitation. Peak acceleration plotted against each storey in Figure 5, reveals that one SMA-TSD

Figure 4: Peak Interstorey Drift for Ten-Storey Shear Building



(a) Peak Interstorey Drift for El Centro 50%

(b) Peak Interstorey Drift for El Centro 100%

(c) Peak Interstorey Drift for El Centro 150%

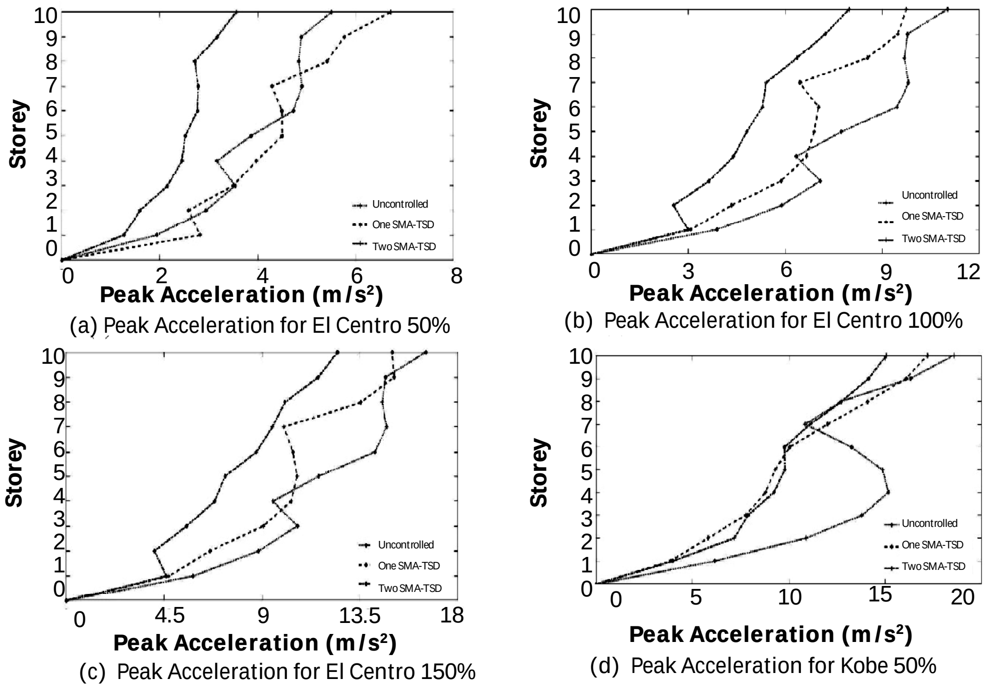
(d) Peak Interstorey Drift for Kobe 50%

effectively controls acceleration almost every floor barring few exceptions under all seismic excitations. Reduction in seismic response parameters for ten-storey building with one SMA-TSD is attributed to supplemental damping offered by superelastic SMA wire which ranged between 13 and 21% under various seismic excitations.

3.2 Controlled Building with Two SMA-TSD

It is seen that seismic response parameters are mostly controlled by utilizing one SMA-TSD with ten-storey shear building. However, peak interstorey drift and peak accelerations at few storeys are not being controlled. Therefore, one more SMA-TSD is fitted between first and second storey of the ten-storey shear building. Placement of SMA-TSD in the building is decided referring to peak interstorey drift response of uncontrolled building. Controlled building, now fitted with two SMA-TSD, as shown

Figure 5: Peak Acceleration for Ten-Storey Shear Building



in Figure 1C, is subjected to different levels of El Centro seismic excitations and 50% Kobe seismic excitation. Design parameters of SMA-TSD has been kept same as that of derived for one SMA-TSD, so efficacy of two SMA-TSD is distinctly visible. Table 2 shows seismic response parameters of controlled building with two SMA-TSD under various seismic excitations. Bracketed quantity shows percentage difference between controlled and uncontrolled seismic response; –ve sign shows reductions. It is clearly evident that two SMA-TSD yields substantial reduction (4└ 53%) in peak displacement, interstorey drift and acceleration vis-à-vis uncontrolled building for different levels of El Centro seismic excitations. However, for 50% Kobe seismic excitations, seismic response control is moderate (4└ 19%) since higher vibration modes are excited under this seismic excitation.

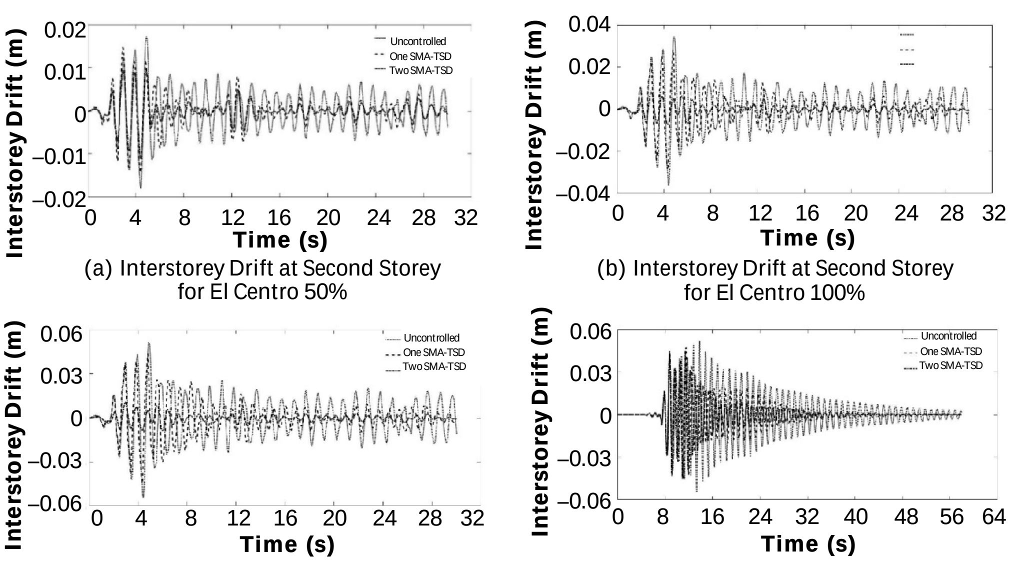
Author pl. check symbols are missing

It is important to note here that two SMA-TSD outperforms one SMA-TSD in terms of seismic response control. The comparison among these passive dampers made possible as diameter and number of SMA tension slings are kept unchanged. However, length of SMA tension slings are altered to ensure maximum strain produced in them due to applied stress remains well within the maximum permissible strain of 6%. This restriction of induced strain in SMA wire prevents permanent deformation of SMA-wire from its original equilibrium position, i.e., no divergence from its base line. On the other hand, it limits damping capabilities of SMA-wire in SMA-TSD and thus remain slightly underutilized towards seismic response control.

Figure 4 shows peak interstorey drift plotted for ten-storey shear building with two SMA-TSD for each seismic excitation. It is evident that SMA-TSDs efficiently reduces peak interstorey drift for each storey of the building for different levels of El Centro seismic excitations when they are fitted at bottom two storeys. However, it has been found that the said placement of SMA-TSDs could not control the peak interstorey drift for upper storeys for 50% Kobe seismic excitation. Thus, SMA-TSD placements are rearranged with one SMA-TSD at bottom storey and other between second and third storey to achieve better seismic control. Peak acceleration at each storey for the same building is plotted in Figure 5. It is evident that two SMA-TSD yields substantial reduction at each storey of controlled building vis-à-vis uncontrolled building under all seismic excitations.

Time history plot for interstorey drift at second storey of the uncontrolled and controlled buildings (with one and two SMA-TSD) are given in Figure 6 for each seismic excitation accounted for. It is revealed that both SMA-TSD (one and two) show good interstorey drift control throughout time extent of seismic excitations. It is evident that controlled buildings creep back to its base line without any offset. Two SMA-TSD outperforms one-TSD performance in reducing peak seismic response

Figure 6: Interstorey Drift at Second Storey Level of Ten-Storey Shear Building



(a) Interstorey Drift at Second Storey for El Centro 50%

(b) Interstorey Drift at Second Storey for El Centro 100%

(c) Interstorey Drift at Second Storey for El Centro 150%

(d) Interstorey Drift at Second Storey for Kobe 50%

quantities and controlling response throughout time history. Table 2 shows peak damper force magnitude increases with levels of seismic excitations with highest damping force offered by SMA-TSD for Kobe seismic excitations. The study reveals that pulse type Kobe seismic excitation requires relatively larger length of SMA tension slings for passive seismic response control as compared to El Centro seismic excitation.

Conclusion

In this paper, ten-storey shear building is fitted with one and two SMA-TSD to passively control its seismic response. El Centro seismic excitations with 50%, 100% and 150% levels and 50% Kobe seismic excitations are considered. Behavior of SMA-TSD is characterized by Tanaka model considered with isothermal conditions. Equivalent linear model for SMA-TSD is developed using Voigt model of linear dynamic theory for viscoelastic material with memory effects. Passive damper force is represented with two components of stiffness and viscous damping characterized for each seismic excitation considered in the study. Uncontrolled seismic response of ten-storey shear building is evaluated and is compared with controlled buildings fitted with one SMA-TSD and two SMA-TSD. Seismic parameters, peak displacement, interstorey drift, acceleration and peak damper force are evaluated. Design parameters of SMA-TSD, diameter, length and number of SMA tension slings are determined through iterative search method. It has been found that one SMA-TSD yields moderate seismic response control for El Centro seismic excitation of 100% and 150% levels. Controlled building with two SMA-TSD very effectively controls seismic response for all seismic excitations and outperforms one SMA-TSD. SMA-TSD is slightly underutilized towards seismic response control due to constraint imposed on it for maximum strain. Seismic parameters of superelastic SMA-based TSD can be optimized to yield better seismic response control.

References

Author pls provide missing volume and issue numbers for 1, 6, 10, 12, 15, 16, 21, 24, 25, 26, 30, 31 and 32 references

1. Aiken I D and Kelly J M (1992), "Comparative Study of Four Passive Energy Dissipation Systems", *Bulletin of New Zealand Society for Earthquake Engineering*, Vol. 25, pp. 175-192.
2. American Association of State Highway and Transportation Officials, Guide Specifications for Seismic Isolation Design (1991), Washington DC.
3. Boyd J D and Lagoudas D C (1996), "A Thermodynamical Constitutive Model for Shape Memory Materials Part I: The Monolithic Shape Memory Alloy", *International Journal of Plasticity*, Vol. 12, No. 6, pp. 805-842.
4. Buehler W and Wiley R (1961), Nickel Based Alloys, Patent US3174851A.
5. Chen G, Garret G T, Chen C and Cheng F Y (2004), "Piezoelectric Friction Dampers for Earthquake Mitigation of Buildings: Design, Fabrication and

Characterization", *Structural Engineering and Mechanics*, Vol. 17, Nos. 3&4, pp. 539-556.

6. Dolce M, Cardone D, Ponzo F and Valente C (2005), "Shaking Table Tests on Reinforced Concrete Frames Without and With Passive Control Systems", *Earthquake Engineering and Structural Dynamics*, Vol. 34, pp. 1687-1717.

7. Fan Y, Sun K, Zhao Y *et al*. (2019), "A Simplified Constitutive Model of Ti-Ni SMA with Loading Rate" , *Journal of Materials Research and Technology*, Vol. 8, No. 6, pp. 5374-5383.

8. Ghodke S and Jangid S (2016), "Equivalent Linear Elastic-Viscous Model of Shape Memory Alloy for Isolated Structures", *Advances in Engineering Software*, Vol. 99, No. 22, pp. 1-8.

9. Graesser E and Cozzarelli F (1991), "Shape Memory Alloys as New Materials for Seismic Isolation", *Journal of Engineering Mechanics*, Vol. 117, No. 11, pp. 2590-2608.

10. Hartl D J and Lagoudas D C (2008), "Shape Memory Alloys: Modelling and Engineering Applications", *Springer Science*, pp. 53-119.

11. Housner G W, Bergman L A, Caughey T K *et al*. (1997), "Structural Control: Past, Present and Future", *Journal of Engineering Mechanics*, Vol. 123, No. 9, pp. 898-971.

12. Jani J M, Leroy M, Subik A and Gibson M (2014), "A Review of Shape Memory Alloy Research, Applications and Opportunities", *Materials and Design*, Vol. 56, pp. 1078-1114.

13. Jansen L M and Dyke S J (1999), "Semi-Active Control Strategies for MR Dampers: A Comparative Study", *Journal of Engineering Mechanics*, Vol. 126, No. 8, pp. 795-803.

14. Liang C and Rogers C A (1997), "One-Dimensional Thermomechanical Constitutive Relations for Shape Memory Materials", *Journal of Intelligent Material Systems and Structures*, Vol. 8, No. 4, pp. 285-302.

15. McCormik J, DesRoches R, Fugazza D and Auriccchio F (2006), "Seismic Vibration Control Using Superelastic Shape Memory Alloys", *Journal of Engineering Materials and Technology,* Vol. 128, pp. 294-301.

16. Miller D J, Fahnestock L and Eatherton M (2012), "Development and Experimental Validation of a Nickel - Titanium Shape Memory Alloy Self Centering and Buckling Restrained Braces", *Engineering Structures*, Vol. 40, pp. 288-298.

17. Mortazavi S M R, Ghassemieh M and Motahari S A (2013), "Seismic Control of Steel Structures with Shape Memory Alloys", *International Journal of Automation and Control Engineering*, Vol. 2, No.1, pp. 28-34.

18. Ozbulut O E, Hurlebaus S and Desroches R (2011), "Seismic Response Control Using Shape Memory Alloys: A Review", *Journal of Intelligent Material Systems and Structures*, Vol. 22, No. 14, pp. 1531-1549.

19. Ozdemir H (1976), "Nonlinear Transient Dynamic Analysis of Yielding Structures", PhD Dissertation, University of California at Berkeley, Berkeley, CA.

20. Pall A S and Marsh C (1982), "Seismic Response of Friction Damped Braced Frames", *Journal of Structural Engineering, ASCE*, Vol. 108, No. 6, pp. 1313-1323.

21. Purohit S P and Chandiramani N K (2012), "Semi-Active Control Using Magneto-Rheological Dampers with Output Feedback and Distributed Sensing", *Shock and Vibrations*, Vol. 19, pp. 1427-1443.

22. Ren W, Li H and Song G (2007), "A One-dimensional Strain-Rate-Dependent Constitutive Model for Super-Elastic Shape Memory Alloys", *Smart Mater Struct*, Vol. 16, No. 1, pp. 191-197.

23. Sae-Ung S and Yao J T P (1978), "Active Control of Building Structures", *Journal of the Engineering Mechanics*, Vol. 104, No. 2, pp. 335-350.

24. Schmidt I (2006), "A Phenomenological Model for Super-Elastic NiTi Wires Based on Plasticity with Focus on Strain-Rate Dependency Caused By Temperature", *Journal of Engineering Material and Technology*, Vol. 128, pp. 279-284.

25. Soong T T and Spencer B F (2002), "Supplementary Energy Dissipation: State-of-the-Art and State-of-the-Practice", *Engineering Structures*, Vol. 24, pp. 243-259.

26. Spencer B F and Nagarajaiah S (2003), "State of the Art Structural Control", *Journal of Structural Engineering, ASCE*, Vol. 129, pp. 845-856.

27. Sun C T and Lu Y P (1995), *Vibration Damping of Structural Elements*, Prentice Hall Series, Pearson Publications, ISBN: 0130792292.

28. Symans M D and Constantinou M C (1998), "Passive Fluid Viscous Damping Systems for Seismic Energy Dissipation", *Journal of Earthquake Technology*, Vol. 35, No. 4, pp. 185-206.

29. Symans M D, Charney F A, Whittaker A S *et al*. (2008), "Energy Dissipation Systems for Seismic Applications: Current Practice and Recent Developments", *Journal of Structural Engineering, ASCE*, Vol. 134, No. 1, pp. 4-21.

30. Tanaka K A (1986), "Thermomechanical Sketch of Shape Memory Effect: One-Dimensional Tensile Behaviour", *Research Mechanical*, Vol. 18, pp. 251-263.

31. Yuen K, Shi Y, Beck J and Lam H (2007), "Structural Protection Using MR Dampers with Clipped Robust Reliability-Based Control", *Struct Multidisc Optim*, Vol. 34, pp. 431-443.

32. Zhang Y and Zhu S (2007), "A Shape Memory Alloy-Based Reusable Hysteretic Damper for Seismic Hazard Mitigation", *Smart Materials and Structures*, Vol. 16, pp. 1603-1613.

Reference # 62J-2021-01-0x-01

Electronic Journal of STRUCTURAL ENGINEERING

Login

ABOUT CURRENT ARCHIVES EDITORIAL TEAM SUBMISSIONS CONTACT ANNOUNCEMENTS

SEARCH

ISSN: 1443-9255

OPEN ACCESS JOURNAL

Electronic Journal of Structural Engineering is an open access journal, so articles are freely available to the readers.

OPEN ACCESS

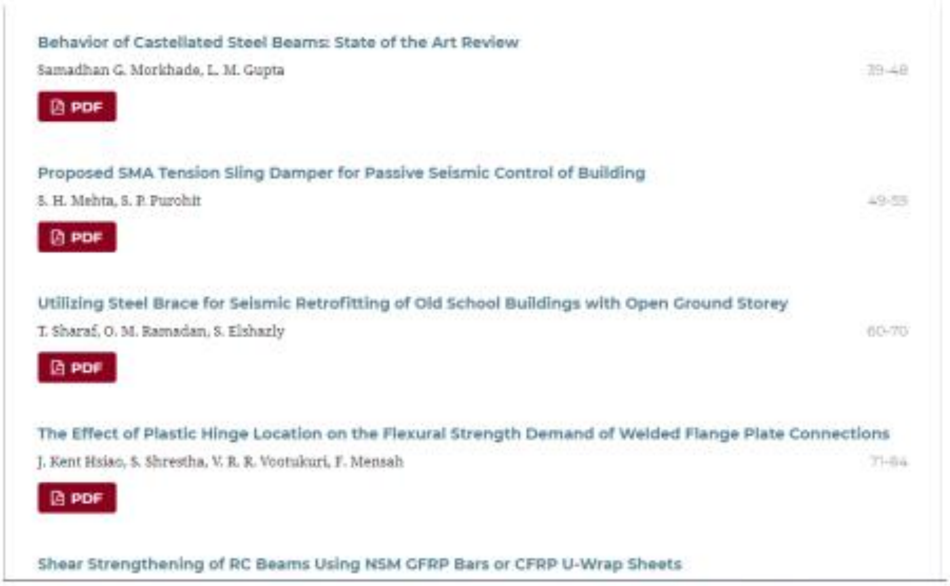
MAKE A SUBMISSION

INFORMATION

About the Journal

Electronic Journal of Structural Engineering

Electronic Journal of Structural Engineering is an **open access**, peer-reviewed journal that presents scientific research in various fields within structural engineering. Being one of the first digital journals around the world, the Electronic Journal of Structural Engineering (EJSE) is an international forum for the dissemination and discussion of leading-edge



Seismic response control of modal building using shape memory alloy tension sling damper

Sujata H. Mehta and Sharadkumar P. Purohit*

Civil Engineering Department,
School of Engineering,
Institute of Technology,
Nirma University,
Ahmedabad, Gujarat, 382481, India
Email: 13extphde106@nirmauni.ac.in
Email: sharad.purohit@nirmauni.ac.in
*Corresponding author

Abstract: Unprestrained NiTinol shape memory alloy wire-based tension sling damper, SMA-TSD, is developed to produce passive damper force at ground story of a three-story modal building. Nonlinear hysteretic behaviour of superelastic SMA is represented by one-dimensional Tanaka model. SMA-TSD is characterised by linear Voigt model with equivalent stiffness and equivalent viscous damping components under seismic excitations to implement it with linear modal building. Equivalent viscous damping ratio is evaluated by proposed instantaneous damping approach more appropriately simulating practical scenario as well as constant damping approach used in other studies. Uncontrolled and controlled responses of modal building are obtained to prove efficacy of superelastic passive SMA-TSD. Seismic performance indices are found to reduce substantially for controlled modal building when design parameters of passive superelastic SMA-TSD are adjusted.

Keywords: tension sling damper; superelastic SMA; Tanaka model; modal building; performance indices.

Reference to this paper should be made as follows: Mehta, S.H. and Purohit, S.P. (2022) 'Seismic response control of modal building using shape memory alloy tension sling damper', *Structural Engineering*, Vol. 12, No. 3, pp.240–263.

Biographical notes: Sujata H. Mehta is a research scholar at Civil Engineering Department, School of Engineering, Institute of Technology, Nirma University, Ahmedabad, Gujarat, India. She received her Postgraduate degree from Gujarat University, Ahmedabad, Gujarat, India.

Sharadkumar P. Purohit is a Professor at Civil Engineering Department, School of Engineering, Institute of Technology, Nirma University, Ahmedabad, Gujarat, India. He received his Postgraduate and Doctoral degrees from Indian Institute of Technology Bombay (IITB), Powai, Mumbai, India. His research areas include dynamic response control of structures, reduced and large scale experimental investigation on structural element/structure, seismic analysis and design of structures, smart materials application to civil structures, experimental investigation on composite steel-concrete sections. He is involved in externally funded research projects in these research areas. He is teaching structural engineering related courses to undergraduate and postgraduate program.

Copyright © 2022 Inderscience Enterprises Ltd.

1 Introduction

Seismic response control of buildings can be achieved by modifying rigidities, masses, damping, shape, and by providing passive or active counter forces. Practical difficulties in modifying mass, shape and rigidity have led to evolution of base isolation technique and provision of counter forces through passive and active dampers (Tsai and Kelly, 1994; Soong and Constantinou, 1994). Passive dampers absorb the seismic energy and reduce seismic response of building without any external power input while active dampers need external power supply and can vary the counter force as per requirement. However, active dampers may not remain functional due to power disruption during seismic event and may destabilise system under powerful excitation. Passive dampers are found to be safe, reliable and reusable for seismic applications. Passive dampers like metallic yield damper, friction damper, viscoelastic damper, viscous damper, etc. perform well under seismic excitations (Symans et al., 2008). Efficacy of such dampers and base isolator for framed buildings for near-fault and far-fault seismic excitations have been studied with more emphasis on near-fault seismic excitations comprising of impulsive type accelerograms, which show large-amplitude pulses (Foti, 2014). In recent past, dampers have been developed utilising materials with controllable properties, called smart materials, such as piezo-electric, electro-rheological fluid, magneto-rheological fluid, etc. (Dyke et al., 1996; Jansen and Dyke, 1999; Xu et al., 2000; Soong and Spencer, 2002). Understanding of unique characteristics of smart materials through experimental research has encouraged their use as a damper with improved properties as compared to passive damper for seismic response control of buildings and structures. Variety of semi-active and active dampers with various control algorithms have been successfully implemented for seismic response control of structural frames (Spencer and Nagarajaiah, 2003; Dyke and Jansen, 1999; Purohit and Chandiramani, 2010; Lavasani and Doroudi, 2020).

A relatively newer class of smart materials having unique characteristics of shape memory effect (SME) and superelasticity, named shape memory alloys (SMA) have been commercially explored and implemented exceedingly in the domain of biomedical, aeronautical, robotics and automotive industry (Buehler and Wiley, 1961; Jani et al., 2014). SMA exhibit non-linear hysteresis, high actuation stress and strain, high energy density and three dimensional actuation other than its' unique characteristics making it suitable for civil engineering applications (Jani et al., 2014). While Cu-Zn, Cu-Al and Cu-Sn based SMAs have shortcomings of thermal stability, brittleness and mechanical strength, NiTi alloys are widely used SMAs for engineering applications (Dasgupta, 2014). Further, alloy composition and properties of SMA wire are found to have considerable effect on its capabilities to improve structural response (Hartl and Lagoudas, 2008). Clarke et al. (1995) and Ocel (2004) experimentally established effectiveness of NiTi wires with steel framed structures. SMA have been used for shape restoration, self-rehabilitation, seismic retrofit of structural elements, base isolation, energy dissipation, etc. as a part of civil engineering applications (Song et al., 2006). Huang et al. (2014) and Ghodke and Jangid (2016) have implemented SMA as components of base isolator. Dolce et al. (2005) and McCormik et al. (2006) have implemented SMA based passive damper with reinforced concrete frame. SMA based passive damper has been used for seismic response control of steel frame by Mortazavi et al. (2013) and SMA based BRBs have been developed by Miller et al. (2012). Due to high damping capacity, greater fatigue life and large recoverable strains, NiTi wires are increasingly studied for structural response control (Ren et al., 2007; Fan et al., 2019). Zhang and Zhu (2007) have also established that NiTinol wire having 0.6 mm diameter can sustain 2000 load cycles with maximum strain amplitude of 8%. It was found that prestrained NiTi wires were more effective in controlling norm drift ratio and norm level acceleration of a building while unprestrained wire were more effective in controlling residual drift (Zhang and Zhu, 2008).

Since most of civil engineering applications of SMA, hitherto, rely on prestraining to improve damping characteristics of the dynamic system, the major objective of the present paper is to utilise hysteretic properties of superelastic SMA, without prestraining, for seismic response control of modal building. It is further aimed to develop novel tension only damper using superelastic SMA wires and implement it for passive seismic response control of modal building. In the present paper, novel SMA based tension sling damper (SMA-TSD) is developed and is fitted between ground and first story of three story modal building. SMA-TSD utilises unprestrained NiTi based SMA wire with superelastic properties to improve damping characteristic of the building. Hysteretic stress strain relationship of SMA-TSD is represented by one-dimensional unified Tanaka model. It is implemented with linear modal building under seismic excitations using linear Voigt model comprising of stiffness and damping components following seismic guidelines of AASHTO – guide specification for seismic isolation design (AASHTO, 2014). Performance of SMA-TSD under pulse and strong motion type of seismic excitations is studied using more practical instantaneous damping approach proposed in the present study along with constant damping approach used in other studies. Suitable design parameters such as numbers, diameter and length of SMA sling are evaluated in order to ensure peak strain in SMA to remain within elastic recoverable limit of~4% to 6%. Peak response quantities of the modal building controlled by SMA-TSD are compared with results reported by Dyke et al. (1996), using controllable fluid based magnetorheological (MR) damper to establish its' efficacy.

2 SMA based tension sling damper

SMA-TSD employing unprestrained superelastic NiTi wires is developed to produce passive damping force. Geometric design of the damper is so proposed that SMA slings are subjected to tensile strain under alternative input motion from the source. Experimental studies have established that damping offered by SMA based dampers is a function of wire diameter, mechanical properties, strain rate and amplitude, prestaining of SMA wire and ambient temperatures (Hartl and Lagoudas, 2008). Design parameters of the unprestrained superelastic SMA-TSD considered for the present study are diameter and length of SMA wire at ambient temperature. These design parameters of the damper fitted with different structures should be estimated constraining maximum recoverable elastic strain of~4%–6%.

Isometric view of the SMA-TSD is shown in Figure 1 with various components, where number and diameter of superelastic NiTi SMA slings may vary as per damper design. Bottom plate with slit has two fixed rods connected on either side of the rigid core box. Bottom plates are connected to the fixed bracing element as shown in Figure 2(a) and plan view of SMA-TSD at rest is shown in Figure 2(b). Set of SMA slings are wound around fixed rods on either side of the rigid core box. Rigid core box receives input motion through central rigid rod connected to top plate, causing tensile strain in one set of SMA slings at a time while other set of SMA slings on opposite side of rigid core box disengages itself until velocity of SMA-TSD is ceased. Figure 2(c) and Figure 2(d) show motion of SMA-TSD fitted with modal building when subjected to seismic excitations and corresponding set of engaged SMA slings producing passive damper force. Upon reversal of input motion, set of SMA slings will regain original state due to superelasticity. Placement of SMA-TSD in principal diagonal is preferred over horizontal position attributed to flexibility of accommodating relatively longer design length of SMA tension slings.

Figure 1 SMA based tension sling damper (SMA-TSD) – 3D view (see online version for colours)

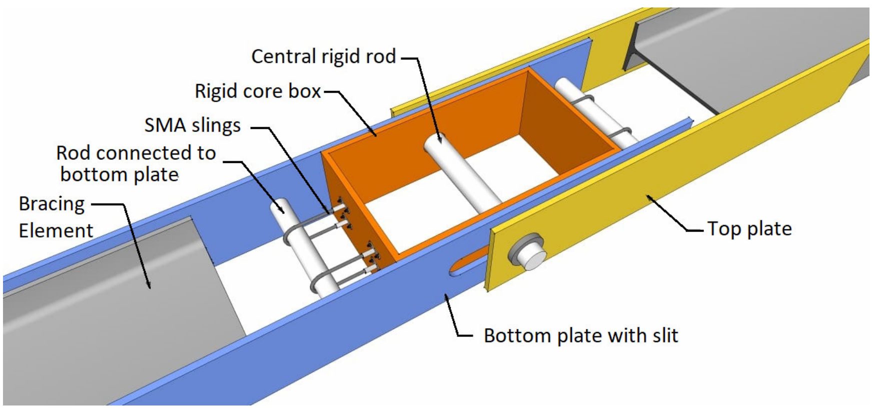
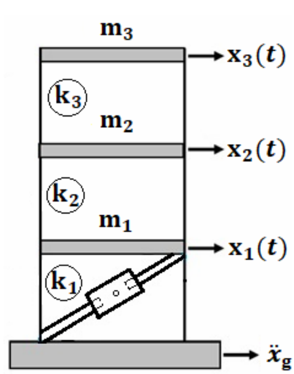
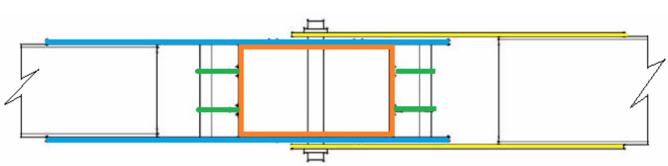


Figure 2 (a) SMA-TSD fitted in principal diagonal of three story benchmark building (b) SMA-TSD at rest (c) right sway of SMA-TSD and (d) left sway of SMA-TSD under input motion (see online version for colours)

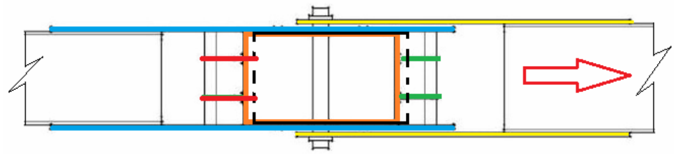


(a)

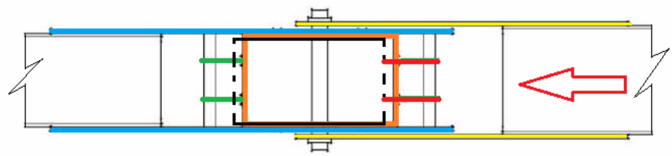


(b)

Figure 2 (a) SMA-TSD fitted in principal diagonal of three story benchmark building (b) SMA-TSD at rest (c) right sway of SMA-TSD and (d) left sway of SMA-TSD under input motion (continued) (see online version for colours)



(c)



(d)

SMA-TSD developed in the present study has few distinct advantages when compared with currently practiced passive devices like steel X-bracings, Pall friction damper, SMA wire bracings and buckling restrained bracings (BRBs) which include:

1 elimination of buckling of SMA-TSD due to absence of compressive force in the damper

2 saving of SMA material as the component carrying compressive force is eliminated

3 recentering of structural system without any residual displacement

4 flexibility to adjust design parameters to meet passive force requirements to varied input motion

5 reusability and reconfigurability.

Present study aims to establish efficacy of developed SMA-TSD when used passively vis-à-vis passive off MR damper device used by Dyke et al. (1996), with three story modal building.

2.1 Hysteresis model of SMA-TSD

SMA are alloys which have ability to undergo large deformation and return to their undeformed shape upon removal of the stress due to superelastic effect. Out of various types of SMA like Cu based SMAs, NiTi SMAs, ferrous SMAs, shape memory ceramics and shape memory polymers; NiTi based SMAs are most preferred in engineering applications because of its superior ductility and high fatigue life. NiTi alloys were discovered by William Buehler in 1959 but its commercial applications became possible after shape memory effect was revealed by William Buehler and Frederick Wang in 1962. Present study uses NiTinol SMA with 55% Nickel and 45% titanium. Study of SMA hysteretic behaviour is very important to effectively utilise SMA-TSD with modal building under various seismic excitations. However, it is difficult to establish a constitutive model which is appropriate for the design of SMA device due to complexity of the SMA material behaviour (Ren et al., 2007).

Tanaka (1990) has developed a one-dimensional phenomenological model for SMA that uses volume fraction of martensite as an internal variable and defines strain as a function of stress and temperature. The model provides set of exponential equations for evolution of kinematics of martensite volume fraction for SMA. Tanaka's model was extended by Liang and Rogers (1997) by describing the transformation kinetics through cosine law in place of exponential function. Brinson (1993) has improved the thermo-mechanic constitutive relationship to represent SMAs behaviour over the full range of temperature. Graesser and Cozzarelli (1991) have studied macroscopic characteristics of SMA and modified existing one dimensional hysteresis model by Ozdemir (1976) which is a special case of Bouc-Wen model. This is widely known as classical G-C model, has considered varying levels of strain amplitude and strain rate for the cyclic behaviour of NiTi SMAs. Wilde et al. (1998) have extended classical G-C model to include hardening behaviour of SMA materials. G-C model uses identical parameters for loading and unloading boundaries leading to some difference between prediction and experimental results and thus model is updated by Ren et al. (2007) by different parameters for loading and unloading branches. These one dimensional rate dependent models are computationally intensive by its formulation. In the present study, hysteretic behaviour of SMA is represented by Tanaka's one-dimensional phenomenological model due to its simplicity and versatility.

Table 1 Mechanical properties of NiTinol SMA wire

Modulus of elasticity for martensite and austenite, E_M and E_A	46 GPa and 55 GPa
Austenite and martensite start temperature, A_S and M_S	–3°C and –28°C
Austenite and martensite finish temperature, A_f and M_f	7°C and –43°C
Stress influence co-efficient, $C_A = C_M$	7.4 MPa/°C
$H^{cur} = H^{max}$	0.0560

Tanaka model employed in present study to represent hysteretic behaviour of SMA does not allow explicit inclusion of loading rate. Experimental studies carried out by Ren et al. (2007) on NiTinol SMA wire with different strain rates suggested increase in dissipated energy for increment of strain rate in the range of 3 mm/min to 15 mm/min, however, amount of dissipated energy reduces for strain rate beyond 15 mm/min. This finding is consistent with similar studies conducted by Toboushi et al. (1998) and Fan et al. (2019). The largest value of RMS strain rate experienced by the NiTinol wire in the present study, is 6.6 mm/min due to various seismic excitations. Hysteretic characteristics of the NiTinol SMA wire are considered for strain rate 3 mm/min in the present study, projecting reduced dissipated energy as compared to the expected amount of dissipated energy at actual strain rates. Thus, seismic response control by developed passive SMA-TSD leads to conservative results. This may be sufficient to establish a proof of concept for passive superelastic SMA-TSD for seismic response control of the modal building. Table 1 shows mechanical properties of NiTinol SMA wire considered in the present study (Hartl and Lagoudas, 2008).

Hysteretic behaviour of NiTinol wire used in passive SMA-TSD is represented by unified one dimensional Tanaka model for isothermal process as,

$$\sigma = \left[E_A + \xi\left(E_M - E_A\right)\right]\left[\varepsilon - \xi H^{cur}(\sigma)\right] \tag{1}$$

where ξ = % of martensite by volume fraction and H^{cur} (σ) = maximum transformation strain, E_A = elastic modulus of austenite, E_M = elastic modulus of martensite, σ = mechanical stress and ε = total strain in SMA wire.

Loading/unloading of set of NiTinol SMA tension slings of passive SMA-TSD induces phase transformation represented by percentage of martensite by volume fraction 'ξ', which is a function of applied stress. Martensite volume fraction (ξ) can be evaluated through equation (2) to equation (5).

$$\xi = 0; \qquad \text{if } T \geq M_s^\sigma \text{ or } T \geq A_f^\sigma \tag{2}$$

$$\xi = \frac{\left(M_s^\sigma - T\right)}{\left(M_s - M_f\right)}; \qquad \text{if } M_f^\sigma < T < M_s^\sigma \tag{3}$$

$$\xi = \frac{\left(A_f^\sigma - T\right)}{\left(A_f - A_s\right)}; \qquad \text{if } A_s^\sigma < T < A_f^\sigma \tag{4}$$

$$\xi = 1; \qquad \text{if } T \leq M_f^\sigma \text{ or } T \leq A_s^\sigma \tag{5}$$

where

$$A_s^\sigma = A_s + \frac{\sigma}{C_A}; \qquad M_s^\sigma = M_s + \frac{\sigma}{C_M};$$

2.2 *Characterisation of passive SMA-TSD*

Implementation of Tanaka model representing nonlinear hysteresis behaviour of SMA-TSD with linear modal building requires tedious and computationally intensive nonlinear dynamic analysis to be performed. Most research studies on nonlinear hysteresis passive damping devices utilise various linear models developed over a period of time for their simplified implementation with linear systems. Various seismic codes like AASHTO, permits modelling of nonlinear hysteretic material with equivalent linear elastic stiffness and equivalent viscous damping. AASHTO guide specifications for seismic isolation design allows such modelling of nonlinear base isolators for its' preliminary design. It further specifies applicability of equivalent elastic stiffness and viscous damping ratio modelling if equivalent viscous damping ratio derived does not exceed by 30%. This modelling approach has been implemented in isolator for seismic response control of unsymmetrical building and exhibited promising results (Ghodke and Jangid, 2016). This approach yields good estimate of peak displacement of base isolator and are found suitable for flexible structures (Sodha et al., 2021). NiTinol SMA wire used in passive SMA-TSD is considered as viscoelastic material in the present study since its behaviour depends not only on current loading condition but on the loading history (Sun and Lu, 1995). The viscoelastic material is well defined by Voigt model which is a combination of a linear spring and a dashpot. The force and displacement relationship of Voigt model for linear theory is given by

$$F(t) = kx(t) + c\dot{x}(t) \tag{6}$$

where k is stiffness of the material, c is damping of the material, x and $\dot{x}$ are displacement and velocity of the input motion.

Nonlinear hysteresis behaviour of passive SMA-TSD can be characterised as linear Voigt model in which stiffness, k, and damping, c, of equation (6) are replaced with equivalent stiffness k_{eq}, and equivalent linear viscous damping c_{eq}, to be derived from flag shaped nonlinear hysteresis stress-strain curve given by Tanaka model. The modified force-displacement relationship of linear Voigt model given by equation (7) is termed as equivalent linear viscoelastic model of passive SMA-TSD.

$$F_{SMA}(t) = k_{eq}x(t) + c_{eq}\dot{x}(t) \tag{7}$$

Figure 3 shows hysteresis curve of NiTinol SMA super-imposed with equivalent viscoelastic model to define equivalent linear parameters of equation (7). Equivalent stiffness, k_{eq}, can be determined as follows,

$$k_{eq} = \frac{(F_{\max} - F_{\min})}{(x_{\max} - x_{\min})} \tag{8}$$

where F_{max} and F_{min} are maximum and minimum force induced by passive SMA-TSD, x_{max} and x_{min} are maximum and minimum displacement of passive SMA-TSD.

The equivalent viscous damping, c_{eq}, expresses energy dissipation capacity of the material during vibration, as

$$c_{eq} = 2\xi_{eq}\sqrt{k_{eq}m} \tag{9}$$

where ξ_{eq} is the equivalent viscous damping ratio and m is mass of the story where SMA-TSD is fitted. Equivalent viscous damping ratio ξ_{eq}, can be defined following energy dissipation by SMA-TSD in one cycle as

$$\xi_{eq} = \frac{W_D}{2\Pi k_{eq}x_{\max}^2} \tag{10}$$

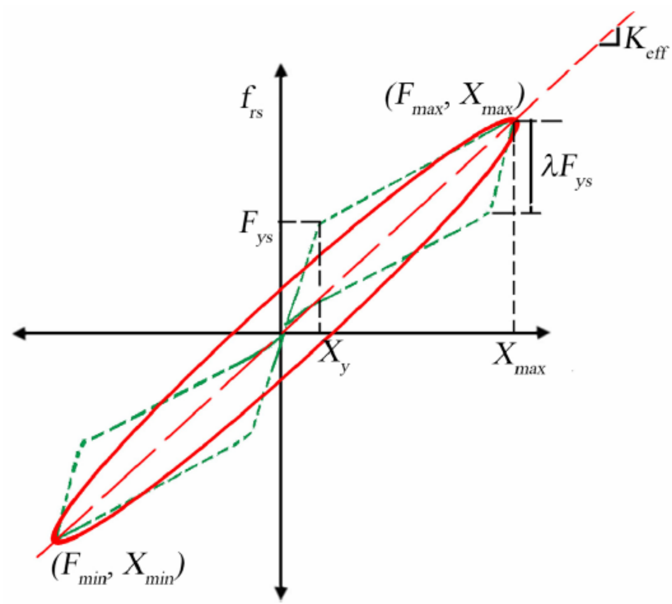
where W_D is energy loss per cycle by the hysteretic SMA-TSD. The energy loss per cycle within the flag-shaped hysteresis loop of SMA is determined from area covered from the hysteresis loop from known coordinates of SMA NiTinol wire at ambient temperature.

Damping force given by equation. (7) for SMA-TSD in the present paper is estimated by following two approaches;

1. Instantaneous damping approach: In this approach equivalent linear parameter for damping, c_{eq}, is evaluated at each instant of time from hysteretic force-displacement curve as it grows with input motion. The proposed approach is simulating more closely practical situation of damper force generation by passive SMA-TSD.
2. Constant damping approach: In this approach equivalent linear parameter for damping, c_{eq}, is determined equating energy dissipated per cycle by hysteresis force-displacement curve with viscous damping curve as shown in Figure 3 which remains constant irrespective of input motion.

This approach is used by few studies for structural response control of system under dynamic excitation with SMA-based devices. One of the recent works by Ghodke and Jangid (2016) represented non-linear SMA hysteresis model by Ren et al. (2007), with equivalent linear elastic viscous model for base isolated benchmark building following AASHTO guidelines on hysteretic device. Representing hysteretic passive damper device by linear viscoelastic model was found compatible for preliminary design of the device. It has been found that it conservatively predicts displacement and base shear while underpredicts floor acceleration (Sodha et al., 2021). However, exploring use of linear viscoelastic model representing variety of nonlinear hysteretic energy dissipation devices is essential to prove its' capability to capture structural response close to corresponding nonlinear hysteretic model. AASHTO guide specifications for seismic isolation design permits use of linear viscoelastic model for nonlinear hysteretic damping curve if equivalent viscous damping ratio is up to 30%.

Figure 3 Hysteresis curve of SMA NiTinol wire and its equivalent linear model (see online version for colours)

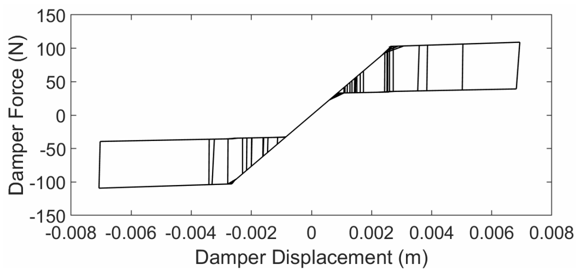


Source: Ghodke and Jangid (2016)

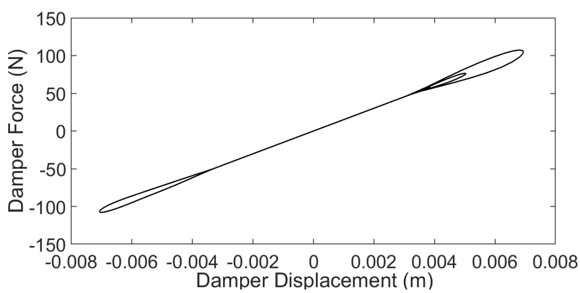
The hysteresis behaviour of SMA-TSD represented by unified Tanaka model subjected to seismic excitations have been evaluated and representative plot for Kobe seismic excitation is given in Figure 4(a). SMA-TSD is characterised as equivalent linear viscoelastic model following concept stated in Figure 3 and using equation (7) to equation (10) with instantaneous damping approach. Figure 4(b) shows damper force to damper displacement relationship derived through equivalent linear viscoelastic model. It is evident that peak damper force and peak displacement obtained by equivalent linear viscoelastic model, Figure 4(b), shows good agreement with corresponding values by Tanaka model, Figure 4(a).

Damper force to damper displacement for SMA-TSD is determined considering linear viscoelastic model with constant damping approach under Kobe seismic excitations and as shown in Figure 4(c). This approach also shows good agreement for peak damper force and peak displacement values with Tanaka model, Figure 4(a). Energy dissipated by SMA-TSD defined by unified Tanaka model is calculated as 4.56 J while it is 4.75 J for equivalent viscoelastic model with constant damping approach where damper mass is assumed to be in the range of 10 kg to 12 kg. SMA-TSD characterised as linear viscoelastic model and fitted to modal building is solved considering both, instantaneous damping approach and constant damping approach discussed above, neglecting mass of the damper since it is very less (<4% of total mass of the modal building).

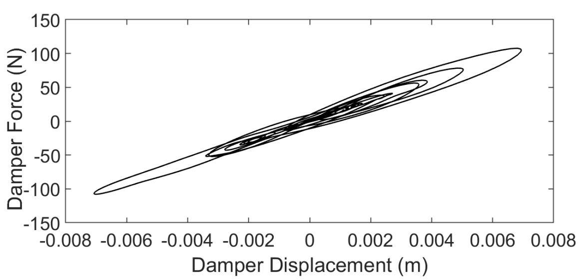
Figure 4 (a) Damper force vs. damper displacement of SMA-TSD by Tanaka model for Kobe seismic excitation (b) Damper force vs. damper displacement of SMA-TSD by equivalent viscoelastic model with instantaneous damping approach for Kobe seismic excitation (c) Damper force vs. damper displacement for SMA-TSD by equivalent viscoelastic model with constant damping approach for Kobe seismic excitation



(a)



(b)



(c)

3 Modal building fitted with SMA-TSD

Building considered in the study is a laboratory based modal building by Dyke et al. (1996) widely used to test efficacy of control devices developed by researchers. Three story modal building fitted with SMA-TSD in principal diagonal at the ground story is shown in Figure 2(a). A lumped mass modelling approach is used to derive equation of motion for modal building. Equation of motion for a controlled modal building with SMA-TSD is given as

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = Gf(t) - ML\ddot{x}_g(t) \tag{11}$$

where M = mass matrix, C = damping matrix, K = orthogonal stiffness matrix, G = location of SMA-TSD, $f(t)$ = passive SMA-TSD force, L is influence vector associated with seismic ground excitation, $x(t)$, $\dot{x}(t)$ and $\ddot{x}(t)$ are displacement, velocity and acceleration vectors of the mass relative to the ground. Mass, stiffness and damping matrices are given by equation (12) as defined by Dyke et al. (1996).

$$\begin{gathered} M = \begin{bmatrix} 98.3 & 0 & 0 \\ 0 & 98.3 & 0 \\ 0 & 0 & 98.3 \end{bmatrix} kg; \quad K = 1\times 10^5 \begin{bmatrix} 12 & -6.84 & 0 \\ -6.84 & 13.7 & -6.84 \\ 0 & -6.84 & 6.84 \end{bmatrix} N/m; \\ C = \begin{bmatrix} 175 & -50 & 0 \\ -50 & 100 & -50 \\ 0 & -50 & 50 \end{bmatrix} Ns/m; \; f = [F_{SMA}]; \quad G = \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix}; \quad L = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}; \end{gathered} \tag{12}$$

Passive damping force by SMA-TSD and its location are defined in equation (12). Influence vector, L, indicating location of masses for the modal building is also defined in equation (12). Displacement degree of freedom $x = [x_1\ x_2\ x_3]^T$ associated with mass, m_i, where i = 1,2,3 are defined as shown in Figure 2a.

Defining state z vector, $z = [\ x\ \ \dot{x}\ ]^T$ and output vector $y = [\ddot{x}_1 \quad \ddot{x}_2 \quad \ddot{x}_3 \quad x_1 \quad x_2 \quad x_3]^T$, equation (11) can be converted to state space form given by,

$$\dot{z} = Az + Bf + E\ddot{x}_g \tag{13}$$

$$y = Cz + Df \tag{14}$$

where A is system matrix, B is input matrix, C is output matrix, D is direct transmission matrix and E is location matrix of seismic ground excitation.

$$\begin{gathered} A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}; \quad B = \begin{bmatrix} 0 \\ M^{-1}G \end{bmatrix}; \quad E = -\begin{bmatrix} 0 \\ L \end{bmatrix}; \\ C = \begin{bmatrix} -M^{-1}K & -M^{-1}C \\ I & 0 \end{bmatrix}; \quad D = \begin{bmatrix} M^{-1}G \\ 0 \end{bmatrix} \end{gathered} \tag{15}$$

In the present study, Modal building is subjected to two types of seismic ground excitations; pulse type – Kobe and Lomaprieta; strong motion type – El Centro and Taft seismic ground excitations for comparison and adding dataset to existing literature. Seismological details of these seismic ground excitations are given in Table 2. Equation (11) to equation (15) are solved using 4th order Rangekutta numerical integration method with MATLAB based programming considering both approaches to estimate equivalent linear damping, c_{eq}, for SMA-TSD as defined in Section 2.2.

Table 2 Seismological details of pulse and strong motion type seismic ground excitations

Seismic excitation	*Fault and component*	*D (km)*	*Scale*		*Data points*	*Δt (s)*	*PGA (m/s²)*
			M	*MMI*			
Kobe (1995) – KJMA station	Strike-slip N-S	1.0	6.9	X	2,400	0.02	8,132 (0.83g)
Lomaprieta (1989)-Corralitos station	Oblique slip (reverse) E-W	2.8	7.0	IX	7,985	0.005	6,278 (0.64g)
El Centro (1940) imperial valley irrigation district – array station 09	Strike-slip N-S	12.2	6.9	X	1,500	0.02	2,845 (0.29g)
Taft (1952) Lincoln school station	Oblique slip E-W	36.2	7.3	XI	3,400	0.02	1,756 (0.17g)

Notes: D – distance from fault, M – magnitude, MMI – modified Mercalli scale intensity, Δt – acceleration recording interval, PGA – peak ground acceleration.

Seismic response of modal building fitted with SMA-TSD is evaluated in terms of normalised performance indices (PI) defined by Ohtori et al. (2004). Relevant PI's considered in the present study are peak interstory drift ratio J_1, level acceleration J_2, base shear J_3 and control force J_{11} as shown in equation (16).

$$J_1 = max\left(\frac{\max\left(\left(\left|\frac{d_i(t)}{h_i}\right|\right)\right)}{\delta^{max}}\right); \qquad J_2 = max\left(\frac{\max|\ddot{x}_{ai}(t)|}{\ddot{x}_{ai}^{max}}\right);$$
$$J_3 = max\left\{\frac{|\max|\sum_i m_i\ddot{x}_{ai}(t)|}{F_b^{max}}\right\}; \qquad J_{11} = max\left\{\frac{\max|f_l(t)|}{W}\right\}; \qquad (16)$$

where, d_i (t) is interstory drift and h_i is the height of the of controlled modal building, δ^{max} is maximum uncontrolled interstory drift, $\ddot{x}_{ai}(t)$ and $\ddot{x}_{ai}^{max}$ are absolute acceleration for controlled and uncontrolled buildings, respectively. m_i is seismic mass of the story here i = 1,2,3, F_b^{max} is maximum uncontrolled base shear, f_l (t) is control force offered by SMA-TSD and W is the total seismic weight of the modal building.

4 Results and discussion

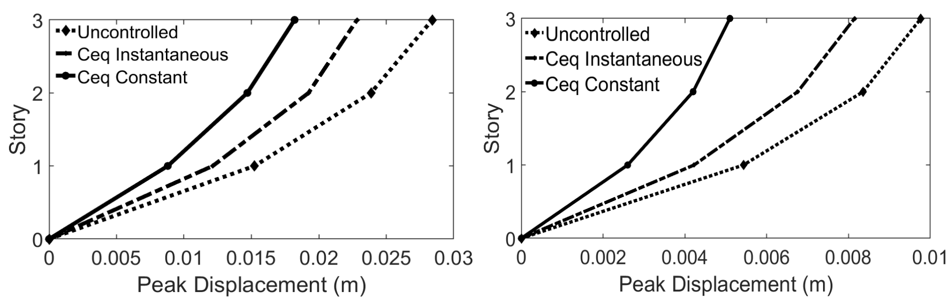
Controlled modal building fitted with SMA-TSD and uncontrolled modal building, F_{SMA} = 0 in equation (11), have been solved under pulse and strong motion type seismic excitations. Pulse type seismic excitations comprises of severe acceleration pulses for shorter duration while strong ground motion type seismic excitation contain significant acceleration over longer time duration.

Modal building being a scaled laboratory-based model, seismic excitation data has been scaled down by five times the recorded rate except for Lomaprieta seismic excitation, where data was already available at the required record rate. It has been verified that these seismic excitations are capable to excite the fundamental modes of vibration of the modal building. Uncontrolled seismic response of the modal building has been obtained in terms of peak values of displacement, interstory drift and acceleration for El Centro seismic excitations and are reported in Table 3. These response quantities when compared with existing results by Dyke et al. (1996) shows very good agreement (difference is ~5%).

Seismic response quantities for controlled modal building are evaluated using proposed instantaneous damping approach and constant damping approach and are compared with uncontrolled modal building in Table 3 for El Centro seismic excitations. Performance of passive SMA-TSD is compared with magneto-rheological (MR) fluid damper-passive off case with constant applied voltage of 2.5 V, as seismic response quantities for controlled modal building with this case were reported by Dyke et al. (1996). It is evident from Table 3 that SMA-TSD with constant damping approach yields substantial reduction (> 44%) in peak displacement, interstory and acceleration response quantities vis-à-vis uncontrolled modal building. Reduction in these response quantities is found to be moderate (13%–22%) for controlled modal building with instantaneous damping approach. Comparison amongst seismic response quantities for controlled modal building with passive SMA-TSD (constant damping approach) and with MR damper passive off case shows comparable reduction with maximum difference of ~17%. Thus, passive SMA-TSD (constant damping approach) proves to be as effective as MR damper passive off case as observed in Table 3. Similar or better seismic response control of modal building with SMA-TSD can be obtained by adjusting design parameters; diameter and length of NiTinol wires, other than the ones used in the present study given in Table 4.

Peak seismic response quantities for controlled modal building subjected to seismic excitations have been determined. In this section, representative plots of Kobe seismic excitations – pulse type and El Centro seismic excitations – strong ground motion type are discussed. Peak displacement response of controlled modal building subjected to Kobe and El Centro seismic excitations are plotted in Figure 5(a) and Figure 5(b). It is evident that peak displacement reduces substantially at each story of the modal building. Peak displacement at roof level shows reduction of 47.96% for controlled building with constant damping approach under El Centro seismic excitations. It is seen that SMA-TSD with constant damping approach yields maximum reduction in seismic response quantities followed by instantaneous damping approach vis-à-vis uncontrolled modal building.

Figure 5 Peak displacement response of controlled modal building to seismic excitations; (a) Kobe and (b) El Centro



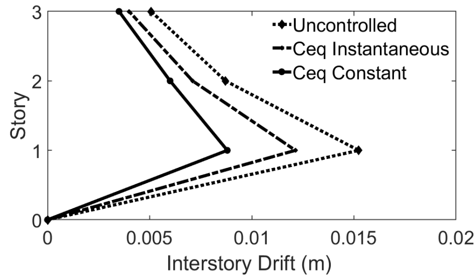
(a) (b)

Figure 6(a) and Figure 6(b) shows peak interstory drift response for controlled modal building showing maximum interstory drift occurring at first story level. SMA-TSD with both, instantaneous and constant damping yields reduction in peak interstory drift for each story of the modal building. While instantaneous damping approach brings similar order reduction, in peak interstory drift at each story of modal building under both Kobe and El Centro seismic excitation, constant damping approach yields relatively higher reduction in peak interstory drift for El Centro seismic excitation than the Kobe seismic excitation. Maximum attenuation in peak interstory drift is found to be 51.85% at first story of controlled modal building with constant damping approach under El Centro seismic excitations. Reduction in peak interstory drift at first story of controlled modal building is 22.22% under Taft seismic excitation which is least amongst all seismic excitations considered for the study. SMA-TSD with constant damping approach performs better than practical instantaneous damping approach due to higher stiffness and damping values which remain constant over seismic excitation events.

Table 3 Peak seismic response quantities for three story modal building for El Centro seismic excitations

	Story level	*Uncontrolled response*		*Controlled response*		
					Passive SMA-TSD	
		Dyke et al.	*Present study*	*MR damper passive off case Dyke et al.*	*Instantaneous damping approach (present study)*	*Constant damping approach (present study)*
Peak displacement (cm)	1	0.54	0.54	0.21	0.42	0.26
			(0.00)	(–60.78)	(–22.22)	(–51.85)
	2	0.82	0.84	0.36	0.68	0.42
			(2.44)	(–56.46)	(–19.05)	(–50.00)
	3	0.96	0.98	0.46	0.81	0.51
			(2.00)	(–52.70)	(–17.35)	(–47.96)
Peak inter–story drift (cm)	1	0.54	0.54	0.21	0.42	0.26
			(0.37)	(–60.78)	(–22.22)	(–51.85)
	2	0.32	0.30	0.15	0.26	0.16
			(–6.33)	(–52.04)	(–13.33)	(–46.67)
	3	0.20	0.19	0.10	0.16	0.10
			(–5.47)	(–48.76)	(–15.79)	(–47.37)
Peak acceleration (m/s^2)	1	8.56	8.38	4.20	6.60	4.64
			(–2.18)	(–50.93)	(–21.24)	(–44.65)
	2	10.30	10.69	4.80	8.45	5.54
			(3.75)	(–53.40)	(–20.89)	(–48.12)
	3	14.00	13.48	7.17	10.69	6.90
			(3.87)	(–48.79)	(–20.72)	(–48.84)
Damper force (N)				258.00	116.14	79.16

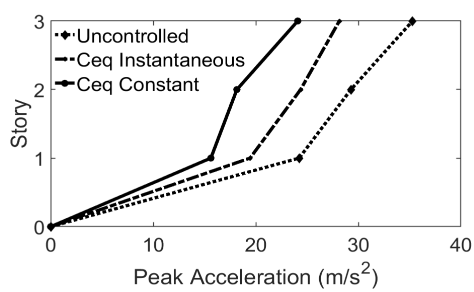
Figure 6 Peak interstory drift response of controlled modal building to seismic excitations; (a) Kobe and (b) El Centro



(a) (b)

Peak acceleration response of controlled modal building under Kobe and El Centro seismic excitations is plotted in Figure 7(a) and Figure 7(b), respectively. It is evident that SMA-TSD with both instantaneous and constant damping approach yields substantial reduction at each story of the modal building. Roof peak acceleration reduces to 20.72% and 48.84% for controlled modal building with instantaneous and constant damping approach, respectively, under El Centro seismic excitation. It is observed that similar to peak interstory drift response quantity, SMA-TSD with constant damping approach yields substantial reduction in peak acceleration response quantity at each story for El Centro seismic excitation. It is seen that amongst all seismic excitations considered, reduction in peak acceleration response quantity at each story is least for Taft seismic excitation.

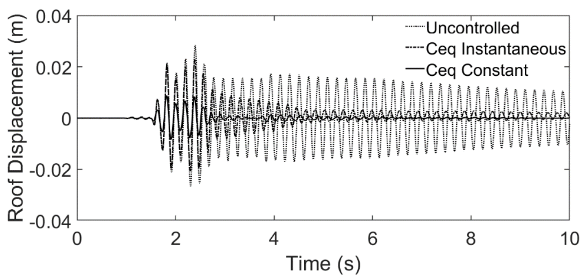
Figure 7 Peak acceleration response of controlled modal building to seismic excitations; (a) Kobe and (b) El Centro



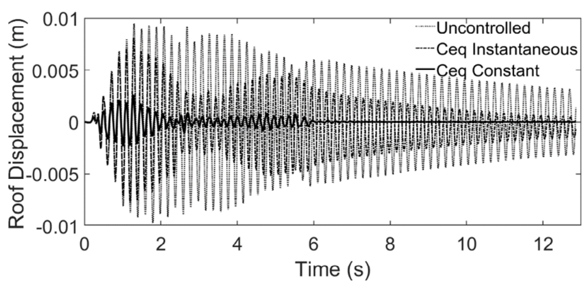
(a) (b)

Controlled modal building with both instantaneous and constant damping approach yields moderate to substantial reduction in all seismic response quantities under pulse type as well as strong motion type seismic excitations considered for the present study. It has been found that SMA-TSD with constant damping approach yields higher reduction in all seismic response quantities than one with instantaneous damping approach. This is attributed to maximum value assigned to stiffness and damping value for hysteretic SMA-TSD. It has been realised that seismic response of modal building can be controlled effectively if frequent phase transformation took place in SMA-TSD resulting into higher damping component of the Voigt model for SMA-TSD. Design parameters; numbers and diameter of SMA tension slings are so adjusted that SMA-TSD with instantaneous damping approach act as stiffness device for strain values incapable of phase transformation under seismic excitations. This is true for substantial portion of seismic excitation data leading to limited damping contribution from SMA-TSD and is a major difference from constant damping approach. Thus, it is expected that seismic response of controlled modal building is relatively higher by instantaneous damping approach vis-à-vis constant damping approach. However, seismic response quantities show moderate reduction of response of controlled modal by instantaneous damping approach when compared with uncontrolled response of modal building.

Figure 8 Roof displacement time history of controlled modal building to seismic excitations; (a) Kobe and (b) El Centro



(a)

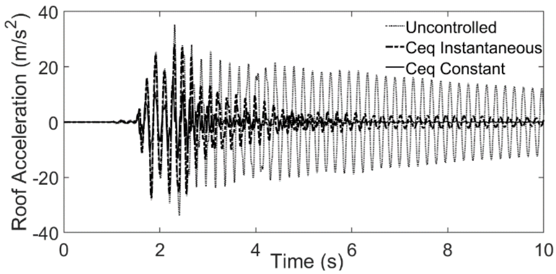


(b)

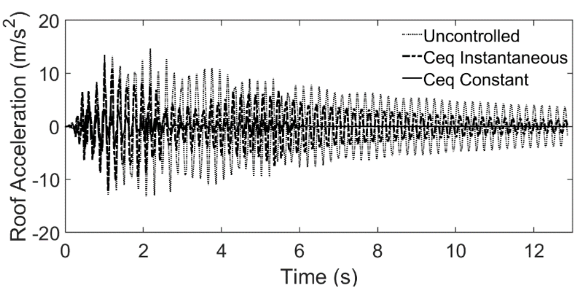
Roof displacement time history responses of controlled modal building subjected to Kobe and El Centro seismic excitations are shown in Figure 8(a) and Figure 8(b). It is clearly visible that passive SMA-TSD with both instantaneous damping and constant damping approach effectively control displacement response throughout seismic event. Similar displacement response results are obtained for controlled modal building for Lomaprieta and Taft seismic excitations. Uncontrolled peak roof displacement response of modal building 0.96 cm, reduces to 0.81cm (–17.35%) and 0.51 cm (–47.96%) for controlled modal building subjected to El Centro seismic excitation with instantaneous and constant damping approach, respectively. With instantaneous and constant damping approach, this quantity reduces from 0.79 cm to 0.70 cm (–11.39 %) and 0.34 cm (–56.96%) for Taft, from 1.85 cm to 1.18 cm (–36.46 %) and 1.07 cm (–42.16%) for Lomaprieta, from 2.84 cm to 2.28 cm (–19.72 %) and 1.82 cm (–35.92%) for Kobe seismic excitations. It has been found that peak roof displacement for controlled modal building occurs earlier than uncontrolled modal building for all seismic excitations. It is also observed from

Figure 8(a) and Figure 8(b) that roof displacement of controlled modal building maintains static equilibrium position without any residual displacement from its base thus proving that strain in SMA-TSD remains within recoverable limits and design parameters of SMA are well placed.

Figure 9 Roof acceleration time history of controlled modal building to seismic excitations; (a) Kobe and (b) El Centro



(a)



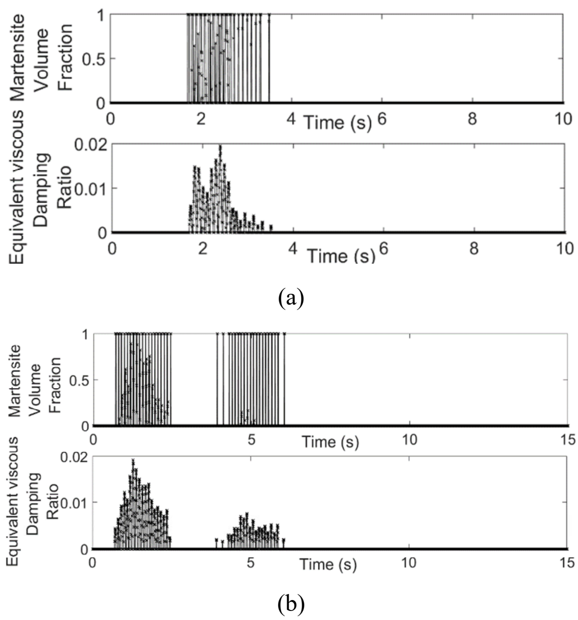
(b)

Figure 9(a) and Figure 9(b) represents roof acceleration time history response of controlled modal building under Kobe and El Centro seismic excitations. It is observed that passive SMA-TSD performs well to control roof acceleration of controlled modal building over entire seismic excitation event. Peak roof acceleration of uncontrolled building 14.00 m/s^2 reduces to 10.69 m/s^2 (20.72%) and 6.90 m/s^2 (48.84%) with instantaneous and constant damping approach, respectively, for El Centro seismic excitations. It is reduced from 9.193 m/s^2 to 8.093 m/s^2 (11.97%) and 4.065 m/s^2 (55.78%) for Taft, from 21.285 m/s^2 to 13.845 m/s^2 (34.95%) and 12.230 m/s^2 (42.54%) for Lomaprieta and from 35.283 m/s^2 to 28.146 m/s^2 (20.23%) and 24.088 m/s^2 (31.73%) for Kobe seismic excitations for instantaneous and constant damping approach, respectively. Similar to roof displacement time history responses, roof acceleration time history responses show early occurrence of peak value for controlled modal building vis-à-vis uncontrolled building. It can be seen from Figure 9(a) and Figure 9(b) that SMA-TSD with instantaneous damping approach shows relatively higher roof displacement and acceleration response as compared to constant damping approach for the reasons discussed earlier in the section.

Martensite Volume Fraction (MVF), as defined through equation (1) to equation (5), induced in SMA-TSD with instantaneous damping approach along with corresponding instantaneous damping ratio, as defined by equation (10), offered are plotted in

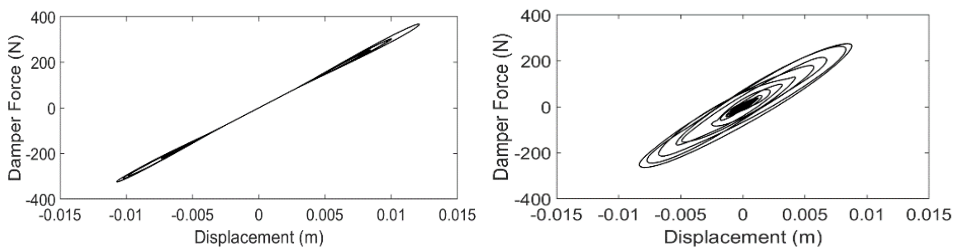
Figure 10(a) and Figure 10(b) for Kobe and El Centro seismic excitations. It is evident that, at each instant of time when SMA-TSD undergoes phase transformation indicated by MVF, equivalent viscous damping ratio sees increment in its value depending upon strain level present in the SMA-TSD. Thus, SMA-TSD offers additional stiffness and damping to the modal building during these time period results into reduction in seismic response quantities. For rest of the time period, when no phase transformation took place, SMA-TSD contributes additional stiffness to the modal building and thus acts as stiffness device only. It is observed that if design parameters are adjusted, SMA-TSD can contribute maximum additional damping of the order~20% to inherent damping of the modal building under various seismic excitations. However, numbers of time SMA-TSD undergoes phase transformation depends upon seismic input.

Figure 10 Variation in martensite volume fraction and equivalent viscous damping ratio for SMA-TSD to seismic excitations, (a) Kobe and (b) El Centro



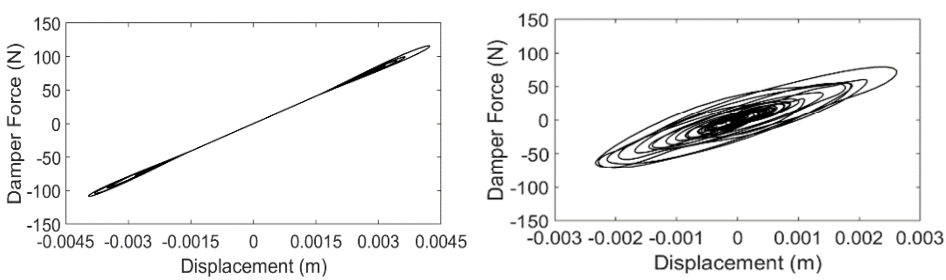
Damper force produced by passive SMA-TSD, F_{SMA}, with instantaneous and constant damping approach plotted in Figure 11(a) and Figure 11(b) for Kobe seismic excitations. Difference between these figures is width of hysteresis loop. Larger width of hysteresis loop obtained for SMA-TSD with constant damping approach is one to the fact that both stiffness and damping are added at each instant of time, irrespective of phase transformation. However, SMA-TSD with instantaneous damping approach adds only stiffness until strain in SMA-TSD reach to a limit of face transformation and thus, resulting into limited damping addition. This is evident as central portion of hysteresis loop is straight line with no width and thus, SMA-TSD behaves like a stiffness dependent device. Figure 12(a) and Figure 12(b) show damper force offered by passive SMA-TSD with instantaneous and constant damping approach for El Centro seismic excitations. A similar nature of damper force to displacement is observed for SMA-TSD to that of Figure 11(a) and Figure 11(b) with relatively lower stiffness but larger damping owing to the seismic input. Peak damper force of 116.14 N and 74.16 N is achieved for SMA-TSD with instantaneous and constant damping approach, respectively. Table 4 shows peak-damper force offered by passive SMA-TSD under Lomaprieta and Taft seismic excitations. It is realised that use of prestraining action in action NiTi SMA wire for seismic application by Zhang and Zhu (2008) and some other research studies is justified in order to improve damping component of the SMA device. However, employing external means to improve damping component of SMA device are in developing phase.

Figure 11 Damper force vs displacement for SMA-TSD to Kobe seismic excitations using (a) instantaneous damping approach (b) constant damping approach



(a) (b)

Figure 12 Damper force vs. displacement for SMA-TSD to El Centro seismic excitations using (a) instantaneous damping approach (b) constant damping approach



(a) (b)

Normalised performance indices (PI) are defined by equation (16) in Section 3 are determined for controlled modal building subjected to pulse and strong motion type seismic excitations given in Table 2. Design parameters; numbers, diameter and length of SMA sling are evaluated through iterative process such that it yields reduction in seismic response quantities. In the present study design iterations were carried out keeping diameter of SMA sling as 0.58 mm since mechanical properties were derived for this diameter in experimental studies by Zhang and Zhu (2008) and numbers of tension slings as 1, in order to study performance of SMA-TSD under different seismic excitations. Table 4 summarises PI's along with maximum strain in damper and peak-damper force for pulse and strong motion type seismic excitations. It is evident that passive SMA-TSD performs well and substantially reduces all PI's barring few of them where reduction is moderate under all seismic excitations. Passive SMA-TSD requires relatively higher tension sling length to achieve seismic response control of modal building when subjected to pulse type seismic excitations as compared to strong motion type seismic excitations. This may cause some practical difficulties in installation of SMA-TSD with modal building. However, design parameters of passive SMA-TSD can be adjusted to fit in with requirements. Base shear PI, J_3 reduces substantially as SMA-TSD increases damping over inherent damping of the modal building. Control force PI, J_{11} indicates that with relatively low control efforts from SMA-TSD, substantial reduction in seismic response quantities of modal building is achieved.

Table 4 Seismic response performance indices for controlled modal building

Seismic excitations	*SMA sling length (m)*	*Modelling approach (1*, 2*)*	*Performance indices (PI)*				*Maximum strain in damper*	*Peak damper force (N)*
			J_1	J_2	J_3	J_{11}		
Kobe	0.50	1	0.797	0.798	0.350	0.127	0.022	275.34
		2	0.578	0.675	0.182	0.095	0.018	368.89
Loma-prieta	0.4	1	0.623	0.650	0.581	0.051	0.014	145.97
		2	0.618	0.604	0.312	0.049	0.014	141.57
El Centro	0.26	1	0.778	0.793	0.542	0.040	0.015	116.14
		2	0.486	0.521	0.148	0.027	0.010	79.16
Taft	0.185	1	0.903	0.784	0.539	0.003	0.009	7.51
		2	0.778	0.766	0.374	0.003	0.009	8.21

Note: 1*-Instantaneous damping approach, 2*-Constant damping approach.

It is observed that from Table 4 that maximum strain produced in SMA-TSD is within~ 2.5% under each type of excitations considered in this study. SMA-TSD with instantaneous damping approach yields higher or equivalent maximum strain vis-à-vis constant damping approach. Difference in maximum strain is 22.22% and 50% for Kobe and El Centro seismic excitations, respectively. Passive SMA-TSD undergoes higher maximum strain when subjected to pulse type seismic excitations.

5 Conclusions

NiTi based SMA is used to produce damper force from novel SMA-TSD fitted at ground story of the modal building by Dyke et al. (1996), subjected to pulse type and strong motion type seismic excitations. One-dimensional Tanaka model is considered to represent hysteretic behaviour of SMA-TSD due to its versatility. Characterisation of SMA-TSD under seismic excitations are carried out using linear Voigt model to map non-linear hysteretic behaviour of Tanaka model following AASHTO guide specifications for seismic isolation design. Linear Voigt model comprising of equivalent stiffness and damping components is implemented with linear modal building using practical instantaneous damping approach featured in the present study and constant damping approach used in other research studies. Seismic response quantities; peak displacement, interstory drift, acceleration, normalised PI, maximum strain, and damper force are evaluated for uncontrolled and controlled modal building under seismic excitations. Design iterations are performed for SMA-TSD design parameters; diameter, length and number of tension slings to achieve seismic response control of modal building.

Following conclusions are made from the present study:

1 Proposed superelastic SMA-TSD reduces seismic response quantities moderately (~13%–23%) with instantaneous damping approach and substantially (~44%–52%) with constant damping approach for controlled modal building.

2 Proposed SMA-TSD with constant damping approach performs at par with MR damper – passive off case of Dyke et al. for controlled modal building subjected to El Centro seismic excitations.

3 Design parameters of SMA-TSD are so adjusted that maximum strain induced in SMA tension sling under various seismic excitations remain within ~3% (< 4.5% of elastic recoverable strain) making it purely super elastic device effective in seismic response control of modal building without residual displacement.

4 Normalised performance indices (PI), peak inter story drift J_1, level acceleration J_2, base shear J_3 and control force J_{11} show moderate to substantial reduction for controlled modal building fitted with SMA-TSD under pulse and strong motion type seismic excitations considered in the present study.

5 Passive SMA-TSD requires relatively larger sling length for seismic control of modal building under pulse type seismic excitations as compared to strong motion type seismic excitation.

6 Passive SMA-TSD with 0.58 mm diameter and single tension sling of varied length adds supplemental damping of the order 1.9%–20.6% to the controlled modal building under various seismic excitations

7 Representation of hysteresis behaviour with linear Voigt model seems to be justified as maximum damping ratio achieved by passive SMA-TSD for various seismic excitation is of the order ~21% is lower than permissible limit of 30%, damping ratio representing linear viscous damping for hysteretic device, defined by AASHTO guide specifications for seismic isolation design.

Installation of SMA-TSD with modal building may require careful attention when designed length of SMA slings are relatively longer with respect to story dimensions. Another set of design parameters for SMA-TSD which can yield similar or better seismic response control of modal building than the present study may be arrived using various optimisation techniques with constraint function on displacement and/or acceleration response.

References

AASHTO (2014) *Guide Specifications for Seismic Isolation Design*, 4th ed., American Association of State Highways and Transportation Officials, Washington, DC.

Brinson, L.C. (1993) 'One dimensional constitutive behavior of shape memory alloys: thermomechanical derivation with non-constant material functions', *Journal of Intelligent Material Systems and Structures*, Vol. 4, No. 2, pp.229–242.

Buehler, W. and Wiley, R. (1961) *Nickel Based Alloys*, patent US3174851A.

Clarke, P.W., Aiken, I.D., Kelly, J.M., Higashino, M. and Krumme R. (1995) 'Experimental and analytical studies of shape-memory alloy dampers for structural control', *Proceedings of SPIE*, San Diego, CA, US, Vol. 2445, pp.241–251.

Dasgupta R. (2014) 'A look into Cu-based shape memory alloys: present scenario and future prospects', *Journal of Materials and Research*, Vol. 29, No.16, pp. 1681-1698.

Dolce, M., Cardone, D., Ponzo, F. and Valente, C. (2005) 'Shaking table tests on reinforced concrete frames without and with passive control systems', *Earthquake Engineering and Structural Dynamics*, Vol. 34, No. 14, pp.1687–1717.

Dyke, S.J., Spencer, B.F. Jr., Sain, M.K. and Carlson, J.D. (1996) 'Modelling and control of magnetorheological dampers for seismic response reduction', *Smart Materials and Structures*, Vol. 5, No. 5, pp.565–575.

Fan, Y., Sun, K., Zhao, Y., Yu, B. and Fan Y. (2019) 'A simplified constitutive model of Ti-Ni SMA with loading rate', *Journal of Materials Research and Technology*, Vol. 8, No. 6, pp.5374–5383.

Foti D. (2014) 'Response of frames seismically protected with passive systems in near-field areas', *International Journal of Structural Engineering*, Vol. 5, No. 4, pp.326–345.

Ghodke, S. and Jangid, S. (2016) 'Equivalent linear elastic-viscous model of shape memory alloy for isolated structures', *Advances in Engineering Software*, Vol. 99, No. 22, pp.1–8.

Graesser, E. and Cozzarelli, F. (1991) 'Shape-memory alloys as new materials for seismic isolation', *Journal of Engineering Mechanics*, Vol. 117, No. 11, pp.2590–608.

Hartl, D.J. and Lagoudas, D.C. (Eds.) (2008) *Thermomechanical Characterization of Shape Memory Alloy Material, Shape Memory Alloys: Modelling and Engineering Applications*, pp.53–119, Springer Science, ISBN: 978-1-4419-4297-5.

Huang, B., Zhang, H., Wang, H. and Song, G. (2014) 'Passive base isolation with superelastic NiTinol SMA helical springs', *Smart Materials and Structures*, Vol. 23, No. 6, 065009.

Jani, J.M., Leary M., Subic A. and Gibson, M.A. (2014) 'A review of shape memory alloy research, applications and opportunities', *Materials and Design*, Vol. 54, pp.1078–1113.

Jansen, L.M. and Dyke, S.J. (1999) 'Semi-active control strategies for MR dampers: a comparative study', *Journal of Engineering Mechanics*, Vol. 126, No. 8, pp.795–803.

Lavasani, S.H.H. and Doroudi, R. (2020) 'Meta heuristic active and semi-active control systems of high-rise building', *International Journal of Structural Engineering*, Vol. 10, No. 3, pp.232–253.

Liang, C. and Rogers, C.A. (1997) 'One-dimensional thermomechanical constitutive relations for shape memory materials', *Journal of Intelligent Material Systems and Structures*, Vol. 8, No. 4, pp.285–302.

Mans, M.D., Charney, F.A., Whittaker, A.S., Constantinou, M.C., Kircher, C.A., Johnson, M.W. and McNamara, R.J. (2008) 'Energy dissipation systems for seismic applications: current practice and recent developments', *Journal of Structural Engineering*, Vol. 134, No. 1, pp.4–21.

McCormik, J., DesRoches, R., Fugazza, D. and Auriccchio, F. (2006) 'Seismic vibration control using superelastic shape memory alloys', *Journal of Engineering Materials and Technology*, Vol. 128, No. 3, pp.294–301.

Miller, D.J., Fahnestock, L. and Eatherton, M. (2012) 'Development and experimental validation of a Nickel – Titanium shape memory alloy self centering and buckling restrained braces', *Engineering Structures*, Vol. 40, pp.288–298.

Mortazavi, S.M.R., Ghassemieh, M. and Motahari, S.A. (2013) 'Seismic control of steel structures with shape memory alloys', *International Journal of Automation and Control Engineering*, Vol. 2, No. 1, pp.28–34.

Ocel, J., DesRoches, R., Leon, R., Gregory Hess, W., Krumme, R., Hayse, J.R. and Sweeney, S. (2004) 'Steel beam-column connections using shape memory alloys', *Journal of Structural Engineering*, Vol. 130, No. 5, pp.732–740.

Ohtori, Y., Christensen, R.E., Spencer, B.F. Jr. and Dyke, S.J. (2004) 'Benchmark problems for seismically excited nonlinear buildings', *Journal of Engineering Mechanics*, Vol. 103, No. 4, pp.366–385.

Ozdemir, H. (1976) *Nonlinear Transient Dynamic Analysis of Yielding Structures*, PhD Dissertation, University of California at Berkeley, Berkeley, CA.

Purohit, S.P. and Chandiramani, N.K. (2010) 'Optimal static output feedback control of a building using an MR damper', *Structural Control and Health Monitoring*, Vol. 18, No. 8, pp.852–868.

Ren, W., Hongnan, L. and Gangbing S. (2007) 'A one-dimensional strain-rate-dependent constitutive model for superelastic shape memory alloys', *Smart Materials and Structures*, Vol. 16, No. 1, pp.191–197.

Sodha, A.H., Soni, D.P. and Vasanwala, S.A. (2021) 'Evaluation of linear viscoelastic model of quintuple friction pendulum isolator', *International Journal of Structural Engineering*, Vol. 11, No. 1, pp.19–43.

Song, G., Ma, N. and Li, H.N. (2006) 'Applications of shape memory alloys in civil structures', *Engineering Structures*, Vol. 28, No. 9, pp.1266–1274.

Soong, T.T. and Constantinou M.C. (1994) *Passive and Active Vibration Control in Civil Engineering*, pp.271–274, Springer Science, ISBN: 978-3-211-82615-7.

Soong, T.T. and Spencer B.F. (2002) 'Supplementary energy dissipation: state-of-the-art and state-of-the-practice', *Engineering Structures*, Vol. 24, No. 3, pp.243– 259.

Spencer, B.F. and Nagarajaiah, S. (2003) 'State of the art structural control', *Journal of Structural Engineering*, Vol. 129, No. 7, pp.845–856.

Sun, C.T. and Lu, Y.P. (1995) *Vibration Damping of Structural Elements*, Prentice Hall Series, Pearson Publications, ISBN 0130792292.

Tanaka, K. (1986) 'A thermomechanical sketch of shape memory effect: one-dimensional tensile behaviour', *Research Mechanical*, Vol. 2, No. 3, pp.59–72.

Tobushi, H., Shimeno, Y., Hachisuka, T. and Tanaka, K. (1998) 'Influence of strain rate on superelastic properties of TiNi shape memory alloy', *Mechanics of Materials*, Vol. 30, No. 2, pp.141–150.

Tsai, H.C. and Kelly, J.M. (1994) 'Seismic response of heavily damped base isolation systems', *Earthquake Engineering and Structural Dynamics*, Vol. 22, No. 7, pp.633–645.

Wilde, K., Gardoni P. and Fujino Y. (1998) 'Experimental and analytical study on a shape memory alloy damper', *Smart Structures and Materials 1998: Smart Systems for Bridges, Structures and Highways Proc. SPIE*, San Diego, CA, US, Vol. 3325, pp.182–191.

Xu, Y.L., Qu, W.L. and Ko, J.M. (2000) 'Seismic response control of frame structures 'using magnetorheological/electrorheological dampers', *Earthquake Engineering Structural Dynamics*, Vol. 29, No. 5, pp.557–575.

Zhang, Y. and Zhu, S. (2007) 'A shape memory alloy-based reusable hysteretic damper for seismic hazard Mitigation', *Smart Materials and Structures*, Vol. 16, No. 5, pp.1603–1613.

Zhang, Y. and Zhu, S. (2008) 'Seismic response control of building structures with superelastic shape memory alloy wire dampers', *Journal of Engineering Mechanics*, Vol. 134, No. 3, pp.240–251.

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**shodh sarita**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	Shodh Sarita (print only)	Shodh Sanchar Educational and Research Foundation	2348-2397	NA	from September-2019 to April- 2021	Discontinued from April 2021

Showing 1 to 1 of 1 entries

Previous 1 Next

ISSN - 2348-2397
UGC CARE LISTED JOURNAL
SIS
Shodh Sarita
January-March, 2021
Vol. 8, Issue 29
Page Nos. 182-186
AN INTERNATIONAL BILINGUAL PEER REVIEWED REFEREED RESEARCH JOURNAL

EXPLORING THE IMPACT AND TRAJECTORIES OF COMMERCIAL GENTRIFICATION

Dr. Vasudha Ashutosh Gokhale*
Shruti Joshi**
Dr. Deepa Joshi ***

ABSTRACT

Gentrification represents the urban development process that results in the upgrading of urban areas where a wealthier group of people displaces the original inhabitants due to socio-economic changes. The gentrification phenomenon is often promoted under the banner of urban renewal, regeneration, or revitalization, ignoring its negative impact on a city's residential and commercial districts. This research examines the phenomenon of commercial gentrification with JM Road Pune as a case. It is aimed to identify the characteristics of the emerging commercial gentrification in India today. Methods used were archival documentary analysis, oral history, field investigation, and semi-structured interviews. The research findings indicate that the commercial upgrading of JM road excluded long-established local businesses, presenting a significant commercial gentrification example. The change in the commercial landscape decreased diversity as a cultural asset; besides, it is accompanied by intense feelings of relative deprivation amongst local people. The analysis helps architects, planners, and policymakers to go for an inclusive and equitable planning process that avoids displacement and marginalization of local inhabitants in the wake of urban development.

Keywords: *Streetscape, commercial, displacement, cityscape, place-identity.*

INTRODUCTION

Innovated by British sociologist Ruth Glass in 1964, Gentrification is the process of renovation and revitalization of an area with higher-income individuals replacing lower-income individuals living in the respective area currently. (Weinstein, 2015). Defined as an urban strategy by Neil Smith (2002), Gentrification contributes to the accumulation of wealth and the changing of social preferences instead of the inclusion and advancement of residents. Gentrification is a social and economic paradigm in the neighbourhood that brings in younger, professional, middle- and high-income individuals displacing low-income minority groups from their homes and businesses. Zukin(2009) It changes the neighborhood's dynamics because of the shift between current residents, current business owners, incoming residents and businesses, and the local economy. (Jeong, Heo, & Jung, 2015) It is a three-step process that includes disinvestment, displacement, and rebranding of an area. (Gonzalez & Waley, 2013).

THE IMPACT OF GENTRIFICATION

As per "the broken windows theory" described by Michener, it is the process where the neighbourhood began to break down because of the reduction in resources. As a result, a downward spiral of dilapidation and disparity may occur. Limited resources of residents for rehabilitating the neighbourhood lead to the continual loss of investment. Michener (2013) As stated by Marcuse (1985), displacement can be seen in four ways: direct last resident displacement, direct chain displacement, exclusionary displacement, and displacement pressure. Direct last-resident displacement represents a relocation of the original tenant because of a rent hike for new tenants for getting more profit within the occupied space. The second type is the direct chain displacement that

*Professor - B.N. College of Architecture, Pune
**Associate Professor - B.N.College of Architecture, Pune
***Assistant Professor - Govt.College Bijawar.

occurs to revitalize the area that considers several displaced tenants, not just the last to occupy the space. When vacant homes are because of the previous displacement are no longer available to low-income tenants due to the building owner's desire to refurbish the home for a higher price, exclusionary displacement occurs. Displacement pressure occurs due to the surrounding changes no longer reflect the needs of current tenants. (Komakech &Jackson, 2016) When tenants feel that they no longer belong to the area and leave it due to new entrants, new business, and rising costs, displacement starts. Rebranding of the area occurs where developers start paying attention to the new area.

It is found that consumers often search for authenticity within a place with an identity of its own that is unknown to others. (Jeong et al.2015) This phenomenon initiates the rebranding of the area opposed by the local residents who used to live and shop there. They are skeptical about the authenticity of the place in satisfying the needs of gentrifiers and new entrants. (Parzer & Huber, 2014) Often, low-income areas of cities are referred to as dead zones because they are decrepit, unhealthy, and undesirable. (Gonzalez & Waley, 2013). In such cases, Gentrification is considered the preferred solution. (Parzer & Huber, 2014). In the development process, the areas which are identified to produce low rents and other unique attributes are exploitable by developers rendering the local environment more acceptable and embraced. (Rankin & McLean, 2014)

COMMERCIAL GENTRIFICATION

Given the entry of big chain stores, small business displacement occurs as the previous owner fails to effectively compete for market share (Jeong, Heo, & Jung, 2015). This displacement is referred to as commercial or retail Gentrification that leads the closer of long-standing businesses by encroaching the customer base (Shepard, 2013). Retail Gentrification in a concentrated area displaces local businesses, which have sustained the surrounding neighborhood and the residents for many years and make them obsolete. (Ernst & Doucet, 2014). Gentrification brings social and cultural impacts on a community which affects commercial developments. (Ocejo, 2011)Having a strong impact on the small business community, Gentrification caused many small business owners to close or relocate their business because of displacement and rises in rent prices through closures and relocations. This process is coupled with other negative consequences such as losing the authenticity of the neighborhood and customers and loss in revenue, thus impacting a small business's ability to maintain profits. (Gonzalez & Waley, 2013). The influence on the city level landscape changed the culture, and the long-standing authenticity of the area is caused by commercial and neighborhood Gentrification is quite visible in many cities all over the world. (Jeong, Heo, & Jung, 2015). Gentrification brings social and cultural impacts on a community which affects commercial developments. (Ocejo, 2011)Having a substantial impact on the small business community, Gentrification caused many small business owners to close or relocate their business because of displacement and rises in rent prices through closures and relocations.

GENTRIFICATION TACTICS.

Numerous strategies were adopted to make room for higher-paying tenants and displace the current tenants, including redlining and negligence. It has been stated that Gentrification is not a naturally occurring phenomenon, but it is a pre-emptive tactic against existing inhabitants. (Lloyd 2015) Neil Smith (2002) coined the rent gap theory, which postulates that the difference between the current cost and potential best cost of property results in a rent gap that indicates the potential for an increase in rents as its price worth more than the current price. This phenomenon initiates the gentrification process and consequent exploitation of the price gap that make tenants susceptible to higher rents. However, the building owner takes efforts to renovate the building to meet market demand, advertise to gentrifies, and charge a higher price to the new tenants. (Weinstein, 2015).

GENTRIFICATION AS A PROPOSED SOLUTION AND URBAN POLICY.

Gentrification leads to begin investing in the neighborhood, creating a financial ability to property maintain areas, promote neighborhood goods and services to consumers outside of the local area, and revitalize it (Logan, 2013). Gentrification can have economic benefits to use in other areas of the city, but it adversely affects the gentrifying area's residents. (Lloyd, 2015). Besides, it leads property values and taxes to increase, forcing the local residents to leave, affecting the local business. A shift in the retail experiences occurs to satisfy gentrifiers' needs rather than the low-income residents that inhabit the area. (Doucet, 2014, Lloyd, 2015, Komakech & Jackson, 2016) Gentrification is referred to as the revitalization of the city through economic development. The public policy aims to overcome the situation by diverting the funds from one neighborhood to another.(Marcuse, 2015). The local government promotes Gentrification as a beneficial and positive solution for the abandoned area, which benefits economically. Policymakers adopt it under the banners of regeneration, renewal, or revitalization, ignoring its negative consequences by and large. (Wyly & Hammel, 2005).

GENTRIFICATION AS SOCIO-ECONOMIC PROCESS

Gentrification is a social and economic process where individual homeowners and renters and private capital reinvest in fiscally abandoned neighborhoods. (Perez, 2004, Lees, Slater, &Wyly, 2008). In this process, individual homeowners and renters and private capital reinvest in fiscally abandoned neighborhoods. Another effect is the changes in the landscape and the city's cultural makeup by increasing property values and changing consumption patterns. This phenomenon makes gentrification a social and economic process that substantially impacts many cities around the globe. City undergoing Gentrification, changes in the demographic landscape of the city, and economic changes take place. (Lees et al., 2008). An increase in rental property, housing prices, and property taxes is caused by Gentrification that homeowners and business owners cannot afford to pay. (Godsil, 2013). When the gentrification process takes place in a community, the demographical landscape drastically changes, and they progress slowly over time or without notice. These changes have positive or negative effects on small business owners. Changes in demographical landscape bring the alteration in the consumption and buying patterns of people living in the city. People need to adapt to the changes with some adjustments. (Zukin, 2011b).

THE METHODOLOGY

This study used a mixed methodology that includes archival documentary analysis, oral history, field investigation, and semi-structured interviews. Semi-structured interviews were performed with the business owners present at the initial development stage and people living therein. The archival documentary study, oral history, and discussion with experts yield valuable information about the transformation of the JM road presented in the net section.

The area where JM road is located was a horticulture land earlier in the eighteenth century. It was a path used by cattle. Initially, the land was used for farming and selling fodder used for horses and cattle. It also used for organising public meetings and place to gather and loiter around. The JMR was initially developed as a residential area with lavish bungalows occupied by a community with a strong sense of life. The business activity started in the form of a juice center to serve mainly the residents nearby. Small-scale business establishments and lodges initiated the gentrification of JMR. These were increased quietly, starting a move towards the whole street's gentrification. Subsequently, a new eating outlet typology emerged to the map of JMR and the street became the first restaurant cluster of Pune. Location triggered the gentrification process of JMR. Located within 1to 2 km of the street were many educational institutes with more than 50,000 students. The restaurants, branded shops were not only suitable for the JM Road business district's fashionable and popular styles.

Jangali Maharaj Road witnessed new food culture trends due to the emergence of food outlets serving various cuisines like North Indian food and fast food. In the last 15- 20 years, JM road became famous as food Street and still maintains its name. However, in the age of Shopping malls and multiplex, JM road has now started to shed its old character. It has now surpassed Laxmi road, famous for clothing and apparel, and has acquired fame to get all foreign branded clothes. The current commercial establishments are shown in fig.1

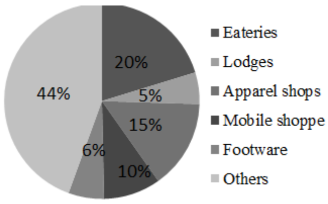


Fig.1. The current commercial outlets.

The street was characterized by elegant old stone buildings in various architectural styles, as shown in fig 2, which is now replaced by glass facade buildings (fig.3).

Fig. 2. Indo Saracenic style building.

Fig.3. Glass facade building.

International food chain replacing the local food joints that representing Pune's culture. (Fig.3)

Fig.4. International food outlet.

The commercial gentrification of JM road has changed the character of the streetscape. Fig 5 shows the streetscape captured from archival records; however, fig. 6 presents the street's current status.

Fig.5. JM road in 1951. Source: Courtesy Aditya Shirole

Fig 6. Present scenario of JM road.

Although the gentrification process has brought a welcoming change in JM road's spatial character, it is coupled with the local residents' displacement.

CONCLUSION

This paper highlighted the notion of commercial gentrification and its impact on the streetscape. It analyzed the commercial gentrification process from the perspective of spatial transformation. It has been found that while widely celebrated, commercial gentrification can lead to deleterious consequences in terms of displacement of the old businesses. The changes brought by this urban restructuring are resulting in a stereotype development and vanishing character and identity of the place. The analysis indicates the need for an inclusive and equitable planning process that avoids displacement and marginalization of local inhabitants.

References:

1. Doucet,Giloth, R. & Betancur, J. (1988) Where downtown meets neighborhood: Industrial displacement in Chicago, 1978–1987, Journal of the American Planning Association, 54(3), pp. 279–290.
2. Ernst, O., & Doucet, B. (2014). A window on the (changing) neighbourhood: The role of pubs in the contested spaces of gentrification. Tijdschrift voor Economische en Sociale Geografie, 105, 189-205.
3. Godsil, R. D. (2013). The gentrification trigger: Autonomy, mobility,and affirmatively furthering fair housing. Brooklyn Law Review, 78, 319-338.
4. Gonzalez, S., & Waley, P. (2013). Traditional retail markets: The new gentrification frontier? Antipode, 45(4), 965-983.

5. Jeong, Y., Heo, J., & Jung, C. (2015). Behind the bustling street: Commercial gentrification of Gyeongridan, Seoul. Procedia-Social and Behavioral Sciences, 170, 146-154

6. Komakech, M., & Jackson, S. (2016). A study of the role of small ethnic retail grocery stores in urban renewal in a social housing project, Toronto, Canada. Journal of Urban Health, 93, 414-423.

7. Lees, L., Slater, T. & Wyly, E. (2008) Gentrification (London: Routledge (Taylor & Francis Group)

8. Lloyd, J. (2015). Fighting redlining and gentrification in Washington, D.C.: The AdamsMorgan organization and tenant right to purchase. Journal of Urban History, 41, 1-19.

9. Logan, C. (2013). Mrs. McCain's parlor: House and Garden tours and the inner-city restoration trend in Washington, D.C. Journal of Urban History, 39, 956-974.

10. Marcuse, P. (2005) On the presentation of research about gentrification. Department of Urban Planning, Columbia University, New York.

11. Michener, J. (2013). Neighborhood disorder and local participation: Examining the political relevance of "broken windows". Political Behavior, 35, 777-806.

12. Ocejo, R. E. (2011). The early gentrifier: Weaving a nostalgia narrative on the lower east side. City & Community, 10, 285-310

13. Parzer, M., & Huber, F. (2014). Migrant businesses and the symbolic transformation of urban neighborhoods: Towards a research agenda. International Journal of Urban and Regional Research, 39, 1270-1278.

14. Perez, G. M. (2004). The near northwest side story: Migration, displacement, and Puerto Rican families. Berkley: University of California Press.

15. Rankin, K., & McLean, H. (2014). Governing the commercial streets of the city: New terrains of disinvestment and gentrification in Toronto's inner suburbs. Antipode, 47, 216-239.

16. Shepard, B. (2013). The battle of Brooklyn: World city and space of neighborhoods. Theory in Action, 6(2), 15-51.

17. Smith, N. (2002). New globalism, new urbanism: Gentrification as global urban strategy. Antipode, 54(3), 427-450.

18. Weinstein, Hannah. 2015. "Fighting for a Place to Call Home: Litigation Strategies for Challenging Gentrification." UCLA Law Review 62:794.

19. Wyly, E. & Hammel, D. (2005) Mapping neoliberal American urbanism, in: R. Atkinson & G.Bridge (Eds) Gentrification in a Global Context: The New Urban Colonialism, pp. 18–38 (London:Routledge).

20. Zukin, S. (2011b). Reconstructing the authenticity of place. Theory & Society, 40, 161-165.

21. Zukin, S (2009) Changing Landscapes of Power: Opulence and the Urge for Authenticity, International Journal of Urban and Regional Research. 33 (2), 543-553.

❒❒❒

Safari File Edit View History Bookmarks Window Help 57%

mjl.clarivate.com

Consortium for Academic and Res... | Consortium for Academic and Res... | Science Master Journal List - Sea... | Mail - Dhruv Chandwania - Outl... | Master Journal List - Journal Pr...

Web of Science Group

Search Journals | Match Manuscript | Downloads | Help Center

Welcome, dhruv chandwania

Settings | Log Out

NEW Check out our new metric to help you evaluate journals! Dismiss | Learn More

About

General Information

Web of Science Coverage

Journal Citation Report

Center for Open Science Information

Peer Review Information

Return to Search Results

EARLY CHILD DEVELOPMENT AND CARE

Share This Journal

ISSN / eISSN **0300-4430 / 1476-8275**

Publisher **ROUTLEDGE JOURNALS, TAYLOR & FRANCIS LTD, 2-4 PARK SQUARE, MILTON PARK, ABINGDON, ENGLAND, OXON, OX14 4RN**

About

Early Child Development and Care is a multidisciplinary publication that serves psychologists, educators, psychiatrists, paediatricians, social workers and other professionals who deal with research, planning, education and care of infants and young children. The Journal provides English translations of work in this field that has been published in other languages, and original English papers on all aspects of early child development and care: descriptive and evaluative articles on social, educational and preventive medical programs for young children, experimental and observational studies, critical reviews and summary articles.

General Information

Journal Website	Visit Site	**Publisher Website**	Visit Site
1st Year Published	1971	**Frequency**	Semi-monthly

EARLY CHILD DEVELOPMENT AND CARE
https://doi.org/10.1080/03004430.2021.2004134

Routledge
Taylor & Francis Group

Check for updates

REVIEW ARTICLE

Study of perception of parents and their children about day-to-day outdoor play spaces

Dhruv Chandwania[a] and Abhijit Natu[b]

[a]Dr. B. N. College of Architecture, Savitribai Phule Pune University, Pune; [b]BKPS College of Architecture, Savitribai Phule Pune University, Pune

ABSTRACT

The day-to-day environment surrounding the child influences its physical, social, and emotional wellbeing. The study was conducted to understand how the perception of children and their parents about the outdoor play spaces influences their outdoor participation. Face-to-face interviews with parents, a walk-along interview with children and audit of public open space were conducted in different neighbourhoods in the city of Pune (India) which differed in social and spatial characteristics. This paper suggests a conceptual framework that defines the setting of participation and factors influencing the motivation of participation in the outdoor environment. The quantitative study of parents' interviews and qualitative analysis of children's sketches highlight different aspects like play and mobility range, open space visitation, activities of children, spatial qualities of the open space and perception of children and their parents. The findings brought forth difference in parents and children's perception of risk in open spaces.

ARTICLE HISTORY
Received 24 September 2021
Accepted 4 November 2021

KEYWORDS
Play space; children's outdoor activities; spatial and physical characteristics; perception

Introduction

A child's environment on daily basis is its exposure to home, playgrounds, and child-orientated institutions (Bronfenbrenner, 1979). Outdoor play space is considered as 'fourth environment,' where the child without an accompanying adult explores the outside setting (Chaudhury, Oliver, Badland, & Mavoa, 2015). The residential open spaces or neighbourhood open spaces are also visited by children on a day-to-day basis. The Neighbourhood unit concepts put forth by Clarence Perry and others focused on central thought for designing for ease of children's walkability to their nearby destinations.

Function, form and variability of urban open spaces have an effect on users' physical, social and psychological behaviour and wellbeing, especially the children (Woolley, 2003). Jean Piaget's theory of Intellectual development describes child's environment to be a key factor in his/her physical, psychological, social, and emotional development. Piaget defines the development through different age groups according to their cognitive developmental stages. According to Piaget, *'Children from about 7–11 years of age are both capable of constructing hierarchical classifications and of comprehending details'* (Ginsburg & Opper, 1988). Piaget suggests that the age of 7 years to 11 years of age falls under the category of Concrete Operational stage. This is the stage of their age in which children are able to take a decision about the actions and also they understand the reactions of their actions. This research studied the age group of 6 years to 12 years which differs from the suggested bracket of Concrete Operational stage. In the Indian education system, a child starts school from the age of 6 years where a more formal schedule of schooling is followed. At this stage, the environment

CONTACT Dhruv Chandwania ar.dhruv@gmail.com

© 2021 Informa UK Limited, trading as Taylor & Francis Group

of school is experienced by the child without parents being around. The child from hereon gets to see how other children react, interact, and emote to different situations, and thus, a new learning impacts their perceptions. The age of 12 is a threshold for children after which they turn into teenagers and this tagline shift itself gets in a lot of confidence to take decisions for their actions more independently. This age group is also a threshold, where child move to High school from Primary school.

Being able to do physical activity while playing games helps children to be physically healthy. Social benefits include making friends during outdoor play, learning from peers are key take away of engaging in open spaces. Applying and developing creative abilities enhance self-esteem adding to the psychological wellbeing of the children.

Children's independent mobility and outdoor play participation are associated with different attributes of the environment, like physical characteristics of the open spaces, availability of affordances, the social attributes, and perception factors considered by the parents and children (Aziz & Said, 2012; Chauvla, 2016; Freeman, Van Heezik, Stein, & Hand, 2015; Humpel, Owen, & Leslie, 2002). During play, children explore and discover their abilities. The achievements during this process build their confidence which is necessary for their continuity of mental and physical development. It is established that children respond more readily to an enriched environment (Bhan, 2006).

This paper intends to understand the factors, the physical characteristics of the environment and its quality, the factors affecting the perception of the space which may influence child's outdoor play and how the above two are associated. Further, the paper brings forth and compares the perception about risks and benefits with respect to open spaces of parents and children.

Children's environment

'*Two-fifths of the children played on roads, in front of garages, or on adjoining pavements—a figure significantly higher than for those who played in gardens, play areas or on paved areas*' (Woolley, 2003). It is found that children between the ages of 6–10 years may not be able to visit parks, playgrounds, etc. without any adult accompanying them; hence most of the children explore the environment around their home range. Children play in the most of the active spaces around their residence where there is an anxious feeling of being a part of something happening (Gehl, 2011).

Content of the space, organization of the space, spatial disposition and context of the space and the physical envelop of the space define the physical characteristics of the open spaces (Natu, 2007). Outdoor spaces that are experienced by children majorly include gardens, playgrounds, open space around their residence in the premise, open parking spaces, and sports ground which are used for organized play and also, kids play area with swings, slides and alike. Even though the areas around and in between the residences are private or semi-private they are termed as open public spaces as they serve to large number of users like children (Said, 2007).

The greenery, good quality of streets, less traffic, safety, amenity, accessibility, sociability, attractiveness and walkability, availability of facilities and amenities like parks and community play grounds, etc. allow children to be more independent in terms of their mobility in the surroundings ((Chaudhury et al., 2015; Lestan, Eržen, & Golobič, 2014; Veitch, Salmon, & Ball, 2007; Zhang & Li, 2012).

Neighbourhood aesthetics has also been an important aspect of the physical characteristics which influence the perception of safety in the neighbourhood and indirectly makes in effect on children's outdoor participation (Croucher, Myers, Jones, & Ellaway, 2007; Ferguson, Cassells, MacAllister, & Evans, 2013; Handy, Boarnet, Ewing, & Killingsworth, 2002; Nunes & Vale, 2015; Zhang & Li, 2012). The comfort of the child to be able to play in an outdoor environment relies on certain aspects like way finding, enclosure defined by buildings around, different activities that take place in and around that place like passing by people either walking or on vehicles, etc. (Aziz & Said, 2012; Chaudhury et al., 2015; Othman & Said, 2012; Villanueva et al., 2016). An environment with high variability provides better sense of attachment (Freeman et al., 2015) and a challenge to the children with an opportunity to feel accomplished. Such variability in the elements of the play space environment encourages children to have diverse opportunities of creative play (Croucher et al., 2007; Giusti, Svane, Raymond, & Beery, 2018; Kuo, Bacaicoa, & Sullivan, 1998; Zhang & Li, 2012). Parks and playground mostly offer pre-defined way of use and thus fail to be occupied through the time (Lestan et al., 2014) whereas street scenes which include elements like utility poles and light poles, street furniture, trees and shrubs, curbs, pathways, buildings and landscaping (Fyfe, 2006) add to the variety of spatial experience and use for children during free play. Having similar age group children to play and explore is considered an important factor of motivation for open space visitation (Gehl, 2011; Hart, 1979). The affordances that a child get in such an enriched environment provide more social opportunities, engaging surroundings and better health (Brooks & Sorin, 2011; Chaudhury et al., 2015; Kyttä, 2003).

The characteristics of elements present in an environment are either perceived as risky or harmless. The context of element(s) causing a harm to oneself by physical injury, mental stress or impacting one's social participation is analysed by the individual and that further determines the level of participation. Factors which are elemental decision of participation are: human experience (ergonomics of elements in open spaces), comfort and relaxation, personal space and privacy (defensible space), safety and security, boundaries, architectural character, navigation and movement (affected by density, crowding and traffic), spatial experience, attractiveness and physical affordance assigned to the place. These attributes can have beneficial effects or may pose risk on physical, social and emotional wellbeing of the children (Brooks & Sorin, 2011; Chawla, 1992; Salama & Azzali, 2015). These factors determine parental licence for their children's participation in outdoor open spaces. Also, children's perception about the play spaces either motivates or poses a setback in participation. It becomes vital to study, understand, and further compare the perceptions of both parents and their child regarding risks associated with spatial characteristics of play areas which govern their participation.

Perception of parents and children

Gibson (Gibson, 2014) states '*The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill*'. The theory of Affordances states that the environment around the organism provides opportunities for desired activities. Children perceive affordances differently in different ages which correspond to their bodily qualities, functional demands of ongoing activity, and to their intensions at that moment (Kyttä, 2003).

Children's perception of the environment is diverse. They interpret the setting in terms of function and/or by form (the visual appearance) (Kaplan & Kaplan, 1989). The function, here, is defined as an opportunity of spontaneous activity that the open space provides; and by form, it refers to a three-dimensional void which may or may not include man-made features which can be termed as spatial enclosure (Said, 2007). One of the models to understand child and its environmental association is place attachment theory. Chawla (1992) defines childhood place attachment as 'children are attached to a place when they show happiness at being in it and regret or distress at leaving it, and when they value it not only for the satisfaction of physical needs but for its intrinsic qualities'.

Different layers which construct the sense of place categorized into themes like social dimension (framed by encounters with adults and peers), sensory dimension (defining boundary and secrete places, personal places), pragmatic (awareness of safety issues and challenges), imaginative (creative perception through meaningful exchange and learning from multiple everyday settings) and importantly place friendship (place familiarity and engaging) are suggested in research defining a child's perception of everyday spaces (Bourke, 2017; Hart, 1979; Ramezani & Said, 2009; Shabak, Norouzi, Abdullah, & Khan, 2015).

The pull and push theory of migration was first coined by Ravenstein of England for migration theory (Mohamed & Abdul-Talib, 2020). The push and pull theories are used to understand the factors of motivation which state that the end goal become driving force as either a push (motivators) or pull (provides incentives) factor.

The factors that affect children's outdoor play participation are parental licence for active and independent travel, accompaniment status, use of mobile phone technology, safety in the open spaces, availability and types of affordances, past experiences (Chaudhury, Hinckson, Badland, & Oliver, 2019). It is also found that parental license is granted conditionally with prior knowledge of 'time and location' provided by their child (Tyagi & Raheja, 2020). Some of the common barriers listed which hinder the open space experience are lack of facilities, incivilities, stray animals, safety and psychological issues (not wanting to go alone), concerns about environmental quality, access issues and personal issues (preference, children the park has now been replaced by the television and by computer games, parental restrictions on children's movements, etc.) (Dunnett, Swanwick, & Woolley, 2002; Pitsikali & Parnell, 2019).

The conceptual model (Figure 1) tries to understand child's participation in open spaces through motivational factors and perception. The social and physical characteristics of the open space motivate the child to move out of the home environment and go in the outdoors for various activities. An experience is generated through participation which develops perception about the open space. The hypothesis is that perception of parents and their child varies and the mitigated perceptions which are accepted both by parents and the child become the deciding factor of either completing the loop of participation again and again. The perception over here is the *'pull'* factor which determines the degree of participation as either a motivator or as a setback. Motivation would be encouraged thorough positive perception. Interestingly, the setback in the participation has different meanings. Opposite meanings like harmful and challenge both can be noticed as two sides of a coin. The study is investigating the definition of PULL as a factor of participation from both perspectives, beneficial and risky.

The sense of safety is on priority list of any parent while choosing a play setting space. The sense of safety is dependent on factors including traffic, stranger danger, crime, fear of stay animals, or hazards from the elements present in the setting (Zhang & Li, 2012). With respect to defining safety associated with elements in the physical setting of play space, the perception of safety

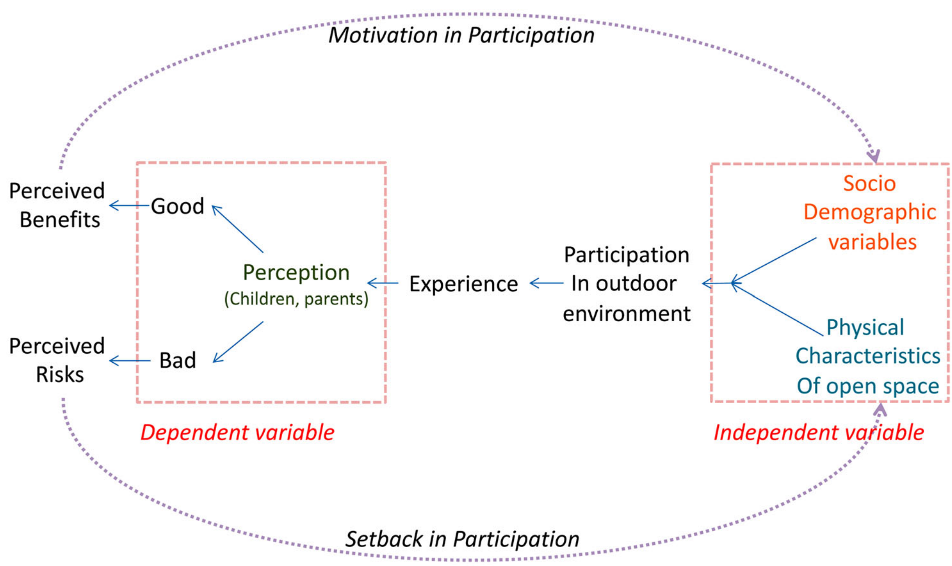


Figure 1. Conceptual framework defining the setting of participation and factors influencing the motivation of participation in outdoor environment.

varies from parent to parent. Climbing a tree may be considered as risk for one parent, but the other may consider it as an adventure offering physical benefit (Slaghekke, 2017).

The spatial activity done by children, outdoors, depends on the parent's defined home range. This home range has shown to increase with age advancement. Children develop place knowledge by direct experience of the environment. Place recognition and naming the ones which are frequently visited, build on to the confidence of the children to negotiate on the home range boundary extension.

As the benefits of participating in outdoor play include improving physical wellbeing of the child, improving self-regulation, promoting cognitive development and improving confidence, etc. (Cooper, 2015). The effects of perceptions of risk control a child's outdoor play timings, area, and accompaniment. Risk perception of the caretakers and participating child may vary. As a reaction to the density increases, parents are getting more vigilant and want their children in the radius of their vigilance. The time spent outdoors gets more controlled with the presence of adults.

Risk is all about thoughts, beliefs, and constructs (Sjöberg et al., 2004). Children learn to develop strategies to negotiate bad places and to read the environment for plausible risks. These risk management strategies include travelling with a friend, sibling or adult, carrying a cell phone to call someone in the event of an emergency, knowing the location of community resources (such as churches) where children can get help and walking with a dog (Wridt, 2010). With risky play, children get exposed to the sensations of fear promoting the development of competencies to manage the potential risks, challenges, and stress associated with life as an adult. Literature suggests that physical activity increases with the challenges that risky plays offer (Bento & Dias, 2017; Obee, Sandseter, & Harper, 2020).

The research related to children and their environment is extensively done in the western countries, especially from Global North like USA, Europe, etc. whereas very few studies are done in Global south countries. The Asian countries like China and India have highest populations in the world. India has the highest population density which makes its case different from other countries. The urban development pattern and policies in India itself are one of the major reasons on how the open space requirement vary from other countries. Few studies done in India have focused on slum areas, whereas this study focuses on general open spaces where all strata of people can access it.

India's children population aged below 14 years of age is 37.71 crore urban areas (Government, 2018). It is vital to understand the relation between child development and child's behaviour in their corresponding surroundings like open spaces (Aziz & Said, 2012; Christensen & O'Brien, 2003) in countries like India where urbanization is rapidly densifying and increasing and how it impacts children's day-to-day play environments.

The study has been done to understand the perception of open spaces from children and their parent's point of view. Children's play participation is dependent on the perceptions which evaluates benefits and risks from elements present in the open spaces. The study also finds the association of the benefits and risks with the open space characteristics.

Study area and methodology

The study was carried out in the city of Pune, Maharashtra, India (Figure 2). Pune is one of the top 10 urbanized cities in India, with fast growing and expanding boundaries. India being second most populated country in the world, and about 3 lakh children below the age of 6 years live in Pune alone (Government, 2011).

Pune is constantly transforming as old properties are getting redeveloped and the density is growing drastically. The case of Pune is a representative case of metro cities in India where the open spaces around the children are getting compromised in their size and quality.

The study has been done across the city by selecting children using Random Stratified cluster from five zones, i.e. North-West, North-East, South-West, South-East and Central (Figure 3). The parents, whose children aged between 6 and –12 years, were approached and were presented

Figure 2. Map of India (Source: Standard 10 Geography book by Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune.)

the schedule. Questionnaire schedule for 90 parents and face to face interviews with 90 children were conducted.

The questionnaire schedule was presented to the parents in which they had to select appropriate choices. The schedule had three different sections: the first section enquired about the demographic details of their child, standard in which their child is studying. Second section enquired about the open space visited by the child in his/her day-to-day including spaces like terrace or garden in and/or around their house and open space that the child visits outside the house. Out of six options, which were derived from the literature and exploratory survey, parents had to select only one frequently visited space. Questions regarding the distance of the open space and accompaniment were asked to understand mobility and time spent in the open space would tell us about how much free time the children would get for outdoor participation. The parents had to choose the type of elements present in that open spaces and the type of activities their child there. The elements would determine the physical characteristics of open spaces. If the open space child

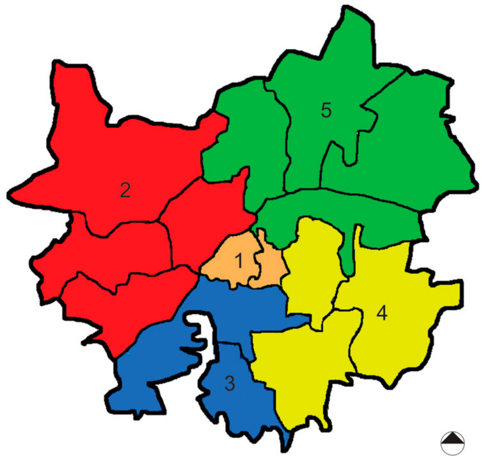


Figure 3. Map of City of Pune indicating broad clusters of sampling (Source: Pune Municipal Corporation).

frequently visited was away from home and the child had to travel to that place, the set of questions about lighting, surface quality, traffic, safety, cleanliness would help determine the perception of parents about the route. Next question enquired about variety of landscape elements, maintenance and quality of the landscape setting, lighting, and adequacy of play space and safety and security of that open space.

The third section was about the rating about the perception of their child's participation in open space for playing which enquired about how it is contributing/affecting in gaining benefits. The next set enquired about risky perception which may discourage parents from sending their child to play outdoors. The rating questions were asked with a five-point Likert scale from 'very much' to 'not at all'. The last section enquired about details about their family like number of members and specifically children in the house and lastly about parent's demographics.

After seeking permission from the parents, their children were requested to sketch two scenarios. Drawing as a medium to express outdoor environments has been used as a tool to interact with children in alike researches. Drawing is known to the children and this activity provides another language of communicating (Merewether & Fleet, 2014). The first scenario sketch was asked to show elements that they find around their day-to-day outdoor play spaces that make them feel happy and playful and the other situation sketch was about elements which make them feel scared and/or has harmed them from their day-to-day outdoor play spaces. These sketches were collected on white paper and were made to be sketched with pencil only to save on time. The time given for sketching was limited to half an hour so the children can give their first impressions which they can immediately think off. After the sketches were done, the children were asked to describe their sketches where they indicated by drawing the elements directly or any incident related to the elements in the open spaces. The notes were taken during the interviews, which further were converted into coding list.

Analysis of the data – thematic presentation

Parent's perception data analysis

Different open spaces that children visited for their day-to-day playing were identified through literature survey and further ratified through a pilot study. Six types of open spaces found in and around the residential areas were (Figure 4): (1) Public Garden which are developed by the government for a neighbourhood; (2) Parking spaces, usually open spaces in and around residences that may be found

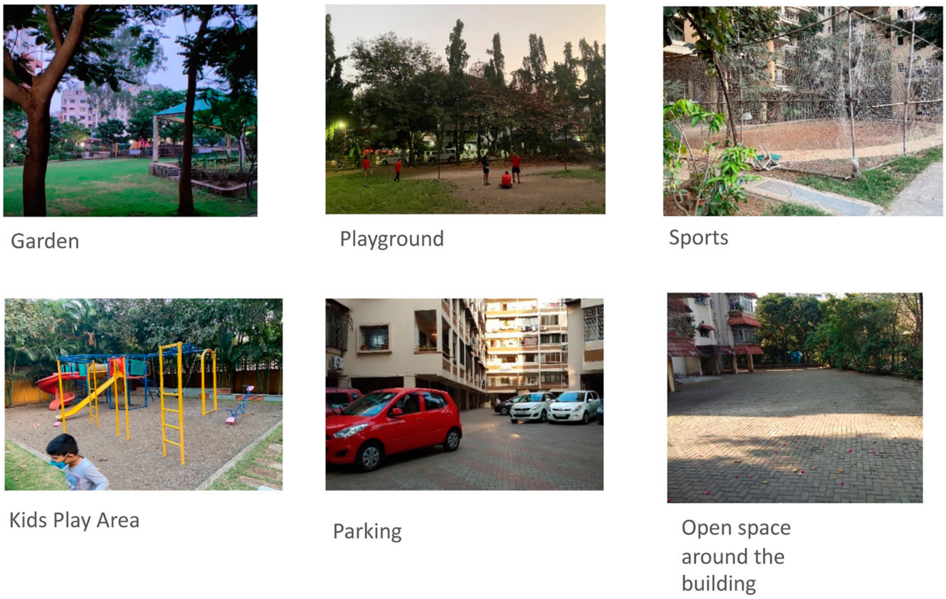


Figure 4. Types of open spaces and open spaces used by children (photos taken by author for the study).

in and out of the premise of the residence; (3) Playground, open maidans which specifically have only open space for sports activities and may or may not have children's play area like slides, swings, etc.; (4) Sports area, open spaces dedicated for sports activities only, primarily having entry only for those enrolled and mostly used for organized sports activities; (5) Kids play area, space which has swings, slides, jungle gyms, sand pit, etc.; (6) Open space around the building, not defined by function as the space may have multiple functions live internal road, parking areas, set back with landscape, etc. The photos in 'Figure 4' show different types open spaces and percentage of children visiting these types of open spaces. Amongst the sample population ($N = 90$), about 42% children played 'around the building', followed by 17% of 'playground' and 14% visiting public gardens (refer Table 1).

While looking at the time spent by the children in playing outdoors, it was observed that more than 50% of children spend between 1 and –2 h and 33% of the children spent more than 2 h playing outdoors.

About 66% of children mostly play in open spaces which are in and around their residence and about 20% travel about 100 m from their residence to open space play visitation. Relatively fewer children travel more than 100 m from their residence for open space play visitation.

Perception of benefits: The factor analysis of benefits (Table 2) showed three common groups as Social Benefits, Physical Benefits, and Emotional Benefits. The first one was the *Social Benefits* group comprising of peer bonding, group activities, being social as a part of the group. All these aspects suggest that when child has friends to play with itself makes the child more socially active. The second, *Physical Benefits* group comprising of active lifestyle, physical strength and being fit as a

Table 1. Type of open spaces around residences and number of children using them in percentage.

Sr. No.	Type of open space around the residences	Children's visitation (in %)
1	Garden	9
2	Playground	17
3	Sports area	9
4	Kids play area	14
5	Parking	9
6	Around the building	42

Table 2. Factor analysis benefits.

Benefits	1	2	3	
Benefits_Peer Bond	0.895			Social benefits
Benefits_Grp Activities	0.830			
Benefits_Social	0.815			
Benefits_confidence	0.707	0.435		
Benefits_Responsible	0.657			
Benefits_Active Lfstyle		0.797		Physical benefits
Benefits_Nature Conn		0.739		
Benefits_Phy Strength		0.739		
Benefits_happiness	0.439	0.681		
Benefits_Being fit		0.569	0.455	
Benefits_Risk Taking			0.737	Psychological benefits
Benefits_Conscious of Surr			0.675	

Note: column heads "Rotated component matrix" spanning all; "Components" spanning 1–3.

part of the group. And the last group, *Emotional Benefits* comprised of risk taking ability and being conscious about surrounding which suggests that participating in the independent open space activities increases.

Perception of Risk: The risk perception of the parents regarding their child's open space participation showed three groups (Table 3) heading Route Characteristics, Unkempt Landscape Aspects, and Injurious Elements. The *Route Characteristics* included crowding, distance of open space from home, traffic on the road, fear of child getting lost, and anti-social elements. The *Unkempt Landscape Aspects* included bad surface where the chid is playing, poor lighting or darkness, unkempt facilities like broken play equipment, unclean surroundings, etc. and stray animals. The third group *Injurious Landscape Elements* included Wild Plants, Unclean open space and Dangerous elements like electric poles, etc. The route characteristics were primary group of concern considered as risky by the parents. This is followed by Unkempt Landscape aspects and Injurious Landscape elements in that order.

Children's sketches

A coding system was implemented where the elements making a happy impact were listed under 'Positive Aspect' and the elements which made a scary impact were listed as 'Negative Aspect'. These aspects were further clubbed to broad categories. The Positive Aspects included Animals, Lawn and Vegetation (including all nature related indications), Hard scape (including play courts, play grounds, streets, etc.), Amenities (seating spaces, water elements, covered spaces), Safety

Table 3. Factor analysis of risks.

RISKS	1	2	3	
Risk_Crowding	0.890			Route characteristics
Risk_OS Distance	0.855			
Risk_Traffic	0.773			
Risk_Getting Lost	0.744			
Risk_Anti Social	0.653	0.589		
Risk_Bad Surface		0.785		Unkempt landscape aspects
Risk_Poor lighting		0.754		
Risk_Unkempt facilities		0.727	0.442	
Risk_Stray Animals	0.522	0.554		
Risk_Wild plants			0.856	Injurious landscape elements
Risk_Unclean OS			0.826	
Risk_Dangerous Elements	0.431		0.624	

Table 4. Coding and categorizing children's sketches of positive aspects and their frequency of responses in percentage.

Children's sketches indicating *Positive Aspects*	Broad categories of *Positive Aspect*	Response frequency in %
Animals	Animals	6
Lawn and Vegetation	Lawn and Vegetation	19
Free space	Hard scape surfaces	46
Parking area		
Play court		
Playground		
Slope		
Street		
Surface		
Level Difference		
Paved areas		
Covered spaces	Amenities	6
Seating Space		
Tracks		
Water elements		
Surveillance	Safety	2
Fencing		
Peer bonding	Social	5
Play Equipments	Play Equipments	16

(surveillance, fencing), Social (friends, peers) and Play equipment. The Negative aspects included Anti-Social (strangers, bullying people), Maintenance (unclean, unkempt facilities, etc.), injurious elements (service poles, stray animals, etc.), Space adequacy (crowded, lack of space, etc.), Traffic (parking, speeding vehicles), Poor Lighting (darkness).

The positive aspects identified from the likes of elements in the open spaces frequented *Hard Surfaces* suggesting a surface which would allow different types of activities like cycling, sports, etc. as most appreciated, for playing. The second most frequented was *Lawns and Vegetation* suggesting the presence of trees, shrubs, green patches, etc. suggesting nature connectedness. Most free play was denoted around these elements. The third most frequented aspect was *Play Equipments* suggesting elements allowing activities for playing on swings, slides, etc. was drawn in almost all drawings (as shown in Table 4 and Figure 5).

The negative aspects identified from dislikes of elements in the open spaces were indicated as *Maintenance* drawn through bad surfaces, unclean surroundings, unkempt facilities, water puddles, and growth of wild vegetation. Second aspect was *Injurious Elements* indicated by steep slopes, service elements like open manholes, any electric poles and presence of stray animals like dogs which were scaring children from playing. The presence of heavy *Traffic and Parking* of Vehicles was another indicating aspect which suggested fear in children's outdoor participation (as shown in Table 5 and Figure 6).

Figure 5. Children's sketches of positive aspects.

Table 5. Coding and categorizing children's sketches of negative aspects and their frequency of responses in percentage.

Children's sketches indicating *Negative Aspects*	Broad categories of *Negative Aspect*	Response frequency in %
Anti social elements	Anti social aspects	16
No surveillance		
Stranger		
Surface	Maintenance	39
Unclean		
Unkept facilities		
Water elements		
Wild vegetation		
Slope	Injurious Elements	19
service elements		
Stray animals		
Crowded	Space Inadequacy	3
Lack of play space		
Level difference		
Traffic	Traffic	17
Parking area		
Poor lighting	Poor lighting	6

Discussion

The children are observed to play around their residence like open space within the compound, gardens, parking spaces, and playground. The knowledge that the children gather by participating in these outdoor play spaces contributes to their social, physical, and psychological development through aspects like peer bonding, physically challenging activities, and assuring confidence by continuous participation in various activities. A new knowledge is constructed with these experiences thus motivating children for day-to-day visitation to open spaces.

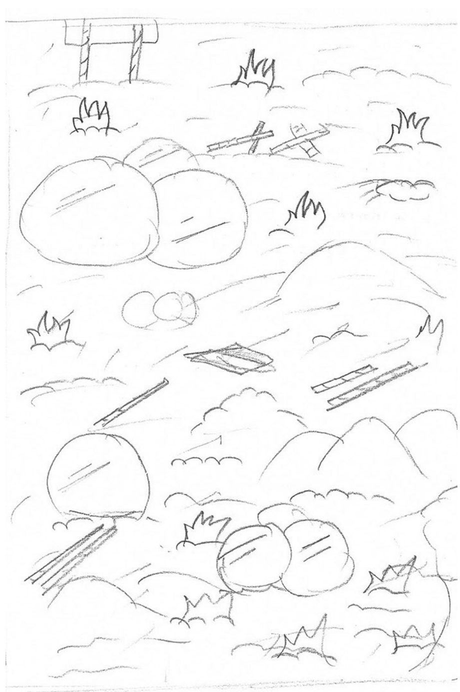


Figure 6. Children's sketches of negative aspects.

Parent's perception about participation in open spaces showed that their children gain perceived benefits from social aspects more than physical aspects. Having accompaniment to participate in open space was ranked high and was perceived as a strong motivation for children's outdoor participation. Whereas for children social aspect was ranked low at only 5%. The most important aspect from children's perspective is having hard scape surface which allows children to play any kind of activities. Hard surfaces like internal roads, streets, and open parking spaces around the building were most commonly used spaces for playing. Hard surfaces seem to be to play activities which give good grip to run, jump, play ball games, do cycling and play on wave/skateboards. The hardness of the surface gives good gripe and toughness increasing required physical agility, balance, composure thus building confidence to participate in activities. The second aspect which is highlighted in children's sketches was 'lawn and vegetation' which includes trees, shrubs, and lawns. Children indicated passive activities and object playing on the lawns and around trees and shrubs.

The physical activities add benefits to the physical wellbeing of the children. Parent's perception next most important aspect indicates that physical wellbeing of their child is benefited through open space activity participation. The outdoors allow more space, variability of surfaces and facilities, and much more qualities to do activities that exerts physical strain, thus contributing to physical wellbeing. Nature connectedness and being happy are also associated with Physical benefits as perceived by the parents.

The most frequented response for play space elements were green areas like lawns, vegetation, kids play area, playground, and free play space around the building comprising of internal road, set-backs, etc.

The independent mobility range was found to be wider as per increasing age, but still it would be in surveillance range of family and friends. The type of facilities available in the surrounding open space did not restrict children from playing in open spaces. If nothing, they would play informal games in which just a space which is open enough to run around to play games like catch–catch, hide and seek, etc. If the available space was wide enough, the children were found to play cricket, cycling, badminton, etc. Play equipments were not found to be a necessity for play, but parents surely made a point of suggesting having a variety of play space in the walking range for better play experiences.

Fear of strangers, stray animals, fast-moving vehicles, and fear of empty/quiet roads are perceived risks stated by parents. Few parents stated perceived risks of bad company and fear of dark spaces as two major concerns. Although traffic is most highlighted as risk aspect by both children and parents, children would manage to find a spot with less vehicular movement and would play in those spaces. To get accustomed to the fear of traffic, children were found to travel in groups. This would give them sense of a team and safety. Older children above the age of 11 years were allowed to travel a relatively larger distance with prior knowledge of traffic rules. In denser areas, like old city, children would travel wider range of distance. Living in dense areas, made children more use to seeing people and traffic, making children more accustomed and adjusting to surrounding scenarios. On the contrary, children till the age of 12 years and below, living in gated communities like bungalow society and/or apartment were always accompanied by elders out of their premise. Denser areas played a vital role in children's understanding of their surroundings, their conscious of what is around them, and making decisions based on the same.

Maintenance and quality of elements in the open space was another aspect in which parents and children raised their concerns unanimously. Risk with respect to physical injury was highlighted if lawns were not mowed, benches or flooring were broken, wires were left to be dangling or open, presence of debris, etc. The unkempt facilities would restrict children's active participation in the outdoor play spaces sometimes by their choice or even by restriction of parental license.

The presence of vegetation was observed more, wherever the risk aspects were less highlighted. This suggests that the presence of vegetation makes children and parents more comfortable with the play spaces that children visited. The presence of lawns, trees and/or shrubs lined on the edge of spaces defined the playing area. It not only defined a visual boundary but also made parents feel more secured about that space. This positive impact of the presence of vegetation is well versed in the literature.

Lighting was another aspect that related to benefits if lighting in the play space was good and to risks if the space was dark or badly lit.

Risk factors are relatively easy to identify through physical characteristics. It is rather challenging to identify characteristics that offer benefits. By using the Push–Pull theory (Mohamed & Abdul-Talib, 2020), the study is categorising the beneficial aspects as Push and Pull factors. The PUSH factor in the study can be found in aspects like social motivators which include friends and the activities that are played in groups. Other Push factor is the affordance the space offers. The presence of surface and space which allows to do various activities is a major incentive that Pushes children from their home to step out and play outdoors. The Pull factors can be defined as retainers which motivate children to keep visiting the day-to-day open spaces for their play. With nature in form of trees, lawns and other vegetation children have called them as 'refreshing' and also indicated as 'feel comfortable' to play around it. Literature suggests the association of nature and comfort for people's participation and the study indicates it as one of the Pull factors. Another retainer is the presence of Play Equipments. Children of about 6–8 years have shown play equipments in their drawings more than children above that age group. According to Piaget, the children till age of 8 years are 'egocentric' suggesting that they are still exploring play and playing in group is a little difficult for them (Ginsburg & Opper, 1988). This was seen in the study that Play equipments can be used by themselves and children don't necessarily need company to play in that zone. The older children's drawings show more group activities and less of play equipments. They are playing sports like football, cricket and badminton. Here the study indicates that the social aspect is both push and pull factor for children's outdoor play participation.

Although the environment is perceived negatively or positively, the children have found to be happy playing outdoors if more social benefits are available. Having friends around is most important and which also suggest like presence other affordances is not necessary all the time for children to go out and play. With the availability of facilities, the variability of playing/activity scenarios increases and hence motivation to play in the same space is positive. According to parents, the places which offer high benefits, more variability, more social benefits suggest a positive impact on their child's physical, social, and psychological development, adding to their physical well-being, socially active and making them more confident.

Conclusion

This study aimed to understand children's play space and independent mobility range with perceived risks and benefits about day-to-day play spaces in outdoors. The walk-along interviews with children showed their creative use of the outdoor space. Even though the case of informal neighbourhood lacked in quality and availability of facilities, the positive social qualities (Chauvla, 2016) like integrated community and availability of other children to play were two primary reasons of children's outdoor experience satisfaction.

One does observe the difference in perception between parents and children, especially the risk perception. Children define environment on mobility range which is sometimes not acceptable to the parents thus affecting parental licence. The analysis of data suggests that parenta licence is dependent on overcrowding and high vehicular traffic, which reflects in their fear about child's safety. The urban level policy needs to review for possible decluttering of vehicular traffic and crowding. One of ways to improvise is, by reworking on vehicular movements within neighbourhood. Thorough traffic should be diverted away from neighbourhood which may positively impact on sense of safety and comfort in parents and children and thus increasing the play range and independent mobility range. The urban design policy and planning need to cater to needs of the children of outdoor play spaces. Outdoor play spaces which are easily accessible, secured, ergonomically usable, well maintained, etc. are the rights of the children.

Neighbourhood with multi-storeyed buildings which are visually disconnected with the open spaces from their homes made surveillance difficult. Here, despite availability of open spaces, the perceived risk was discouraging factor to allow child to play.

The motivation to participate in outdoor activities is strongly associated with social and physical characteristics of the open space. The participation is encouraged only with positive experiences which are built upon perceptions which may be good or bad. Good perceptions are always encouraging, but participation in activities with risk perception may have a setback. Most often it is observed that risk factor is challenged and faced again and again to build upon the confidence of using the space in continuity.

The research gives pointers urban designers, planners, and government agencies to make amends in policies for in the neighbourhoods to accommodate perceptions of children and parents hence making child-friendly neighbourhoods and cities.

Acknowledgements

The authors of this paper would like to thank all the participating parents and children who gave valuable time for interview and sharing their experience of the open spaces around their residence.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Dhruv Chandwania is Associate professor at Dr. B.N. College of Architecture, Pune. He is a PhD scholar, registered in 2018 under the able guidance of Dr. Abhijit Natu from Savitribai Phule Pune University. He pursued B.Arch from M.M. College of Architecture, Pune in 2005 and after which in 2007 he went to Pratt Institute, New York to pursue MS in Architecture. He has 3 papers published at National and International conferences on various topics of Architecture.

Dr. Abhijit Natu graduated from the BKPS College of Architecture, Pune in 1992. He completed Masters in Landscape Architecture from SPA Delhi. After five years of architectural and landscape design practice he joined the BKPS College of Architecture Pune in 1998 as full time teacher. He received the QIP scholarship from the Central Government to pursue PhD and completed PhD in 2008 from the JNT University, Hyderabad. His research interests include environment behaviour, landscape architecture and architectural conservation. He is presently the Chairman Board of Studies in Architecture and Member of academic council at the Savitribai Phule Pune University. He was awarded the Best Teachers Award by the Pune University in 2010. He is a PhD guide at the University and 6 scholars have been awarded PhD under his guidance and 5 more are currently working under him. More than 30 research papers and articles published in National as well as International Journals. He has coordinated and conducted teachers training programs and workshops for the AICTE, COA, University and the Indian Society for Landscape Architects. He is a member of the Education board of ISOLA. He has been appointed on the Board of Reviewers of the Journal of the Indian Institute of Architects.

References

Aziz, N. F., & Said, I. (2012). The trends and influential factors of children's use of outdoor environments: A review. *Procedia-Social and Behavioral Sciences*, *38*, 204–212. doi:10.1016/j.sbspro.2012.03.341

Bento, G., & Dias, G. (2017). The importance of outdoor play for young children's healthy development. *Porto Biomedical Journal*, *2*(5), 157–160. doi:10.1016/j.pbj.2017.03.003

Bhan, R. (2006). Designing Play Environment Journal of the Indian Institute of Architects.

Bourke, J. (2017). Children's experiences of their everyday walks through a complex urban landscape of belonging. *Children's Geographies*, *15*(1), 93–106. doi:10.1080/14733285.2016.1192582

Bronfenbrenner, U. (1979). *The ecology of human development*. Cambridge, MA: Harvard University Press.
Brooks, T., & Sorin, R. (2011). "All the places I've been to [in the tropics] are not really a special place": Investigating children's place attachments through collage and stories. *Etropic: Electronic Journal of Studies in the Tropics*, *10*, 119–130. doi:10.25120/etropic.10.0.2011.3413
Chaudhury, M., Hinckson, E., Badland, H., & Oliver, M. (2019). Children's independence and affordances experienced in the context of public open spaces: A study of diverse inner-city and suburban neighbourhoods in Auckland, New Zealand. *Children's Geographies*, *17*(1), 49–63. doi:10.1080/14733285.2017.1390546
Chaudhury, M., Oliver, M., Badland, H. M., & Mavoa, S. (2015). Public open spaces, children's independent mobility. *Play, Recreation, Health and Well Being, Geographies of Children and Young People*, *9*, 315–335.
Chauvla, L.. (2016). *Growing Up in an Urbanizing World* (pp. 219).
Chawla, L. (1992). Childhood place attachments. In S. Low & I. Altman (Eds.), *In Place attachment* (pp. 63–86). Boston, MA: Springer.
Christensen, P., & O'Brien, M. (2003). *Children in the city. Home neighbourhood and community*. Routledge.
Cooper, A. (2015). Nature and the outdoor learning environment: The forgotten resource in early childhood education. *International Journal of Early Childhood Environmental Education*.
Croucher, K., Myers, L., Jones, R., & Ellaway, A. (2007). Health and the physical characteristics of neighbourhoods: A critical literature review.
Dunnett, N., Swanwick, C., & Woolley, H. (2002). *Improving urban parks, play areas and Green spaces*. London: Department for Transport, Local Government and the Regions.
Ferguson, K. T., Cassells, R. C., MacAllister, J. W., & Evans, G. W. (2013). The physical environment and child development: An international review. *International Journal of Psychology*, *48*(4), 437–468. doi:10.1080/00207594.2013.804190
Freeman, C., Van Heezik, D. Y., Stein, A., & Hand, K. (2015). *Natural neighbourhoods for city children: Report on research findings*. Dunedin: Department of Geography, University of Otago.
Fyfe, N. (2006). *Images of the street: Planning, identity and control in public space*. London: Routledge.
Gehl, J. (2011). *Life between buildings: Using public space*. Washington, DC: Island Press.
Gibson, J. J. (2014). *The ecological approach to visual perception: classic edition* (1st ed.). New York: Psychology Press.
Ginsburg, H. P., & Opper, S. (1988). *Piaget's theory of intellectual development*. Chevy Chase, MD: Prentice-Hall, Inc.
Giusti, M., Svane, U., Raymond, C. M., & Beery, T. H. (2018). A framework to assess where and how children connect to nature. *Frontiers in Psychology*, *8*, 1–20. doi:10.3389/fpsyg.2017.02283
Government, I. (2011). Census 2011.
Government, I. (2018). *Children in India, 2018*. New Delhi: Government of India.
Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: Views from urban planning. *American Journal of Preventive Medicine*, *23*(2), 64–73. doi:10.1016/S0749-3797(02)00475-0
Hart, R. (1979). Children's experience of place: Irvington.
Humpel, N., Owen, N., & Leslie, E. (2002). Environmental factors associated with adults' participation in physical activity: A review. *American Journal of Preventive Medicine*, *22*(3), 188–199. doi:10.1016/S0749-3797(01)00426-3
Kaplan, R., & Kaplan, S. (1989). *The experience of nature. A psychological perspective*. CUP Archive.
Kuo, F. E., Bacaicoa, M., & Sullivan, W. C. (1998). Transforming inner-city landscapes: Trees, sense of safety, and preference. *Environment and Behavior*, *30*(1), 28–59. doi:10.1177/0013916598301002
Kyttä, M. (2003). Children in outdoor contexts. Affordances and independent mobility in the assessment of environmental child friendliness.
Lestan, K. A., Eržen, I., & Golobič, M. (2014). The role of open space in urban neighbourhoods for health-related lifestyle. *International Journal of Environmental Research and Public Health*, *11*(6), 6547–6570. doi:10.3390/ijerph110606547
Merewether, J., & Fleet, A. (2014). Seeking children's perspectives: A respectful layered research approach. *Early Child Development and Care*, *184*, 897–914. doi:10.1080/03004430.2013.829821
Mohamed, M.-A., & Abdul-Talib, A.-N. (2020). Push–pull factors influencing international return migration intentions: A systematic literature review. *Journal of Enterprising Communities: People and Places in the Global Economy*, *14*(2), 234–246.
Natu, A. (2007). *Exploring the association between the physical characterisitics and use of formal community open spaces in urban residentail developments (Ph.D.)*.
Nunes, D. V., & Vale, D. S. (2015). *Physical characteristics that influence urban design qualities of Livable and walkable urban places: Lessons from Portuguese cities*. Paper presented at the 52nd International making cities livable conference.
Obee, P., Sandseter, E. B. H., & Harper, N. J. (2020). Children's use of environmental features affording risky play in early childhood education and care. *Early Child Development and Care*, *Latest article*, 1–19. doi:10.1080/03004430.2020.1726904
Othman, S., & Said, I. (2012). Affordances of cul-de-sac in urban neighborhoods as play spaces for middle childhood children. *Procedia-Social and Behavioral Sciences*, *38*, 184–194. doi:10.1016/j.sbspro.2012.03.339
Pitsikali, A., & Parnell, R. (2019). The public playground paradox:'child's joy'or heterotopia of fear? *Children's Geographies*, *17*(6), 719–731. doi:10.1080/14733285.2019.1605046
Ramezani, S., & Said, I. (2009). Children's perception of place friendliness in an urban neighborhood in Shiraz, Iran.
Said, I. (2007). Architecture for children: Understanding children perception towards built environment.

Salama, A. M., & Azzali, S. (2015). Examining attributes of urban open spaces in Doha. *Proceedings of the Institution of Civil Engineers Urban Design and Planning*, *168*(2), 75–87. doi:10.1680/udap.14.00011
Shabak, M., Norouzi, N., Abdullah, A. M., & Khan, T. H. (2015). Children's sense of attachment to the residential common open space. *Procedia Social and Behavioral Sciences*, *201*, 39–48. doi:10.1016/j.sbspro.2015.08.117
Sjöberg, L., Moen, B.-E., & Rundmo, T. (2004). Explaining risk perception. *An evaluation of the psychometric paradigm in risk perception research*, *10*(2), 665–612.
Slaghekke, J. (2017). *Learning outdoors benefits – Risks*. Nature Play, South Australia: Government of South Australia.
Tyagi, M., & Raheja, G. (2020). Indian parents' perception of children's independent mobility in urban neighbourhoods: A case study of Delhi. *Children's Geographies*, *19*(2), 390–406.
Veitch, J., Salmon, J., & Ball, K. (2007). Children's perceptions of the use of public open spaces for active free-play. *Children's Geographies*, *5*(4), 409–422. doi:10.1080/14733280701631874
Villanueva, K., Badland, H., Kvalsvig, A., O'Connor, M., Christian, H., Woolcock, G., … Goldfeld, S. (2016). Can the neighborhood built environment make a difference in children's development? Building the research agenda to create evidence for place-based children's policy. *Academic Pediatrics*, *16*(1), 10–19. doi:10.1016/j.acap.2015.09.006
Woolley, H. (2003). *Urban open spaces*. London: Taylor & Francis.
Wridt, P. (2010). A qualitative GIS approach to mapping urban neighborhoods with children to promote physical activity and child-friendly community planning. *Environment and Planning B: Planning and Design*, *37*(1), 129–147. doi:10.1068/b35002
Zhang, H., & Li, M.-J. (2012). Environmental characteristics for children's activities in the neighborhood. *Procedia Social and Behavioral Sciences*, *38*, 23–30. doi:10.1016/j.sbspro.2012.03.320

ugccare.unipune.ac.in/Apps1/User/WebA/SearchList

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**Shodh Sanchar**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	Shodh Sanchar Bulletin (print only)	Shodh Sanchar Educational and Research Foundation	2229-3620	NA	from September-2019 to April- 2021	Discontinued from April 2021

Showing 1 to 1 of 1 entries

Previous 1 Next

ISSN - 2229-3620
UGC CARE LISTED JOURNAL
LIS

SHODH SANCHAR Bulletin

January-March, 2021
Vol. 11, Issue 41
Page Nos. 280-284

AN INTERNATIONAL BILINGUAL PEER REVIEWED REFEREED RESEARCH JOURNAL

VERNACULAR BUILDING MATERIALS AND FUTURE ECO MATERIALS OF EAST INDIA

Prof. Pradnya Patki*
Prof. Neha Joshi**

ABSTRACT

Vernacular architecture is a term used to categorize methods of construction which use locally available resources and traditions to address local needs and circumstances. Vernacular architecture tends to evolve over time to reflect the environmental, cultural and historical context in which it exists. It has often been dismissed as crude and unrefined, but also has proponents who highlight its importance in current design. With the current market moving rapidly towards globalized building materials and technology are energy intensive with high carbon footprint. Vernacular building materials have the capacity to offset this energy consumption. India has varied climate and each climatic zone has its climate responsive vernacular building materials. It is important that these materials are identified and brought into the main stream industry. The aim of the paper is to study different vernacular building materials in Eastern region of India. The objectives are to study present and earlier used vernacular materials. To study the potential future eco materials that can be used which are context and region specific. To study advantages and limitations of the same. The proposed outcome is to suggest materials which can be derived from the region but have advantages to be applied in the present scenario.

Keywords : locally available, traditions, evolve, globalized, context, region specific.

1. Introduction

Vernacular architecture is the native science of building which is spontaneous, environment-oriented, and community-based and applies to both local styles and local materials.

Characteristics of vernacular architecture are that these are Traditional technologies built to meet specific needs, accommodating the values, economies and way of life of the cultures that produce them. Each community over the years develops a prototype-responds to local needs and carries it forward through generations. Thatch, Straw, timber, Palm tree trunk, Bamboo, Wattle, *Khapraels*, Cement, Compressed earth blocks, Fiber cement tiles are few of the list of vernacular materials used for roof, wall columns in eastern India. Case examples of few materials are elaborated in the paper.

2. Method

The method used is case study analysis. Different materials are studied from regions in East India. The areas studied are Jharkhand, Chattisgarh, West Bengal, Orissa and Assam. The materials are studied for roof and walls majorly. Presently used, and future materials which can be widely used are studied. Application of these in the residential buildings for different building components like walling, roof, columns, screens, beams etc. is explored.

3. Case studies of vernacular materials

Bamboo- Toda hut is a shape-half cylinder made of wooden planks, bamboo, reeds and grass arch-frames are made of long bunches of bamboo splits, lashed together by a spiral of cane or bamboo splits called Thef. Horizontal roofs framed with palm tree's trunk, bamboo,

*Bharatiya Kala Prasarini Sabha's College of Architecture, Savitribai Phule Pune University, Pune, Maharashtra, India.
**MKSSS'S Dr. Bhanuben Nanavati College of Architecture, Savitribai Phule Pune University, Pune, Maharashtra, India.

trunks of palm tree, hay and earth, supported with bamboo & plastered with clay helpful for heat resistance and storage. Whole & split bamboo exhibits resilience & flexibility in various forms.

Case study-houses in Nagaland- Floor is earth and raised, normally located at the front where the rice plunder is kept; the living quarters are raised and extend to a platform at the rear where tasks such as weaving are performed. *Lhota*, cover the raised floor with woven bamboo slats and mats. Simple layout, barn-like double-pitched roof, plain gable end fortified, stone walls, bamboo spikes, wooden gates, perimeter ditch

Fig 1: Toda Hut

Fig 2: Bangla house

Case study Jharkhand huts- Jharkhand houses have roofing structure of gabled thatched roofs with bamboo mullions & posts. The thick thatch roofs prevents rain from entering the house & provides insulation. Chhatisgarh house called as *jhopri* (hut met) or *haveli* (mansion) is made up of timber, bamboo, clay, straw, cow-dung, special variety of grass. The roof is mainly made of bamboo hay and "*khapraels*", tiles, mud etc. The huts are made of mud walls & thatch roofs. The mud is obtained by souring earth by adding vegetable waste and leaving it to mature. The decaying waste improves the plasticity. This mud is mixed is mixed with cow dung, chopped straw and gravel or stones to make the raw materials for the walls. The walls were formed by applying thick coat of the mixture on both sides of bamboo mesh that wrapped around the posts. Brick-bat coba and lime mortar are the key materials used for constructing high thermal mass walls. Kovar Wall paintings- After a wall is plastered with mud, a coat of black earth or *kalimiti* is applied on it and left to dry. Once dried, it is covered with either white or yellow mud coat. Before the upper coat is dry, it is scrapped. Which reveals a black undercoat, depicting patterns and designs. Cow dung is used to finish walls, floor.

Traditional Assam house-It is a fully wooden structure. Walls are made with timber frame work with panels (*ikara*) cut in size & laid vertically with 3 layers of plaster-mud mortar. Finished coat is of liquid mix of mud and cow dung. Horizontal members are in bamboo. Roof is in corrugated iron sheet fixed in timber purlin by nail. Ceiling is supported by vertical wooden members/steel column. From finished floor level the walls are of half brick thick brick walls up to a ht. 60 cm

***Bunglas* of West Bengal** are traditional Bengali dwelling provided a model for the British bungalow *bangla*.Technology adopted is frame bamboo/ wood posts and beams. The thatched roof generally extended beyond the walls to provide additional shelter from the rains and one side of the roof was often extended four of five feet beyond the wall and supported by a row of bamboo poles to create a small verandah.

4. Present eco -materials

Utilization of waste in material making-Red mud is a waste product from aluminum plants. Stabilized Mud Fly Ash Bricks -Compacted mud fly ash blocks stabilised with lime, cement or other chemicals can be easily made. Stone dust -from granite & sandstone from quarries & processing plants. Coal washery rejects -heavier impurities. Siliceous river sediments -from water treatment plants of Palta Calcutta. Rice husk ash can also be used.

Cellular Light Weight Concrete- Cellular Light Weight Concrete (CLC) can be manufactured by a process involving the mixing of fly ash, cement, coarse sand, fine sand and a forming agent in a mixer to form a thin slurry.

Slurry is poured in moulds and allowed to set. Blocks are removed and cured by spraying water on the stack. Useful in high rise construction reducing the dead weight of the structure. Honeycomb clay block Used both as the inner leaf in cavity walls or as a single skin for external load-bearing construction. The blocks are formed with a cellular structure of vertical perforations that reduces the material quantity as well as weight whilst providing an increased thermal performance. Blocks are assembled through dry vertical interlocking and thin-mortar horizontal jointing.

Advantages are that it has good insulating properties, recyclable, reusable if dismantled carefully, particularly if lime mortar has been used, lower embodied energy than concrete blocks, enables rapid construction when using experienced block layers

Unfired clay block-Uncommon in modern construction despite their excellent environmental credentials. Though limited to non-load-bearing applications, unfired clay blocks are suitable for internal partitions and infill to framed construction. Advantages are that it has very low embodied energy, recyclable, biodegradable (returns to soil), high thermal mass, Can be used to stabilise internal humidity and good sound reduction

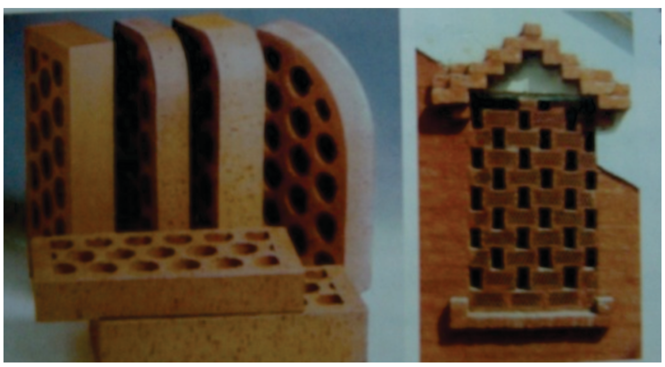


Fig 3: Red mud Stabilized Mud Fly Ash Bricks

Fig 4: Honeycomb clay block

5. Future eco-materials

Ferro-cement-Mixture of Portland cement and sand reinforced with layers of woven steel mesh and closely-spaced small-diameter steel rods. Used in the form of thin curved sheets to make hulls for boats, shell roofs, water tanks, etc. Sculpture and prefabricated building components. Good strength and resistance to impact. Resistance to fire, earthquake, and corrosion than traditional materials, such as wood, adobe and stone masonry.

AAC (autoclaved aerated concrete) blocks- Ideal substitute for traditional clay bricks and hollow concrete blocks used for wall construction made of cement, fly ash, lime, an aeration agent and water. Most suitable for air-conditioned buildings multistoried fire-rated buildings.

Being Light-weight they have high thermal and sound insulation, high fire-resistance

Corrugated bamboo roofing sheets (CBRS)-Excellent alternative to corrugated asbestos, iron, plastic or zinc. Roofing sheets are produced from natural materials and are attractive, durable and resilient to adverse weather conditions and pest attack.

They are environmentally friendly and safe alternative to asbestos, zinc or corrugated iron roofing panels. Quieter in the rain and cooler in the sun than metal roofing panels.

Bagasse boards-Bagasse emerges from sugar factory as a waste and is procured in loose or bale form with 48-50% moisture.

The dried and sized material is mixed with glue binders and is formed in 3 layers, coarse in the middle, fines in top and bottom side and conveyed through caul plates passed through pre-press to consolidate the mat. Then passed on to the hot press and subjected to high pressure with high temperature. These bagasse boards are made at different thicknesses.

The boards are allowed to cure for a day or two and then subjected to sanding to obtain smooth surface and to relieve loose material in the surface and to have uniform thickness of the board.

Water resistant and being hygroscopic material they ensure durability.

Fig 5: Bagasse boards

Fig 6: Agricultural waste

Agricultural waste-Rice husk are solid waste materials with potential for use as building insulation. This board can be formed without use of urea formaldehyde resin or any type of phenol formaldehyde resin which is used in most fiberglass insulation.

Do not use chlorine-base chemicals such as phosgene, propylene chlorohydrins or any ozone - depleting chlorofluorocarbons. Rice husk ash (RHA) and lime can be used as substitute for cement.

Structural components such as the roof, beams, lintels, projection slabs (sunshade), overhead water tank, can also be made with Portland cement, but with 30 % of the required amount replaced by RHA and lime. RHA can be used to produce normal-strength self-consolidating concrete.

with improved hardened properties and durability also. The RHA based sand-cement blocks reduce solar heat transfer.

Coconut husk-The coconut husk is available in large quantities as residue from coconut production. Option for a thermal insulation material. Raw material for making building insulation boards using the hot pressing method of a manufacture process that uses urea formaldehyde resin thus they have a disadvantage in terms of environmental and sustainable issues.

Eco floors made from cow-dung-Cow-dung when sterilized, is entirely odorless and offers some wonderful characteristics for the production of a variety of fiberboard building materials & costs of production are literally dirt-cheap.

The manure essentially replaces the role of sawdust in the production of particle boards, which would cut wood usage as well as posing a creative solution to the huge problem of agricultural waste disposal.

Ecofaebrick- Ecofaebrick, a quality, easily manufactured, low-cost sustainable building material made from cow dung. 20% lighter, but they have a compressive strength 20% stronger than clay bricks and their Production doesn't rely upon devastating quarry mining techniques.

Provide a highly economical solution to a waste problem while helping to curb the destruction of the local environment caused by clay quarries (pictured below). The bricks are made using 75% cow manure and cured in a biogas heating process that reduces the brick factory's co2 emissions significantly over traditional wood fire heat.

Reclaimed bricks-Reusable Durable Negligible embodied energy if sourced locally. No toxic emissions from a manufacturing process Diverts demolition waste from landfill Issues concerning quality assurance

Rammed Earth (RE) and Stabilised Rammed Earth (SRE)-Many of the shortcomings associated with the durability of rammed earth (primarily external surface protection, water resistance, shrinkage and strength) can be averted by the addition of a stabiliser.

Though other forms have been used, the most common stabiliser is cement, which when added typically makes up between 6 or 7% (by volume) of the mix.

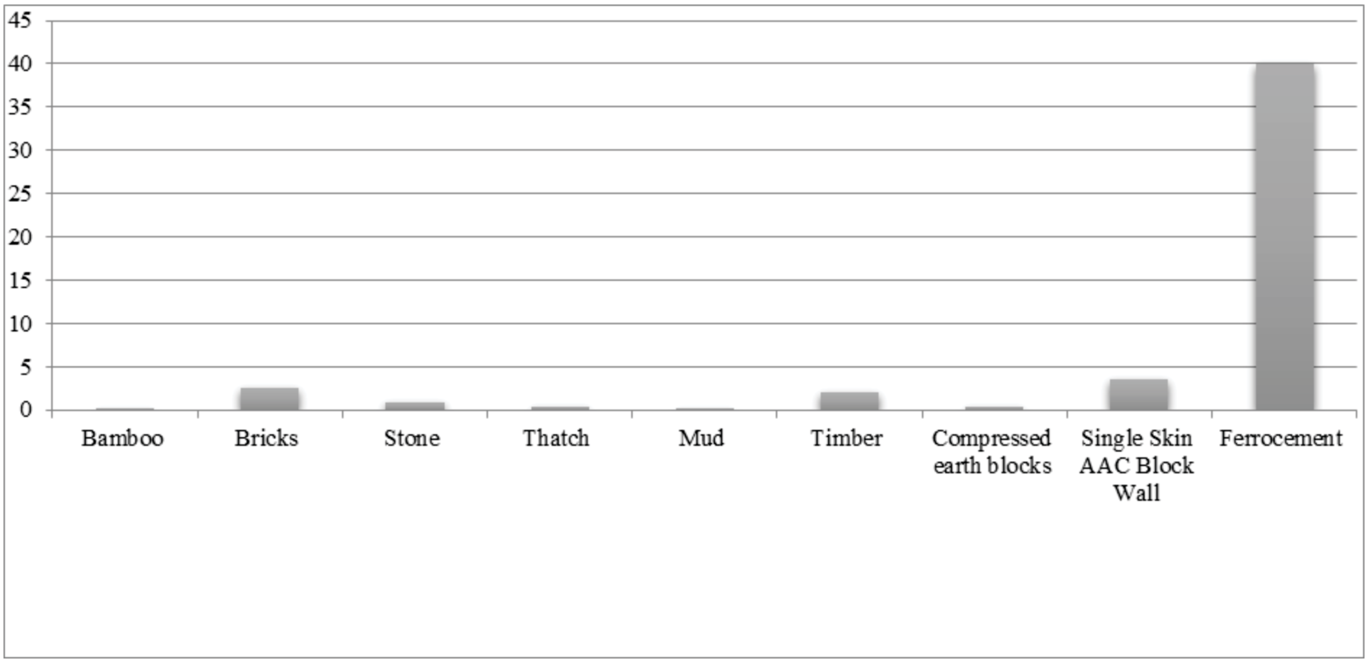


Fig 7: Comparison of embodied energy in MJ/kg

6. Conclusion

Despite being linked to tradition, it could be considered a state-of-art activity, because it offers alternatives to conventional architectural practices that are highly accountable for today's energy crisis. Only 10% of buildings in which we live or work are designed by architects & a huge 90% of world's architecture is vernacular. The analysis provides some recommendations for future design of houses. Vernacular architecture can help in designing an ecofriendly future. Ancient East Indian buildings use the environment, climate responsive design, local & sustainable materials in their design & construction. These building forms embodied an important strategy of environmentally friendly homes: minimal use of energy.

Acknowledgement

The authors are thankful to Ar. Ragini Goswami for providing valuable inputs while working on this paper.

References :

- *Building Materials in India: 50 years,* BMPTC edited by TN Gupta
- *Traditional and Vernacular,* madras craft Foundation
- Http://www.Authorstream.Com/presentation/soumik.Sim-183474-vernacular-architecture-west-bangal-contents-bengal-glance-geography-zonal-classification-according-climatic-conditions-arch-education-ppt-powerpoint
- Http://www.Authorstream.Com/presentation/soumik.Sim-176817-vernacular-architecture-jharkhand-associate-term-local-reular-terms-scope-st-arch-entertainment-ppt-powerpoint

❒❒❒

SAVITRIBAI PHULE PUNE UNIVERSITY

≡ UGC-CARE List

UGC-CARE List

You searched for "**sangeet galaxy**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	Sangeet Galaxy	Sangeet Galaxy Foundation	NA	2319-9695	from July-2021 to Present	View

Showing 1 to 1 of 1 entries

Previous 1 Next

UGC-CARE enlisted & Indexed in the EBSCO International Database of Journals

Exploration of Interrelationship between Music and Architecture

Dr. Sanjeevani Pendse (Assistant Professor)[1]
Dr. Vasudha A. Gokhale (Professor)[2]
B.N. College of Architecture, SPPU Pune
[1]Email: sanjeevani.pendse@bnca.ac.in
[2]Email: gokhale.va@gmail.com

Abstract

Architecture and music share many terms that represent aesthetical quality manifested in music in aural and in architecture in visual form. The Indian craftsman exhibited their constructional skills in connecting architecture with music, while concepts borrowed from Indian music in architectural design are a nascent area of concern. This research analyzes the intrinsic qualities of Indian Classical Music from an architectural perspective. The uses of concepts borrowed from music in creating architecture are discussed. The spatial quality of music and its relationship with architectural form is examined in light of the musical tradition of Gwalior and Jaipur Gharana and the architectural character of historic structures located in the city of Gwalior and Jaipur. The analysis revealed similarities in the aesthetic expression of music and architecture, indicating the potential of Indian classical music to help architects conceptualize an architectural creation.

Keywords: Gharana, firmitas, visual, spatial, shikhara

Introduction:

India is a country with a diverse mixture of tradition and culture. Temples, churches, mosques, and forts are part of Indian Classical architecture, and different art forms like sculpture, painting, literature (style), and music and dance form constitute this tradition and culture. Every medium has developed its rules and regulations sharing the same religious beliefs. The association of spiritual states and symbols and their process was detailed (Vatsyayan K., 1991). Indian classical music is referred to as "ShastriyaSangeet" the Sanskrit word for music is Sangeeta which represents song (Geeta), instrument (Vadya), and dance (Nritya) characterized by a rich, stylized structure containing many musical forms. Music had proved a source of inspiration for architectural development, and many buildings and structures were conceptualized based on musical parameters (Xenakis, 1971). The research shows connections between some musical styles and places, varying in scale from neighbourhoods and cities to the national and multinational or global. It suggests that music plays a very particular and sensual role in producing place partly through its peculiar embodiment of movement and collectivity (Cohen S., 1995). The inspiration for an architectural composition used is music and is termed a "leap vehicle" (Young, Bancroft, & Sanderson, 1993). Music, theatre, visual artwork, and architecture diverse cultures and historical eras possess distinct characteristics and common themes that are represented and revealed with the help of contextual clues within the works of art that need to be interpreted. Architecture and music are two inherently different art forms that rely on an inherently different character. However, if identified, the similarities can provide evidence, and comparisons can be made based on that.

Application of concepts of Music in Architecture:

Historical perspective -

The trace of interrelation between music and architecture is vividly visible in literary sources from ancient times. In the works and philosophy of Roman Imperial architect, Vitruvius the association between music and architecture is seen or understood. In 'De Architecture,' he has written on architecture and mechanics, music theories have much impact. He says that the ratios and proportions found in nature should be applied in the design of musical instruments and structures. Here he has explained an analogy. The volumetric proportions of temples and theatres were such that visual and auditory effects were elevated and augmented.

In the same way, a composer designs the temporal space to create a melody. His description and analysis of temple and theater design were consistently based on applied music theory. The distance between the columns in the temples can be based on the intervals between the tones in the music has also been illustrated. Vitruvius also says that there is a resemblance in musical scales and temple fronts, showing that each temple's analogy and intuitive and aesthetic quality is different (Tayyebi, 2013). The elements of a building are like the different musical units (Enharmonic, Chromatic, and Diatonic), which consists of the primary structural language of the scale as stated in Classical orders (Doric, Ionic, Corinthian) in the Greek period (Walden, 2014).

In the Western context Villa Savoye designed by Le Corbusier, built-in 1929 at Poissy near Paris, resembles a guitar, a musical instrument. The proportions of curved walls and parallel lines match with the instrument. (Figure 1). There is an application of abstract music as a symbol for concrete architecture where the parallel lines evoke a string of notes, and the curved walls are like the shape of a guitar (Imaah N., 2004). In the bays of Notre Dame Paris, a rhythm matches the musical polyphony. There are three levels in the bays, one above the other, and each level is paralleled with a choral voice. (Figure 2)

Figure 1 : Villa Savoye,Paris

Figure 2 : Notre Dame, Paris

The parallel lines of villa savoye match the string of notes of guitar (Imaah N. , 2004) and rhythm in the bays of Notre Dame, Paris shows resemblance with compositions of the composer Perotin in 1240, where the rhythmic phrases were placed one above the other, forming a melody (Jencks, 2013). Research indicated several minarets situated along al Mui'zz el-Din Street, Cairo, inspired by music. Here the optical measurements of the minarets correspond with "Maqam," a set of notes used in Arab music (Riad, 2009), providing them an interesting visual character.

The Indian Precedents:

The spiritual significance of art and science from early ancient Egyptians to Vedas in ancient India was studied by Pythagoras, a mathematician who lived in 580 BCE. The rhythm of harmony and the mathematical law bridge to infinity (Rao R., 2011). In the Indian context, the manifestation of sound is seen in the Mandala of Virabhadra Temple, Keladi in the Shimoga district of Karnataka state. The mandala is a picture of a frozen wave pattern where the wave is depicted to be staying in one place. It is an effort in the medium of art to visualize the concretization of sound vibrations in a two-dimensional representation, depicting a region containing sound waves that are perfectly uniform in distribution (Rao R., 2011). The relationship between music and architecture in the Indian context is visible in many contexts. Musical pillars in Mahamandapam (great-stage) Vithala temple (1422 AD) at Hampi, the world heritage site, are made of granite stone which audible sound when struck with a finger similar to the sound produced by various musical instruments. (Figure 3)

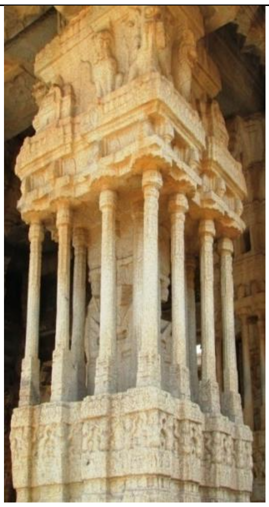


Figure 3 :Vithal temple Hampi

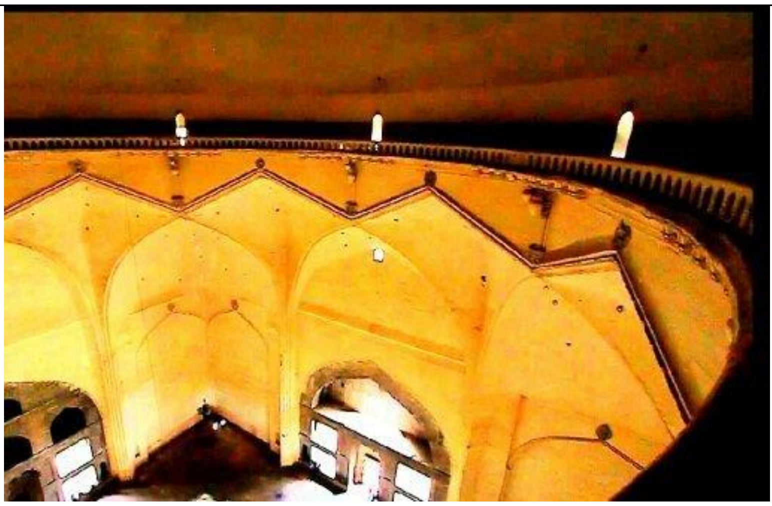


Figure4 : Whispering gallery Golgumbaz, Bijapur.

Suchindram temple Kanyakumari, Meenakshi Temple, Madurai, and Nellaiappar Temple Tamilnadu are other examples of musical pillars (Kumar et al., 2008). The building design for characteristic acoustic performance is exhibited at the mausoleum of Mohammed Adil Shah (1627-55) of the AdilShahi dynasty of Indian sultans named Gol Gumbaj at Bijapur (Figure 4). The structure consists of a colossal dome 43.3 meters in diameter resting on a massive square chamber, making it among one of the giant domes in the world. The construction is acoustically designed so that the slightest sound made at one side of the gallery indie can be clearly heard across the other side.

Aesthetical expression in Music and Architecture:

There are melodic modes in the presentation of Hindustani music where ornaments play a significant role, which helps differentiate the melodic modes with a similar melodic structure (Pratyush, 2010)**.** These are small arrangements done in the presentation of notes to enhance the beauty of the musical piece. To name the ornaments, a glide between two notes, multiple oscillations of a single note, grace note, oscillation between notes, etc. (Pratyush, 2010).

In Indian classical music, the transition space between the notes plays a crucial role along with the sequence of the notes. The gap between the notes is filled by ornamentation, which imparts the aesthetic quality to the music (Ross &Rao, 2012-13). Gamakas alludes to ornamentation utilized as a part of the execution of Indian music. Indian music does not have a settled recurrence for a Swara (note) and can have diverse varieties (developments) around a note, not at all like Western music. The varieties are called Gamakas and can occur in different structures (Figure 5). For instance, it could be a short faltering around a note or a direct move beginning with one note then onto the following. For each raga, just a specific sort of Gamakas (varieties) is permitted 75 round a Swara providing an imperative insight for recognizable proof (Kulmethe&Patil, 2017). About fifteen types of ornamentation are described in the musicological treatises under the generic title of ''*gamak*'' (Rao S. R., 2014). These aspects act as ornaments adding to the aesthetical expression of the composition. A *Meend* is a smooth glide from one note to another touching all the relevant pitches. What pitches are included in a M*eend*depend on the raga. A *Meend*can be sung to a vowel sound, to a syllable of lyric, or to the solfa syllables of the main note(s). The point of a *Meend*is that it includes all the relevant notes in a smooth transition. (Figure 6).

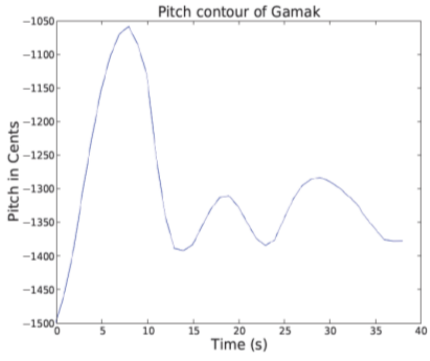


Figure 5. Pitch contour Gamaka(Pratyush, 2010)

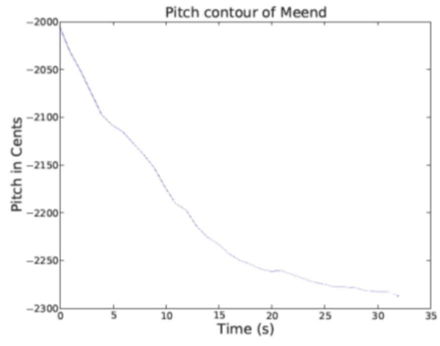


Figure 6. Pitch contour of Meend (Pratyush,2010)

Architectural ornamentation in Indian architecture and the adaptation of aesthetic principles in construction are essential. Hindu temples demonstrate profound use of ornamentation to the interiors and outer surfaces in carvings, sculptures, ornamental pillars, capitals, arches, etc. It includes a wide range of stone reliefs to depict floral, animal, figural, foliated, and geometrical designs. In Mughal architecture, great emphasis is given to the decorations of monumental buildings with various forms of embellishment, including glazed tiling, stone mosaic, inlay works, fresco, mural paintings which render them aesthetically appealing (Gulzar, 2016).

Styles in music and Architecture:

Geographical conditions profoundly influence man's cultural development, and most of the art reflects the influence of the physical environment very patently. However, it is more evident in architecture than other art forms because of its dependency upon the natural surroundings. Location and spatial relationship with the built environment are the significant force in man's cultural progress and, hence, his art that affects the generation of artistic styles and ideas. (Robinson, 1949). The research established that various contextual factors shape artists and their artwork that include their teachers, the preceding styles, demands, and ambitions of their patrons, and their socio-cultural and political environment (Pendse, 2019).

There are two main streams in Indian classical music: north Indian and south Indian based music and styles (Sharma, Panwar, &Chakrabarti, 2014). Both styles have different geographical, historical, and cultural influences, which is very obvious under which these styles have developed. Hindustani and Carnatic music can be distinguished by instruments, i.e., timbre feature and melodic contour. Listeners can distinguish the two styles from the vocal music extracted from the alap section of a performance. (Vidwans, Ganguli, &Rao, 2012)The form of melodic contours of the alaap section can be graphically depicted on the basis of which the two styles can be identified as shown in melodic feature extraction of raga MiyaniTodi (Figure 7) and raga Subhapantuvareli (Figure 8).

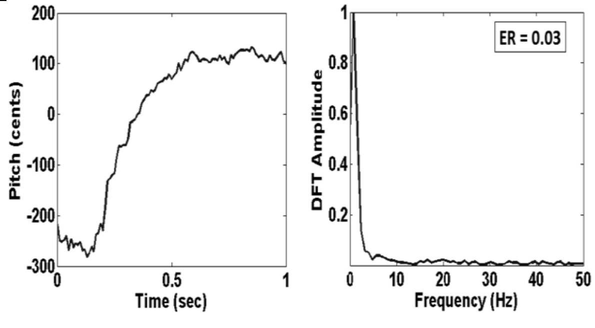


Figure 7.Raga – MiyankiTodi(Vidwans, Ganguli, &Rao, 2012).

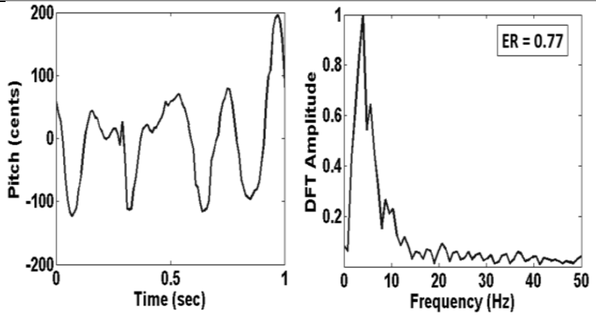


Figure 8. Raga – Subhapantuvareli. (Vidwans, Ganguli, &Rao, 2012).

Shreds of evidence from the old Sanskrit texts on music suggest that the two schools, the Northern or Hindustani and the Southern or Carnatic, preserve several essential ancient elements as well as essential parts.

Ancient Indian temples are classified into two broad types. This classification is based on different architectural styles employed in constructing the temples. Three main styles of temple architecture are the Nagara or the Northern style, the Dravida or the Southern style. It is noticed that the features of Hindustani and the Southern or Carnatic musical systems show close correspondence with the architectural form and structural concepts and apparent aspects of the ancient sacred and historical buildings located in the northern and southern part of India. There is a conspicuous similarity between the music systems and Indian architectural styles. In the North Indian music style, the ornamentation in the form of " Minda" has a curvilinear profile, solid stances, and patterns at a particular speed; however, in south Indian or Carnatic music style, the movement of melodies is very structured, geometric and have definite stages. The curvilinear profile of north Indian shikhara depicts the same concept (Figure 10).

Figure 9 :Shikhara of South Indian style temple.

Figure 10: Nagara style Shikhara

On the other hand, the highly structured profile of south Indian temples, which have progression like a stepped pyramid, exhibit a striking similarity with the aesthetical expression of Carnatic music style (Dhaki, Vatsyayan K., 1991) as shown in (Figure 9).

Music and Architecture : Jaipur

The Jaipur gharana is known for its unique layakari or rhythmic aesthetics. The rich repertoire of ragas. The integrated movement and progression of swara and laya is noticeable where the complex note patterns are rendered with precision and spontaneity. The tanas are basically "vakra" instead of the flat taan, gamak (taan sung with double notes with a delicate force behind each of the component double-notes of the taan) makes the taan spiral into seemingly never-ending cycles. The ornamental approach using meend in aalap and gamak in taan are the characteristic feature of this style of recitation (Gayaki). The historic architecture at Jaipur is known for stone carving, brackets, The intricate detailing of stone jalis, multi-foliated arches, decorative parapet bands, jharokhas, chajjas, all full of ornamentation. Figure 11 presents the Jali pattern at Albert hall museum, Jaipur which is very ornate, decorative and intricate. The entrance façade of Amer fort in Jaipur has ornamental bands, inlay work, which render it highly decorative (Figure 12).

Rambag Palace in Jaipur, built in Indo-Saracenic style. The Square base and round chattris, cusped and multi foliated arched openings, niches, lime jaalis inspired from the Rajput-Mughal vocabulary of architectural aesthetics. It is a beautiful infusion of the Mughal, European and Rajput styles of architecture .

Figure 11 :Jali pattern Albert hall museum, Jaipur

Figure 12: Entrance Amer fort, Jaipur

Use of complex detailing in design and detailing in Jaipur architecture is comparable to the stylistic qualities of gayaki of Jaipur gharana. The use of elaborate ornaments and complex taans, gamak, tans with balpench or curved shape, mukhbandi tans, alapchari in more than one avartan in single breath, bolbanav of laya provide a distinct aesthetical quality that is intricate, and melodious.

Musical tradition of Jaipur gharana characterized by use of jod ragas (compound ragas) and sankeerna ragas (mixed ragas) that is a blend of multiple Raags and preference of new bandishes and rendering of non prevalent ragas. Similarly in Jaipur architecture the use of architectural elements from different architectural styles to create a new aesthetic expression is evident.

Music and Architecture : Gwalior

The image of Gwalior architecture represents planar proportions and scale, subtle coloration and surface effects, interesting superimpositions of form, the play of surface and depth. The imposing structures are bold and massive, with lesser emphasis on decorative elements (Fig . Similarly in the Gwalior gharana the singing with loud full-throated and open voice is preferred. The tan pattern is straight, clear, and varied.

The entrance of Gwalior fort that is bold and imposing (Figure 13) while the jali pattern of Mohamed Ghaus tomb is simple and subtle (Figure 14).

Figure 13: Entrance Gwalior fort

Figure 14: Jali pattern MohmedGhaus tomb, Gwalior

The architectural expression indicate use of simple and known forms wheareas Gwalior gharana's incination towards "Parichit" simple as apposed to compound raga is noteworthy.

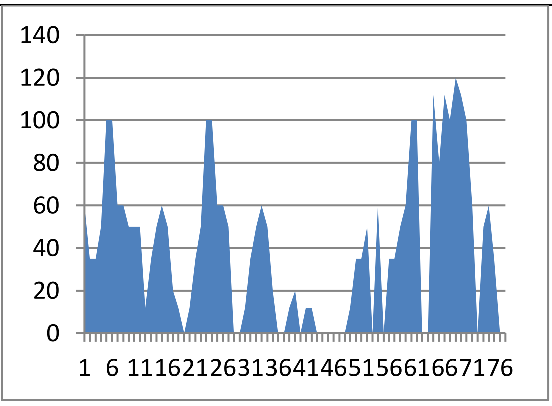
Methodology:

Classical music follows a typical pattern in different ragas and compositions in terms of spatial characters for pause, creating a different effect. To further elaborate this aspect, the spatial character of raga Jaunpuri is analyzed considering the different notation patterns followed in the two different north Indian music schools or gharanas, namely Gwalior and Jaipur. The graphical derivation of ragas is widely used in research particulary for semantic or cross-modal abstraction betwenn two art forms (Duthie,2013, Pendse, 2020).
The Asthayi of a chota khyal is taken from Gwalior and Jaipur Gharana the notation and the frequency of the notes (shruti) is identified (Oak,2010) as shown in the table 1 .

Table.1 : Notation of Chota Khayal of Raga Jaunpuri

RAGA JAUNPURI- Gwalior Gharana																
TEENTAAL - MADHYALAYA																
CHOTA KHAYAL																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	BEATS
DHA	DHIN	DHIN	DHA	DHA	DHIN	DHIN	DHA	DHA	TIN	TIN	TA	TA	DHIN	DHIN	DHA	BOL
ASTHAYI																
						DHA_	MA	PA DHA_	NI_ SA'	NI_	SA'	NI_ DHA_	.	PA	DHA_	**SHRUTI**
						60	35	50 60	80 100	80	100	80 60	60	50	60	**FREQUENCY**
MA	PA	DHA_ MA	PA	GA_	.	RE	.	MA	GA_	RE	SA	RE	MA	PA	PA	**SHRUTI**
35	50	60 35	50	20	20	12	12	35	20	12	0	12	35	50	50	**FREQUENCY**
DHA_	SA'	SA'	SA' RE'	.	NI_											
60	100	100	100 112	100	80											
RAGA JAUNPURI																
TAAL - MADHYALAYA TEENTAAL																
CHOTA KHAYAL																
ASTHAYI																
											DHA_ MA	MA	PA	SA'	SA'	**SHRUTI**
											60 35	35	50	100	100	**FREQUENCY**
ni_																
DHA_	.	PA	.	.	RE MA	. PA	DHA_ PA	GA_	.	RE SA	. RE	MA	PA	SA'	SA'	**SHRUTI**
60	60	50	50	50	12 35	50	60 50	20	20	12 0	12	35	50	100	100	**FREQUENCY**
ni													re			
DHA_	.	PA	.	.	RE MA	. PA	DHA_ PA	GA_	.	.	RE	GA_	SA	RE	RE	**SHRUTI**
60	60	50	.	.	12 35	50	60 50	20	.	.	12	20	0	12	12	**FREQUENCY**
SA	.	.	.	.	SA	RE MA	MA	PA	.	DHA_	.	MA	MA PA	DHA_	SA'	**SHRUTI**
0	.	.	.	.	0	12 35	35	50	.	60	.	35	35 50	60	100	**FREQUENCY**
SA'	.	.	RE'	NI_	RE' SA	GA'	RE' SA'	DHA_	.	PA	DHA_ MA					**SHRUTI**
100	.	.	112	80	12 10	120	12 100	60	.	50	60 35					**FREQUENCY**

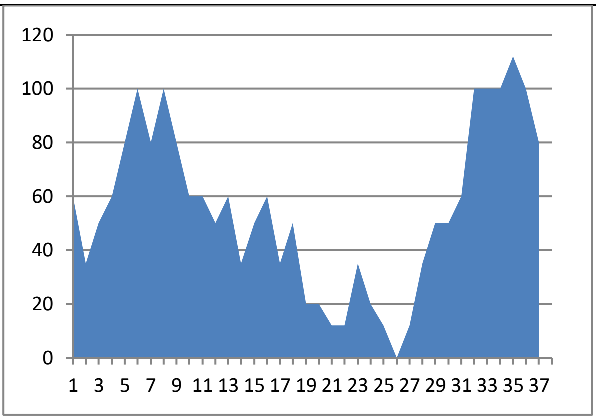
It is translated in graphical mode depicting the pitch contour where the frequency is taken in Y-axis and tempo of the "Tala" in X-axis (Pratyush,2010). Figure 15 shows the graphical form of Raga Jaunpuri in Jaipur Gharana while figure16 shows in Gwalior Gharana.



ASTHAYI

Figure 15 : Raga Jaunpuri- Jaipur gharana

Source:Author



ASTHAYI

Figure 16 : Raga Jaunpuri – Gwalior gharana

Source:Author

Both exhibit different structure, which is based on the way it is composed and improvised by the singer following the set tradition. The graphical form of the raga Jaunpuri in Jaipur Gharana shows a delicate and sleek pattern; however, the graphical form in Gwalior Gharana is massive and bold, corresponding to the defined characteristics of both the Gharanas. The architectural expression in Jaipur architecture represents intricacy of detailing with delicacy having jewel like features that are often exotic. It is similar to the musical composition of Jaipur Gharana, known for its complex and melodic form, which arises out of the involuted and undulating phrases that comprise it. On the other hand, the architecture at Gwalior is bold massive with less detailing in terms of ornamentation. It is in line with the musical tradition of Gwalior Gharana having lucidity and simplicity.

Discussion:

Literature established that the two subjects, music and architecture had a complementary association in the built form, spatial organization, and details. This research found that both art forms share many concepts from a theoretical perspective. Analysis indicated stark similarity in the structure and process in their creation and expression. Both follow principles of aesthetics where the ultimate aim is to provide a feeling of pleasure to the people. Music and architecture were established in the literature as complex phenomena with creative, perceptual, and experiential qualities. It has been stated that there are several vocal schools refereed as gharanas representing different lineages of ideology in music. Each Gharana possesses its character, which is different mainly in musical content and cultural context. Each Gharana follows a specific ideological history and culture where their musical individuality depends on voice production, which is imparted to the followers by the masters through rigorous training. A distinguishing feature of Gwalior Gharana is its simplicity, presentation of well-known ragas, rejecting obscure ones, straight or sapaat tans. A parallel is found in the architecrual creations with simple and bold forms at Gwalior. Jaipur Gharana has a vast repertoire of ragas, including compound (Jod) and mixed (sankeerna) ragas. In this style the use of gamaktaan with a succession of notes with a delicate application of force and oblique formation of notes create complex and melodic form. The delicate and complex nature of aesthetic expression in Jaipur architecture appearantly follow the set aesthetical concepts used in music.

Conclusion:

Indian classical music and architecture are closely related art forms in the context of their aesthetic sensitivity, form and structure, and expression.The great masters of architecture continue to use musical concepts in their architectural compositions. Architects and musicians both work under ideologues to create conducive environments that result in the course of creativity in a particular society. The similarity between two art forms developed in a geographic location is evident as artists' impressions from the environment where they live stimulate their art. However, art is not imitation; it is a way of expressing inter-subjective experiences through the externalization of creativity; the impressions that man derives from his environment is an impetus for his art creation. The art is dynamic; hence the cultural and environmental influences availability of material and technology and mainly highly gifted people affect creations of all art forms similarly. Architecture is intimately intertwined with music; the reciprocity between these art forms can result in inter-influences and mutual collaboration to enrich individual lives and society as a whole. For creating composing a musical piece, musicians use their creative skills within the defined boundaries that are unique but still follow a defined character. It has resulted in the everlasting character because Indian Classical Music has flourished with its long-lived traditions and welcoming new principles. Indian Classical Music has made an irrefutable impact on the life of people and society through the development of their unique melodious compositions. Each raga and composition follows a structure that results in a particular expression. Such principles could be used for architectural planning and design.

References:

1. Cohen, S. (1995). Sounding out the City: Music and the Sensuous Production of Place. *Transactions of the Institute of British Geographers*, 434-446.
2. Duthie, A. C. (2013). *Do music and art influence one another. Measuring cross- modal similarities in music and art.* Iowa: Graduate Theses and Dissertations.
3. Gulzar, S. (2016). Glazed Tile Ornamentation in Mughal Monumental Architecture. *Journal of Research in Chemical, Metallurgical and Civil Engg*, 114 - 117.

4. Horri, F. (2018). Finding the Relevance of Music and Architecture in Shaping Physical Space and Structural Form of Prince Garden, Mahan Kerman. *Urban Studies and Public Administration*, 184-198.
5. Imaah, N. (2004). Music: A source of Inspiration and Harmony in Architecture: An African View. *International Review of the Aesthetics and Sociology of Music*, 169-182.
6. Jencks, C. (2013). Architecture becomes music. *Architectural Review*, 91-108.
7. Kulmethe, M., & Patil, M. (2017). Techniques of Characteristics, Components of a Raga Identification System. *Imperial Journal of Interdisciplinary Research*, Vol-3, Issue-9.
8. Kumar, A., Jayakumar, T., Rao, C., Sharma, G., Rajkumar, K., Raj, B., et al. (2008). Non destructive characterization of musical pillars of Mahamandapam of Vitthala temple at hampi, India. *Journal of Acoust society*.
9. Morris-Kay, G. (2010). The evolution of human artistic creativity. *The journal of anatomy*, 158-176.
10. Mahajan. (2001). *Ragas in Hindustani Music ; conceptual aspects.* New Delhi: Gian publication.
11. Neuman, D. (1985). Music as a Cultural System. *Asian Music*, 98-113.
12. Neuman, D. M. (2012). PressIndian Music as a Cultural System. *University of Texas Press*, 98-113.
13. Oak, D. (2010). *22 Shruti*. Mumbai: Samskar prakashan
14. Ola, C., & Adegbore, A. (2015). Cultural Heriatge collections preserevation and access; case of university of Ibadan. *Journal of african Educational research*.
15. Pendse, S. (2019). "Exploration of the Interelationship of Architecture and Indian Classical Music ", Unpublished Ph.D. dissertation, S.P. University of Pune.
16. Pendse, S. (2020). “Cross-modal Abstraction between Indian Classical Music and Architecture” Connections: Exploring Heritage, Architecture, Cities, Art Media, International conference , University of Kent.
17. Pratyush. (2010). *Analysis and Classification of Ornaments in North Indian (Hindustani) Classical Music.* Barcelona: Universitat Pompeu Fabra.
18. Rao, R. (2011). *Science and Golden Ratios in Mandala Architecture* (First ed.). Delhi: D.K Printwold [P] Ltd.

19. Rao, S. R. (2014). An Overview Of Hindustani Music In The Context Of Computational Musicology. *New Music Research*.
20. Riad, M. (2009). *Archirecture: Music,City and Culture.* Maryland: University of Maryland.
21. Robinson, H. (1949). The Influence of Geographical Factors Upon The Fine Arts. *Geography, M Arch,1949, Vol.34,No.1*, 18-29.
22. Ross, J., & Rao, P. (2012-13). Detection of raga- cahracteristic phrases from Hindustani classical music audio. *Proc of the 2nd comp music workshop.* Istanbul, turkey.
23. Tayyebi, F. (2013). *A Quest on the Relationships between Music and Architecture.* North Cyprus: Eastern Mediterranean University.
24. Trupti, K. (2013). Multiple Techniques for Raga Identification in Indian Classical Music. *National Conference on recent Trends in Computer Science and Technology.* Hyderabad: International Journal of Electronics Communication and Computer Engineering.
25. Vatsyayan, K. (1991). *Concept of space: Ancient and Modern.* New Delhi: Indira Gandhi National Centre for the Arts: Abhinav publications, New Delhi.
26. Walden, D. (2014). Frozen Music; Music and Architecture in Vitrivius' De Architectura. *Greek and Roman Musical Studies*, 124-145.
27. Xenakis, I. (1971). *Musique Architecture.* Tournai: Casterman.
28. Sharma, A., Panwar, A., & Chakrabarti, P. (2014). Analytical Approach on Indian Classical Raga Measures by Feature extraction with EM and Naive Bayes. *International Journal of Computer Applications (0975-8887)*, Volume 107- No 6.
29. Vidwans, A., Ganguli, K., & Rao, P. (2012). Detecting Indian Classical Vocal Styles from Melodic Contours. *2nd Compmusic Workshop.* Istambul: Department of electrical Engineering, Indian Institute of Technology, Bombay.
30. Young, G., Bancroft, J., & Sanderson, M. (1993). Musi-Tecture: Seeking Useful Correlations between Music and Architecture. *Leonardo Music Journal, Vol.3*, 39-43.

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for **"swar sindhu"**. Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	Swar Sindhu	Pratibha Spandan	NA	2320-7175	from January-2021 to Present	View

Showing 1 to 1 of 1 entries

Previous 1 Next

Swar Sindhu: National Peer-Reviewed/Refereed Journal of Music
A UGC CARE listed Journal
ISSN 2320–7175 | Volume 10, Issue 01, January-June 2022
http://swarsindhu.pratibha-spandan.org © The Author(s) 2022

THE DYNAMICS OF AESTHETICAL EXPRESSION IN MUSIC AND ARCHITECTURE

DR. SANJEEVANI A PENDSE[1] & DR. VASUDHA A GOKHALE[2]

1 Assistant Professor, B.N. College of Architecture, SPPU Pune
2 Professor, B.N. College of Architecture, SPPU Pune

Abstract

Music and architecture are the most prevalent forms of artistic expression and are considered creative products. As both the art forms are associated with aesthetics, this research investigates the correlates of aesthetic appreciation of music. Raga, Mood, expression, and note patterns are considered the elements of Indian Classical Music. Raga is a medium to express aesthetical qualities like emotions, and Raga is said to be the soul of music. Different emotions are expressed with Raga as a medium that can change the state of mind. Many ragas are sung in a particular season create a more profound effect on the audience. In an attempt to examine the speculated relationship between music and emotion, a total of hundred subjective emotional responses from the architectural fraternity to pieces of music were investigated. The method employed was music elicitation, as it offers a route to gather data that remains largely unspoken in the conventional research methods. It is argued that the processing of aesthetic experiences and emotional responses to aural stimuli can substantiate theoretical knowledge of aesthetics and creative products in Indian culture. The analysis is aimed to extend the objective and scientific approach to understanding aesthetics.
Keywords: Raga, Frozen, Malhar, Melody, composition.

INTRODUCTION

Every country possesses its ideals manifested in its culture. Architecture and music come from a particular country, region, and area that play a crucial role as a product of the culture it belongs. Art can be regarded as one of the human's defining characteristics, which exists in its many forms (Morris-Kay, 2010). The main objective of art is the expression in the form of audio, video, and performance, which has inherent qualities. These affect the human mind resulting in enjoying its values. Gaquin identified thirteen categories of art forms, including architecture and music, which exist in every community and culture and play an integral part in social life (2008).

Architecture is referred to as frozen music, where its interrelation with music is multiple (Johann Wolfgang von Goethe). Iannis Xenakis, composer, and architect, explained the significant linkage and shared terms between music and architecture (Tayyebi, 2013).

Art creation and art appreciation are deeply emotional processes that provide experiences of sadness, tranquillity, and anguish. As per one of the most creative artists of the 20th century, Pablo Picasso, artists are receptacles for emotions and vehicles for transforming felt emotions into tangible works of art. Musicians or architects being creative people have several personality characteristics that set them apart. They possess artistic and intellectual interests and are curious and open to unconventional new experiences (Ivensic, 2016). In response to this aspect, this research presents the aesthetical appreciation of music as experienced by architecture students.

MUSIC, ARCHITECTURE AND NATURE

The natural world has been a source of inspiration for musicians and architects from historical times. Many famous pieces of music combined melodies, harmonies, and overall musical dynamics to replicate the image of a natural phenomenon like a storm at sea, twinkling of starlight, cool breezes, or everyday sunrise. Indian Classical Music is also closely related to nature. Paintings and theatre are very closely related mediums of communication. Similarly, a raga in Indian classical music is sung at a particular time, and some ragas are performed in specific seasons. The main reason behind this is the creation of a specific mood in the artist himself first and eventually the audience (Bardekar & Gurjar., 2017). The forms, structures, systems, processes, and organisms in nature have been widely assisted designers and architects in finding improved and innovative solutions. The shape and function of nature have inspired architects to seek new design sources from natural elements in building design.Some seasonal ragas like raga Malhar and Raga Megh are sung in the rainy season, Raga Bahaar in the spring season, and Raga Basant in the autumn season. The season for which the raga is assigned can be performed at any time of the day (Bardekar & Gurjar, 2017). *Ragas* are specific to the day and generate a specific sentiment only when played at the right time (Sharma, Panwar, & Chakrabarti, 2014). Different *ragas* performed on relevant timings for an immense impact and increased sentiments on humans' minds (Sharma, Panwar, & Chakrabarti, 2014). *Raga* expresses its total impressions only when rendered/ performed at a specified time (Sharma, Panwar, & Chakrabarti, 2014). Gurjar, states that there are definite times of the entire day and night time when the specific Ragas can be performed with the belief that the composition of notes of that raga is best perceived and felt at that time and gives immense pleasure (Bardekar & Gurjar, 2017).

Architectural features also depend on a natural phenomenon like climate. The effects of climate conditions on a building are among the most essential and natural factors that shape architectural studies (Biket, 2018). A nature inspiration design gets a lot of new ideas from pictures, shapes, mechanisms, or organisms that occur in nature. Visual inspiration is well understood the shape of various organisms or their systems, and to imitate similarly looking functions and systems. A conception inspiration occurred when the designer or engineer applied principles found in nature, and a computational level is inspired by mechanisms or organisms occurring in nature. For example, Lotus temple and Birds nest[refer fig 1 and fig 2].

Figure 1 : Lotus Temple, Delhi

Figure 2 : Bird's Nest
(Beijing iconic national Stadium)

ARCHITECTURE, MUSIC AND EMOTION

Aristotle's theory of Catharsis established the cathartic influence of music on people. It has been stated that all experiences have an inevitable purge, which is referred to as Catharsis, which provides a pleasant relief (Wiktor, 2013). Indian aesthetic theory includes literature and drama, explaining the Rasa theory. Music, dance and sculpture, and architecture, the other art forms, have come under this theory in recent times. Bharata's rasa theory explains bhava, which are the natural feelings arising while experiencing the art forms. These thoughts are different from the familiar feelings experienced in day-to-day life.

From historic time music has been considered as expression various factors that include motion, tension, identity, beauty, human characters, social conditions and religious faith. However it is largely perceived as expressive of emotions (Juslin, 2003). Architectural theory is governed by aesthetical approach which see an architectural object as a functional building which has an aesthetic component which differentiate architecture from mere building as an object.

In Indian classical music, each raga evokes rasa, also of different types (Nagar, 2005). Behavioral and neurological evidence exhibited that music induces emotions due to the corresponding activation patterns in brain circuits. Raaga is much more than a mere sequence of notes. The embellishments, which are a form of note transitions, affect the cognition of ICM. In each raaga, a few notes are emphasized, which changes the composition's emotion. Such notes render a raga capable of evoking a particular emotion (Indurkhya, 2010). In Indian Classical Music, the melody or raga structure is made up of a combination of notes built up in a taal with a specific number of beats called matras. The spacing of notes in these matras creates space. The variation changes the character of the composition, which could be interpreted in terms of an architectural -space. For example, the pause between the notes is a space that could express a particular emotion and dictate the speed and tempo.

The ragas create an effect of a particular environment based on the composition; however, many ragas are sung in a particular season create a more profound effect on the audience.

Raga is to be sung at a particular time during the day as a tradition; however, there is no scientific base. It is often related to the energy being incident at a particular point and time of the day. This phenomenon connects music with nature which is similar to architecture. Indian Classical Music follows a “raga chakra,” which represents a schedule assigned with a particular quality. For example, morning is for prayers (bhakti) to be presented with morning ragas that are soothing and calm, afternoon ragas evoke hot emotions while evening ragas are joyous, and night ragas represent unsteadiness.

AESTHETICAL APPRECIATION IN MUSIC AND ARCHITECTURE

Aesthetic appreciation of music is an appreciation of a musical composition for its hear able form and content rather than its instrumentality for external purposes. It has been argued that the aesthetical appreciation of a musical composition is a multiplicative function of structural, performance, contextual features, and listener personality. Tempo is the most critical factor that affects music expression. However, several other factors such as mode, loudness, melody also influence the emotional valence of a musical composition.

Architecture represents the intellectual activity of creating a distinctive art form. An architectural form results from the intellect and the source of aesthetics that extended beyond the material dimension (Al-Assaf, 2014). The main aim of any art is to feel happy, pleased, and contended. Therefore this term aesthetics is used to express the experience of the perceived art such as aesthetic judgment, aesthetic attitude, aesthetic understanding, aesthetic emotion, and aesthetic value. As we experience nature or people aesthetically, this term also is applied to architecture.

It is argued that the process of emotional elicitation initiated with an 'automatic, immediate response that starts a motor and autonomic activity and prepares the listeners for possible action' causes a process of cognition that may enable them to 'name' the felt emotion (Robinson, 1949). It has been stated that musical elicitation is a very useful technique which can be adopted as a metaphor for intrinsic experiences as well as for extracting tacit knowledge. (Anderson, 2017).

METHODOLOGY: MUSIC ELICITATION

In this research, the pieces of ICM were used as stimuli for examining how respondents perceive them in light of their intended aesthetical, conceptual, and compositional characteristics.

SELECTION OF AURAL STIMULI

The aural stimuli consisted of six melodies of one minute each were selected, depicting the time of the day, seasons, region, festivals, rhythm, and space. Here vocal music has been excluded because lyrics of a composition or song often convey direct intended meanings through words. The intention here is to examine how certain mood and expression hidden in the piece of music based on Indian Classical Music is perceived through aural media. Audio recording of the melodies of one minute each is prepared with a pause between each melody. The respondent is supposed to record their response in the response sheet in a questionnaire provided.

Participants: 100 respondents from architectural fraternity were recruited from Pune. The participants had completed the fundamental courses in which their creativity and design skills were nurtured and had basic knowledge related to architectural aesthetics. They were selected based on their academic and professional background making them competent to make aesthetic judgments of aural stimuli.

Structure of Music elicitation questionnaire: The questionnaire consists of six questions, each representing a particular melody. Each selected melody had a defined character that conveyed a feeling, emotion, or meaning. For each melody, the respondents were asked specific questions to be answered on a five-point Likert scale. The survey was conducted in a group of faculty and students. The questionnaire was circulated and explained to the respondents before the audio recording was played. Participants were asked to provide emotion ratings only after listening to the melody for at least 1 min. This aspect ruled out random responses, and enough time to listen, understand and answer the question.

RESULTS AND DISCUSSION

The findings derived from the survey are as follows:

MELODY I – ALAAP (PHRASES) IN RAGA TODI

It is a morning Raga derived from TodiThaat. Type is sampoorna Raga. It is shown as a gentle, beautiful woman, holding a Veena and standing in a green forest surrounded by deer. It has an inherent pensive mood molded into a festive mood.

The analysis shown in Figure 3, Figure 4 & Figure 5 indicated respondents felt that they wake up at dawn as 56% rated it dawn while 21% felt it is an afternoon 10% night while the remaining 6% were not able to identify the time in the melody. The melody was predominantly calm and severe and rated as sad to a certain extent, while just 4.2% felt it enthusiastic.

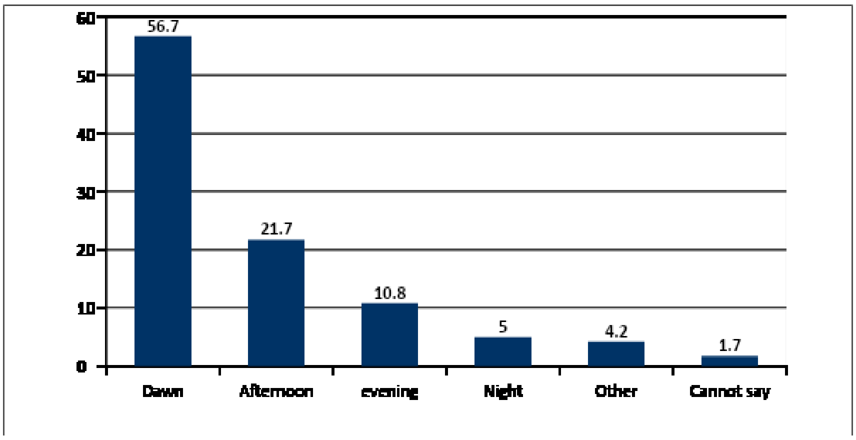


Figure 3 : Time

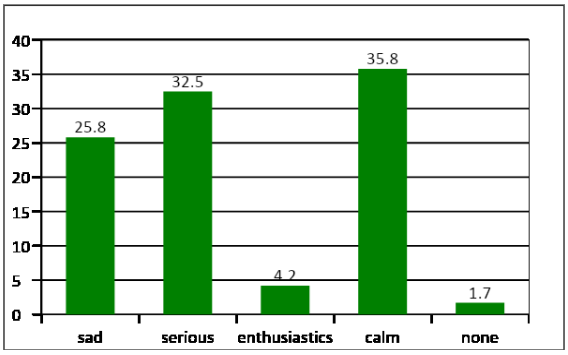


Figure 4 : Mood

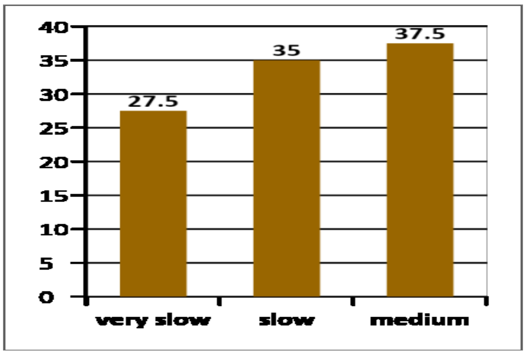


Figure 5 : Tempo

The melody was a piece of composition in Raga Miyan Ki Todi which is a morning Raga.

MELODY 2 – ALAAP IN RAGA VRINDAVANISARANG

It is an afternoon Raga derived from ThaatKafi. The type is odav-odav (5 notes). The rasa of romance named shringar rasa is there in this raga and creates a mystic atmosphere, sung in the summer season.

As per the analysis, 37% of respondents said it was afternoon, while 30% rated it an evening and 19% as dawn. 45% found it serious as far as mood is concerned, while the tempo was rated slow. 31% were not able to distinctly identify mood (refer to Figure 6, Figure 7, Figure 8).

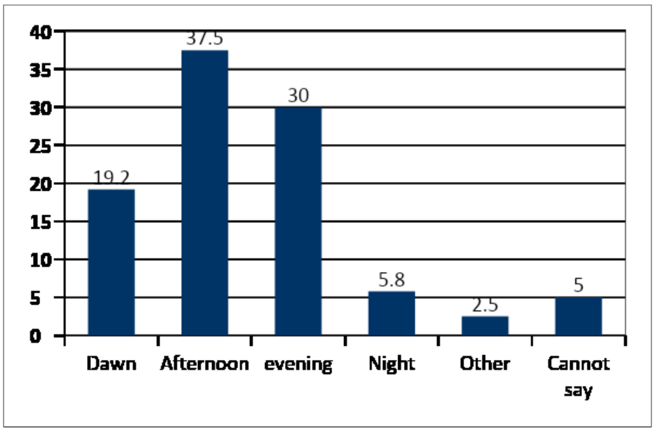


Figure 6 : Time

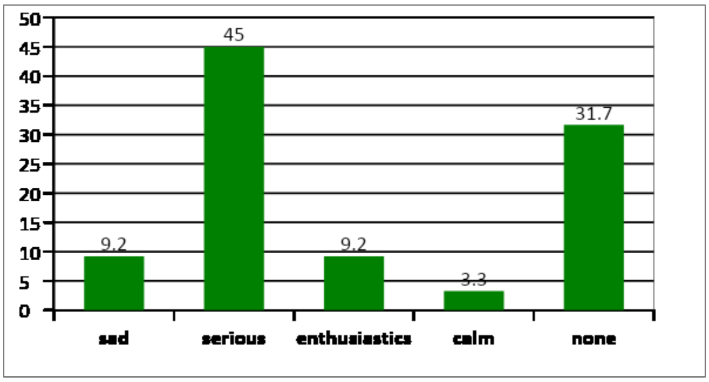


Figure 7 : Mood

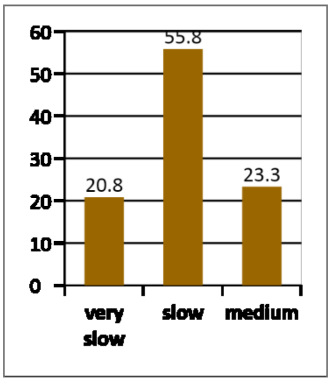


Figure 8 :Tempo

The melody was a piece of composition in Vrindavani Sarang an afternoon raga.

MELODY 3 – ALAAP IN RAGA BHIMPALAS

An evening Raga derived from ThaatKafi. The type is OdavSampoorna. The mood of the raga is serene and dignified which expresses longing of a lover.

Swar Sindhu: National Peer-Reviewed/Refereed Journal of Music
A UGC CARE listed Journal
ISSN 2320–7175 | Volume 10, Issue 01, January-June 2022
http://swarsindhu.pratibha-spandan.org © The Author(s) 2022

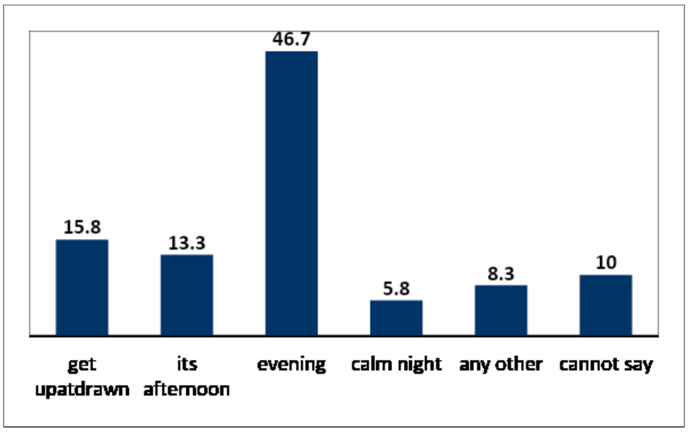


Figure 9 : time

(refer Figure 9 Figure 10, Figure 11) 46.7% respondent's say it is evening time, 27.5% found happy mood, 2.5% respondents could not identify the mood, and 37.5% respondents felt the rhythm is medium paced.

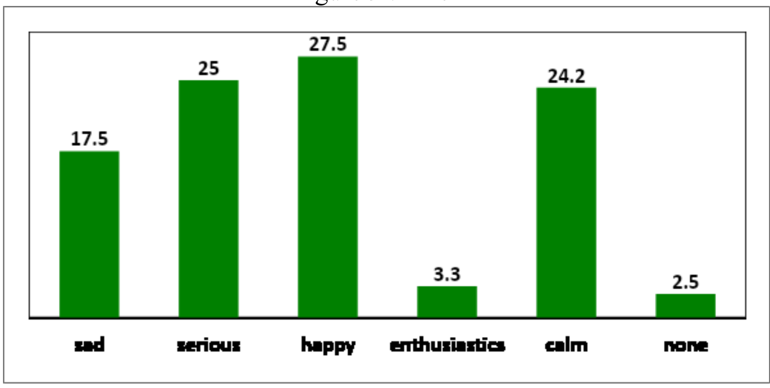


Figure 10 : mood

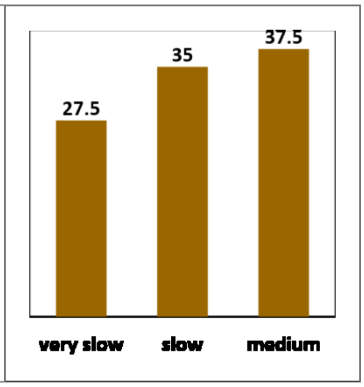


Figure 11 : tempo

The melody was a piece of composition in raga Bhimpalas an evening raga.

MELODY 4- ALAAP IN RAGA MALKAUNS

It is a night Raga derived from thaatBhairavi. The type is Odav. The raga has slow tempo developed in lower octave. It creates a meditative and serious mood.

The effect is soothing and intoxicating (refer Figure 12, Figure 13, Figure 14)

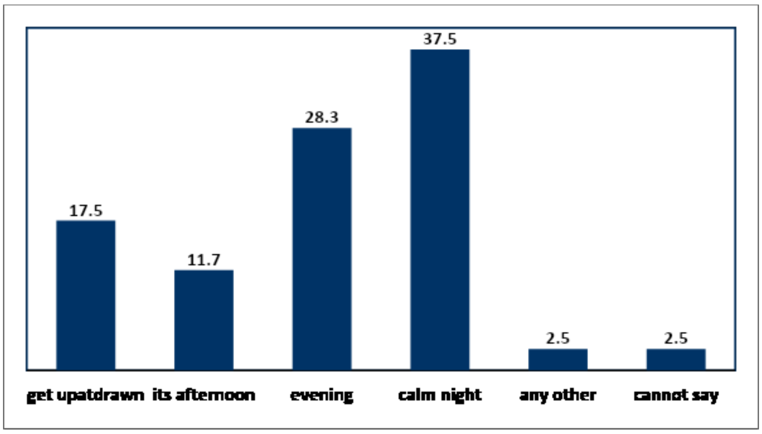


Figure 12 :time

Melody 4: 37.5% respondents felt that it is night and 28.3% respondents felt evening time. 51.7% felt very clam mood. 70% respondents found the tempo medium.

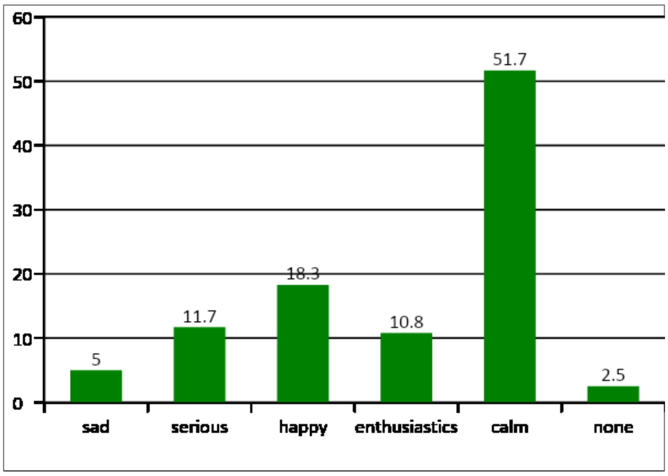


Figure 13 : mood

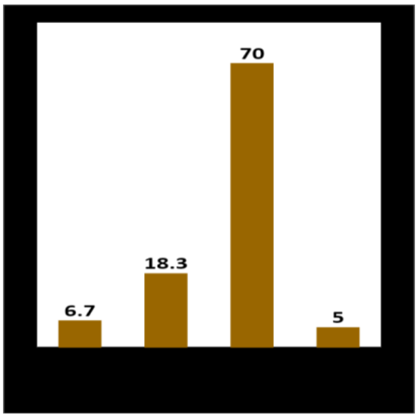


Figure 14 : tempo

The melody was a piece of composition in Raga Malkauns a night raga.

MELODY 5 – RAG BASANT INSTRUMENTAL MELODY

It is sung anytime during spring. Derived from Thaat Purvi. Type is Odav Sampoorna. This is a gentle melody and depicts joy (refer figure 15).

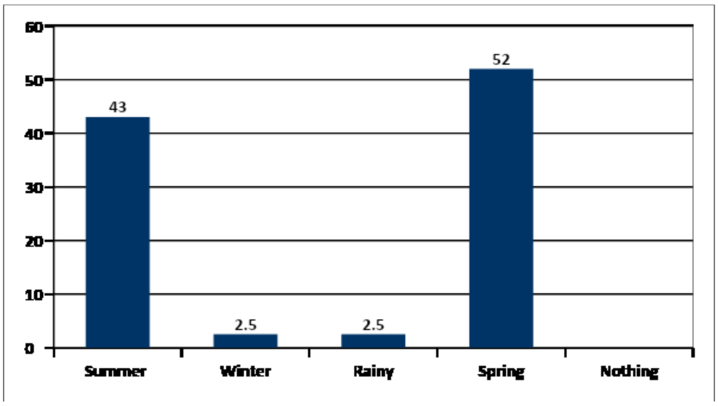


Figure 15 : seasons

Melody 5: 52% spring and 43% summer. The melody was Raga Basant sung in spring.

MELODY 6 – ALAAP IN RAG MIYANMALHAAR

It is a night raga derived from Kafithaat. Type is SampoornaShadavjaati.. It is sung in rainy season (refer Figure 16)

Swar Sindhu: National Peer-Reviewed/Refereed Journal of Music
A UGC CARE listed Journal
ISSN 2320–7175 | Volume 10, Issue 01, January-June 2022
http://swarsindhu.pratibha-spandan.org © The Author(s) 2022

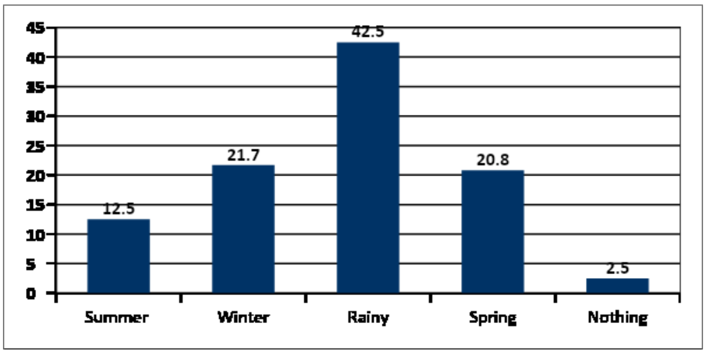


Figure 16 : seasons

Melody 6: 42.5% responded as rainy season, The melody is in Miya Malhaar sung in rainy season.

DISCUSSION

The main objective of art is expression in the form of audio, video and performance which has inherent qualities. These have effect on human mind resulting in enjoying its values. Various categories of art forms which include architecture and music exist in every community, every culture and play an integral part in social life. Aesthetics defines what is beautiful, exciting, interesting, uplifting as well as pleasing in art-forms like music, dance, painting, sculpture, literature, drama and architecture. Based on the type and nature of the art form aesthetical quality is experienced through one, two or more senses of perception. Through the sense of hearing, the aesthetic or rasa is directly experienced as per Indian aesthetic theory of music, while the aesthetical properties of architecture are often experienced predominantly with visual sense. It is believed that during their creation both the arts traverse through the same places and passages and lead to abstraction ultimately. The impact of Music and architecture on each other is invariable creative and promoting which enrich the creators. Instruments used in music and concepts used in architecture are the results of spiritual or abstract concepts underlying them. It is stated that the harmonic relationship between music and architecture always results in aesthetic pleasure. Music and architecture are mutually influencing art forms which share a common language in terminology and aesthetic expression.

CONCLUSION

This research exhibited the capability of ICM in conveying its underlying concepts and meaning through aural media. The characteristic rhythm, structure of composition in terms of swaras connects the listener to natural meteorological phenomenon like seasons or geographical places. It has been found that a raga is able to evoke a particular emotion and mood. Compositions in ICM are based on ragas which were perceived as festive, melodious, and sad. Temporality of ICM was established as the musical piece composed in raga has a direct correlation with the time of the day or night. Music and architecture the both create art forms based on social context aiming at the construction of meaning and value. ICM has continually defined, validated, maintained, and reproduced the music as cultural category of Indian arts which has a direct association with architecture as an art form. Aesthetics defines what is beautiful, exciting, interesting, uplifting as well as entertaining in art-forms like music, dance, painting, sculpture, drama, literature and architecture. The analysis indicated that the primary objective of both art forms is a quest for aesthetical Pleasure.

REFERENCES

Al-Assaf, N. (2014). The Aesthetics symptoms of architectural form: the case of Barcelona Museum. *https://www.researchgate.net/publication/282861714*, 19.

Anderson, B. (2017). A Study of Music and Its Ability to Give Voice: A Photo-Elicitation Project Involving Youth In-Care and the Interpretation of Visuals. *Master Of Social Work*, 2-101.

Bardekar, & Gurjar. (2017). An Empirical Study of Indian Classical Ragas Desh and Todi Structure and its Influence on Brain Waves. *International Journal of Advance Research, Ideas and Innovations in Technology.*, 572-577.

Biket, A. (2018, february 21.02.2018). *Iconda*. Retrieved from irbnet.de: www.irbnet.de/datem/iconda/06059010253.pdf

Gaquin, D. (2008). Artists in the Workforce, 1990-2005. *National Endowment for the arts*.

Geography, M Arch,1949, Vol.34,No.1, 18-29.

Indurkhya, B. (2010). A behavioral study of emotions in south indian classical music andits implications in Music recommendation systems. *https://www.researchgate.net/publication/234802466*, 07.

Juslin, P. (2013). What does music express. Basic emotions and beyond. *Frontiers in Psychology*, Volume 4, Article 596.

Morris-Kay, G. (2010). The evolution of human artistic creativity. *The journal of anatomy*, 158-176.

Nagar, R. (2005). *Natyashastra of Bharatmuni.* Delhi: Amazon.

Robinson, H. (1949). The Influence of Geographical Factors Upon The Fine Arts.

Sharma, A., Panwar, A., & Chakrabarti, P. (2014). Analytical Approach on Indian Classical Raga Measures by Feature extraction with EM and Naive Bayes. *International Journal of Computer Applications (0975-8887)*, Volume 107- No 6.

Tayyebi, F. (2013). *A Quest on the Relationships between Music and Architecture.* North Cyprus: Eastern Mediterranean University.

Wiktor, C. (2013). Catharsis in Poetry therapy. *Polish Journal of Applied Psychology*, 25-38.

Zorana Ivcevic , J. H. (n.d.) (2016) . Creativity, Emotions and the Arts. In J. H. Zorana Ivcevic, *Arts Arts and emotions - Nurturing our Creative Potential.*

journals.sagepub.com/doi/full/10.1177/14780771221140622

SAGE journals

Search this journal | Enter search terms... | Advanced search | Access/Profile | Cart

Browse by discipline | Information for

International Journal of Architectural Computing

View all publication partners | Journal indexing and metrics | JOURNAL HOMEPAGE | SUBMIT PAPER

Free access | Editorial | First published online November 15, 2022

Configurable architecture

Volume 20, Issue 4 | https://doi.org/10.1177/14780771221140622

Contents | PDF / ePub | Cite article | Share options | Information, rights and permissions | Metrics and citations | Figures and tables

This is the Special Issue—eCAADe of the International Journal of Architectural Computing (IJAC) reflecting upon and expanding the topic of a new configurable architecture that was launched at the 39th Education and Research in Computer Aided Architectural Design in Europe (eCAADe) Conference hosted by the Faculty of Technical Sciences, University of Novi Sad, Serbia, in September 2021. The conference organized under the theme "Towards a new configurable architecture" brought researchers and academics from 42 countries. However, due to the COVID-19 pandemic which resulted in restrictions and limited travel possibilities, the event was organized in a hybrid mode allowing global online participation in the event. Active involvement of participants showed that despite the pandemic, there is a constant need to exchange knowledge, experience, and research achievements.

The notion of configuration can be described as a relative arrangement of elements in a particular system, form, figure, or other formations. Configuration represents the essence of the design process. The configurable architecture may include a process of abstract thinking through design and exploitation. It can

NOW AT SAGE
JOURNAL OF INTERIOR DESIGN
Find out more

Related content

Similar articles:

Get citation

Privacy

---

journals.sagepub.com/doi/full/10.1177/14780771221140622

Contents | PDF / ePub | Cite article | Share options | Information, rights and permissions | Metrics and citations | Figures and tables

papers examine the questions and this topic, and provide novel and inspiring insights.

This issue brings together seven articles that are linked with the main topic of configurability and mass customization in architecture.

Two papers in this special issue have a strong focus on structurally informed and fabrication aware design. Lukas Gosch, Julian Jauk, Hana Vašatko, Elizabeta Šamec, Matteo Raffaelli, Stefan Rutzinger, and Milena Stavric carried out fabrication experiments and research in order to develop a novel composite material based on thread reinforcement and clay matrix. Through several physical experiments with clay mixtures, thread types, and knitting methods, authors learned about the constraints that helped in choosing the right strategy for fabricating a 1:1 architectural prototype.

Luis Orozco, Anna Krtschil, Lior Skoury, Jan Knippers, and Achim Menges developed three methods for internal slab layout in timber building systems and compared structural performance of each method through the analysis of their reinforcement layouts. Presented methods could be used for the design of any timber box floor including those that have irregular column layouts.

There are two papers that combined the topic of configurable architecture with the topic of computational design in architectural education. Dhanashree Sardeshpande and Vasudha Gokhale analyzed attributes of associative modeling tools in their work and observed design processes and outcomes of the design studio conducted in the postgraduate program of "Master of Digital Architecture." Through examples of "meta urban hybrid" studio, they show how design diagrams, associative dependencies, and tools for performance validation and optimization can be used to explore the effect of digital mediums on the design cognition of architecture students in an experimental studio setup.

Ioanna Symeonidou, Renate Weissenböck, and Alexandros Efstathiadis investigated the potential of using Augmented Reality in interactive digital design education of site-specific bridges. They observed that AR experience triggered certain modifications in several of the students' projects and that it is a highly motivational activity for the students.

Design processes and BIM was the main topic for three papers. In the article Optimization-Aided Design—Two Approaches for Reflective Exploration of Design Search Space, Likai Wang focuses on design approaches assisted by using performance optimization, showing its efficient in assisting architects in early

Restricted access
Framework of an algorithm-aided BIM approach for modular residential building information models
Show details

View more

SAGE recommends:

SAGE Knowledge
Entry
Game-Based Assessment
Show details

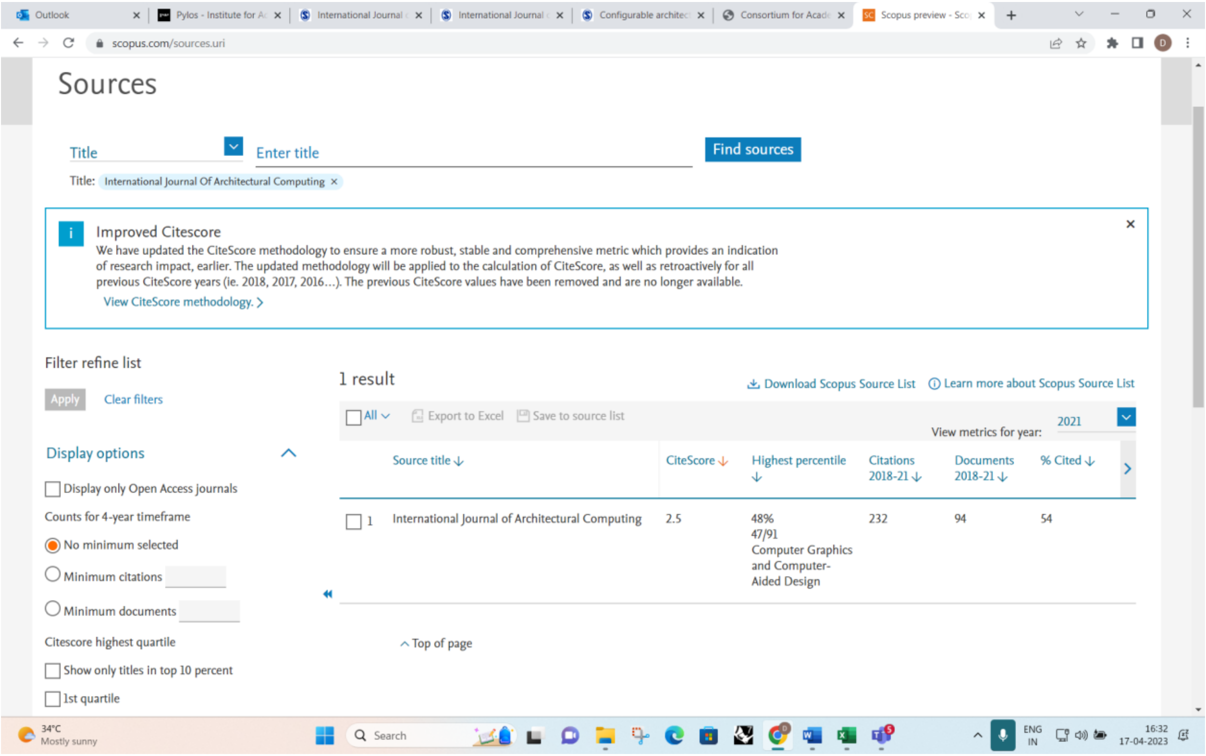
SAGE Research Methods
Book chapter
Publishing Articles in Academic Journals
Show details

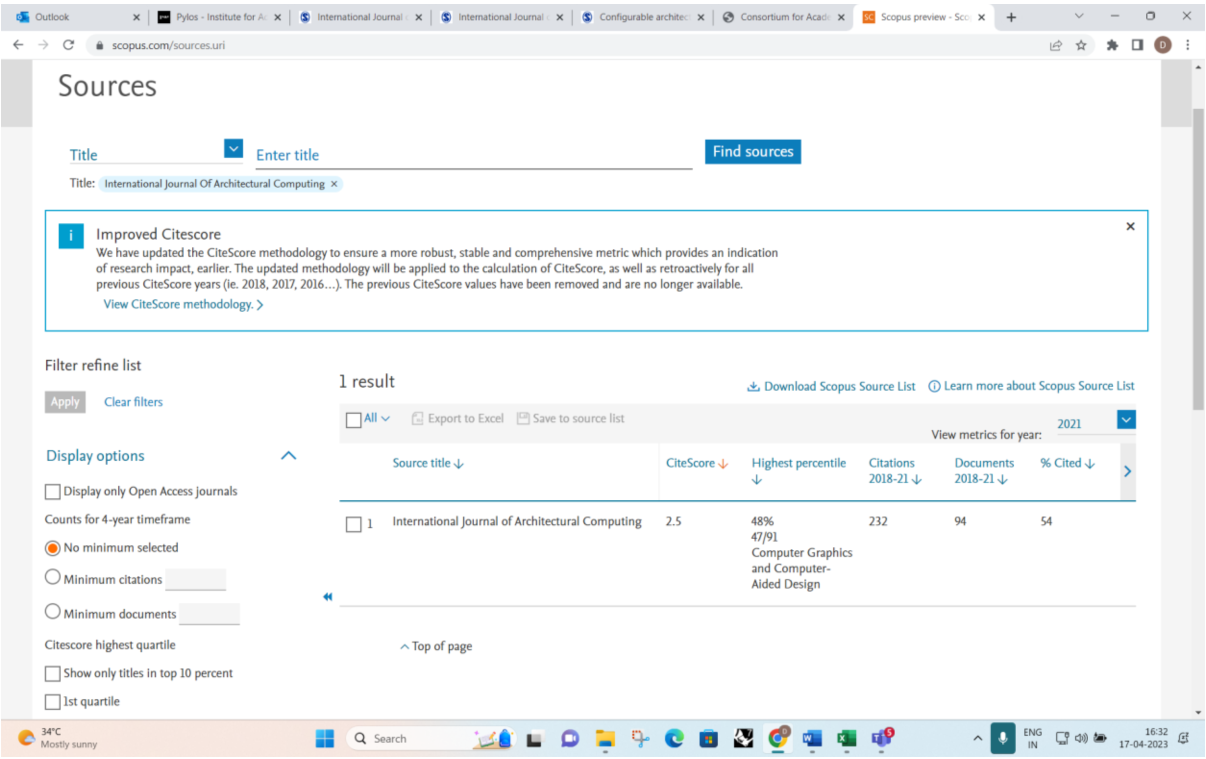
SAGE Knowledge
Literature review
Narrative Configuration in Qualitative Analysis
Show details

View more

Get citation

Privacy





ECAADE_2022,Vol 20,Issue 4

ISSN:1478-0771

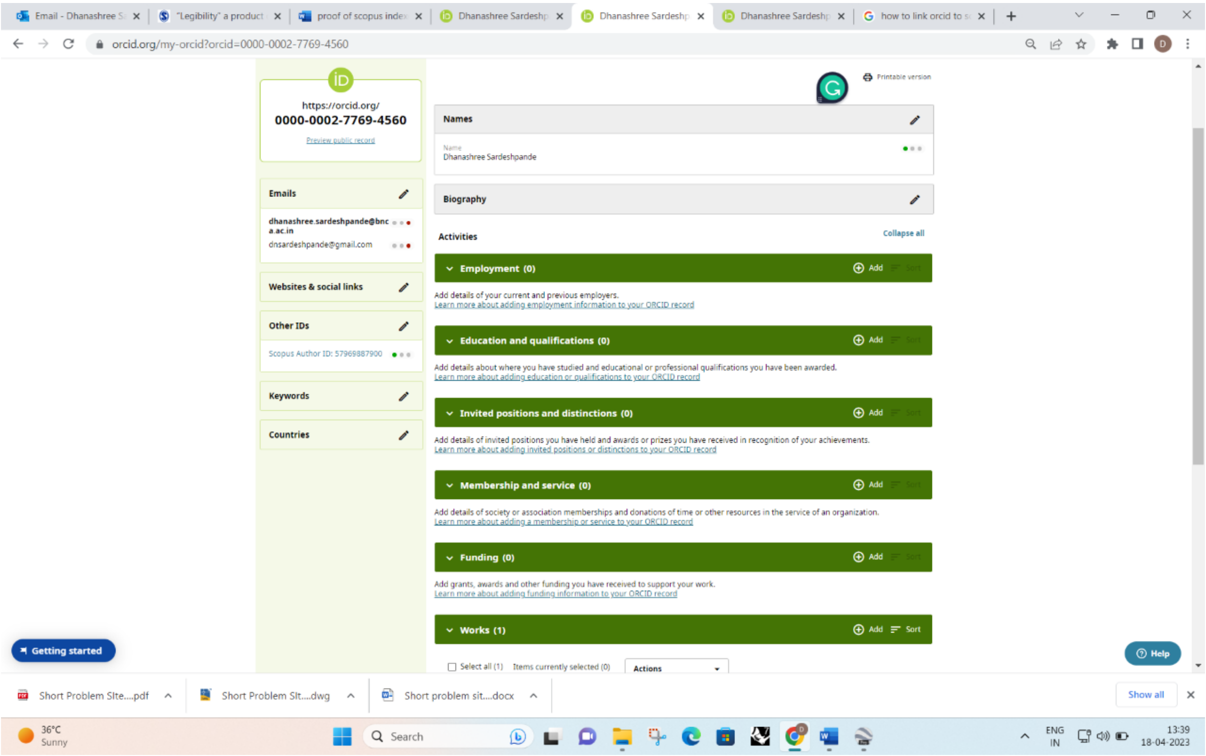
Sage Publications

Legibility” a product of obligatory processes in parametric architectural design: A study of implications of associative modeling on design thinking in a parametric architectural design studio

International Journal of Architectural Computing 2022, Vol. 0(0) 1–14

1.

Sardeshpande D, Gokhale V. “Legibility” a product of obligatory processes in parametric architectural design: A study of implications of associative modeling on design thinking in a parametric architectural design studio. International Journal of Architectural Computing. 2022;20(4):728-741. doi:10.1177/14780771221139911



Check for updates

IJAC

International Journal of Architectural Computing
2022, Vol. 0(0) 1–14
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/14780771221139911
journals.sagepub.com/home/jac
SAGE

"Legibility" a product of obligatory processes in parametric architectural design: A study of implications of associative modeling on design thinking in a parametric architectural design studio

Dhanashree Sardeshpande and Vasudha Gokhale

Abstract

In a problem-based, digital-intensive learning environment, the increased proliferation of computational tools used for architectural design has led to a fundamental transformation in architectural studios. Many studies have shown that this has significantly led to the change in cognition of design environments in academia. Design decisions are made through a recursive process that is cyclically refined by allowing constant feedback and testing. This paper represents an observational study with an aim to understand the impact of digital mediums on design processes and design outcomes focusing on associative modeling using VPL. It contextualizes the difference, the associative modeling system as a parametric subset brings to design thinking when used as a medium to explore architectural design. It analyzes specific attributes of associative modeling, otherwise native to computational thinking, that contribute to the legibility of the design process. The paper demonstrates how associative modeling allows the design process to be examined and edited at any stage during and even after algorithmic development, bringing in flexibility. It is argued that digital design tool affordances enable students to develop multilayered and more structured design logic that augments cognition bringing more legibility to the design thinking process.

Keywords

architectural design pedagogy, digital design pedagogy, parametric design, design thinking, parametric design thinking, computational thinking, legibility, associative modeling using VPL

PhD research Centre, BNCA, Pune, India

Corresponding author:
Dhanashree Sardeshpande, PhD research Centre, BNCA, Maharshi Karve Stree Shikshan Samstha'S, Pune 411052, India.
Email: dhanashree.sardeshpande@bnca.ac.in

Introduction

Each era, in the evolution of architectural design history, has facilitated a medium that brought in its varied opportunities, specific sensory characteristics, and practical challenges. The advancements in computer and information technology have brought in new affordances and a new medium, namely, the digital medium. The formal constructs and concepts of the paper-based culture of design existing in the 90s were thus deliberated and reformulated in the face of these new and unanticipated challenges. Earlier concepts such as representation and precedent-based design typologies were thus substituted by generation, animation, performance-based design, and materialization.[1]

Digital design thinking allows us ways to question cognition of design thinking in the presence of the new digital medium, affording us to understand the differences between traditional paper-based design and the new digital design mediums. It has emerged as an agency that allows designers to rephrase the relationship between the conception, generation, and production of architectural design.[2] In the past few decades, digital design and digital design thinking have appeared as alternative paradigms. The basis of this is computation; computers with their computational abilities extend the cognitive capacity of the learner. Its abilities to simulate, generate, and evaluate provide comprehension-related partnership and thus allow the computer to share the cognitive burden of a designer.[3]

The traditional design process is based on the designer or student's visual reasoning and intuitive reasoning making the process very opaque.[4] Many designers, when probed for reasons to explain their actions, are unable to provide explanations that give the right descriptions of their actions. Under this model, the design process assumes a "mystical" phenomenon.[5] This aspect highlights the opacity of the design conception method followed in design studios. If we investigate the very idea of form conception by designers that allows them to conceive a product, a building, or a city, it is often difficult to trace the process. It is difficult to establish whether the design output is a preconceived image of the narrative that the designers follow in their quest for design or that they design form by immaculate conception. Even if the designed form is justified as the one that is predominantly influenced by function, then is the functional merit always tested, evaluated, and validated, and if so, according to whom and by what criteria?[6] These discussions and questions reveal the inherent opacity in the design process that forms the basis of architectural design thinking in design studios.

Since architectural design pedagogy mimics architectural practice, it shares the inherent opacity, and lack of explicit communication. This makes architectural design thinking an exploratory process that is subjective and often chaotic. Speaking about the design thinking process, Bryan Lawson admits: "It rather resembles one of those chaotic party games where the players dash from one room of the house to another simply in order to discover where they must go next. It is about as much help in navigating a designer through the process as a diagram showing how to walk would be to a one-year-old child"[7] Many academicians, including the authors, have often dealt with the opacity of the design process in the studio wherein the students find it challenging to explain their design process and the subsequent design decisions. Usually, the design decisions are justified verbally through subjective lenses, the merit of which rests completely on articulation by the student. The explicit conveyance of design procedure is even more critical given the fact that the design tasks are often termed as underdetermined for the mere lack of proof toward supporting certainty of design decisions.

Traditional design pedagogical models are a function of a process that stresses thinking about design than exploring it, making the whole process, its tools, and methodology illegible and invisible. An explication of design process mechanisms is thus essential for the development of the design profession, both to authorize it as a professional discipline, and to help individual designers develop their creativity and designerly expression.[8] These discussions point toward a lack of transparency, and inherent ambiguity in the traditional design process that lacks the attributes of clear communication. Attributes of clear communication in design processes hereafter are defined as legibility by the authors. Studies on various pedagogical approaches have advocated inquiry and process-based pedagogical models based on creative thinking, experiential learning, and empirical decision-making, stressing the need for the inclusion of process-based exploratory methods that are central to digital design thinking and digital architectural design pedagogy.[9] The literature review on digital design thinking points toward the cognitive partnership that computational mediums bring in the digital design process. This paper represents an observational study to understand the impact of digital mediums on design processes and design outcomes focusing on associative modeling using VPL, where the domain of AI/ML is not included in the scope. The paper investigates the hypothesis to see whether the attributes of VPL as a digital medium also affect the legibility and conveyance of the architectural design process.

Parametric design thinking as a subset of digital design thinking

Beyond any particular formal style or design tool, parametric design thinking is emerging as a theoretical topic and a critical digital design model.[10] Parametric design thinking with its capacity for associative modeling allows architects to relate the various parameters of design. This associative relationship offers a variety of possibilities allowing the architect to move away from the predetermined design solutions.[11] Parametric design is a subset of digital design and a new approach to designing, understanding its unique method for generating design solutions and alternatives, is thus imperative. The premise of parametric design thinking allows ways to question the cognition of design thinking in the presence of a new digital medium. It allows us to understand the differences between traditional paper-based designs and new digital designs.

Associative modeling a subset of PDT

Associative modeling also termed parametric design is a system that allows the design of built artifacts or built environments through an associative frame that rests on a communicative relationship between parameters that affect the built geometry/artifact.[12] It is an iterative process that allows geometric and physical transformation through its dynamic dependencies. Being a subset of computational thinking, it is a form of analytical thinking that operates between Mathematical, Scientific, and Engineering thinking processes. It is a solution-based problem-solving method based on data. This characteristic allows it to identify with the mathematical thinking processes. It has the characteristics of being a large complex system that operates in relation to real-world constraints and allows it to be evaluated at every stage of development making it a keen to engineering thinking processes.

The current state of digital design pedagogy in India

Digital design education can be referred to as design education that applies various kinds of digital design knowledge. It includes algorithmic geometric modeling, rendering, multimedia, web-based systems, virtual reality, CAD/CAM, and rapid prototyping tools, to ubiquitous devices.[13] Curricula the world over have divergent approaches to design research and expect computer literacy at different levels in their curriculum. These courses operate in a multitudinal bandwidth from basic Auto CAD as representative software and image processing techniques to three-dimensional modeling software.[14]

Studies and research in India lack evidence of the conduction of digital design thinking exercises in architectural design studios. Contemporary research done in this domain is about the analysis of the pedagogical role programming languages play in studios abroad. Although the research includes surveys on the student perception of disruptive practices and their effect on pedagogy in the design-related stream, these studies lack demonstrative evidence. The research conducted in India till now has recommended various bandwidths of possible tools like BIM, augmented/virtual/mixed reality (AR, VR, MR) as potential mediums to disrupt design pedagogy. All the researchers acknowledge the need for more students to leverage the opportunity presented by digital mediums.[15] Although research exists in Design/architectural pedagogy, especially in architectural design, no demonstrative research has yet been done in digital design thinking based on visual programming or algorithmic designing tools in Indian institutes.

The Dr Bhanuben Nanavati College of Architecture, Pune, India, has developed a unique ecosystem in this domain. They started a postgraduate department of "Digital Architecture" in 2011 as an affiliated course to SPPU (Savitribai Phule University of Pune). Ably supported by a team of faculty proficient in digital/parametric pedagogy, the department has developed a robust ecosystem via the Digital Fabrication Lab (DFL) that houses subtractive and additive manufacturing/prototyping bays, including the 6-axis Kuka KR-30-3 robotic arm. This aspect has allowed the faculty involved a unique position to understand the impact of digital medium on design processes and outcomes. This research presents the observations of the process and outcomes of the digital design studio conducted in the second semester of the above-said 2-year postgraduate program. It contextualizes the difference, the associative modeling system as a parametric subset brings to design thinking when used as a medium to explore architectural design.

Example: The "Meta Urban Hybrid" studio

The paper reports on the processes and outcomes of a studio, based on a 16-week course that was recently conducted in the "Digital Design II" studio of the postgraduate course, namely, the M. Arch (Digital Architecture). The studio was titled "Meta Urban Hybrid" and was based on the premise of Pune potentially transforming into a megacity. The students were required to consider responses to several design challenges associated with the program. The brief focused on reimagining the urban tower typology into a hybrid space that would redefine social and functional urban spaces extending its usefulness to a palette of different stakeholders.

Considering the ease and dexterity that McNeel's parametric modeling environment for Rhinoceros™ (Grasshopper™) offers, it was chosen as the main computational medium. This allowed the students to use its variety of plugins and schemers. Furthermore, the course framework of M. Arch (Digital Architecture) in the institute ensures that the students are progressively introduced to various plugins of Grasshopper™ and other software platforms in their due course through different semesters. The said semester included a parallel studio that explored analytical software allowing the students to use various analytical plugins to evaluate their design decisions. The use of Rhinoceros™ and Grasshopper™ allowed the studio to critically understand and align to the methods of associative parametric design thinking that the medium afforded. The authors thus present the process and the outcomes of a recent architectural design studio as an example of how the VPL Grasshopper™ as a digital medium influences design cognition in an academic setting.

Decomposition and abstraction as a part of problem parametrization

The studio explored the relationship between morphological experimentation through form finding, geometry optimization, and performance evaluation (structural, climatic compositional, and programmatic, etc.) The studio demanded in-depth research of the site's surroundings. Rigorous mapping gave preliminary data of the stakeholder's numbers and other scalar quantities, which served as a database for the speculative strategies. The study of urban adjacency allowed the students to inspect their site as a specific urban aggregation that reflected specific conditions of economic and functional dependency of an urban patch. This was an exploratory phase that allowed the students to step out of their assumed notions. Relevant information was gathered about the site, users, and the immediate urban fabric. This allowed the students to understand social, spatial, economic, and cultural interactions in the micro aggregation around the site. The next step was analyzing and organizing user data to pinpoint the problem definition, leading to design ideation and space program; this was done using infographics.

In the initial stage, the studio used explication and abstraction to understand design goals. This explication led to problem parametrization and formed the first step of the parametric design studio. The explication phase of the parametric process relied heavily on generating analytical diagrams. These diagrams progressed from mapping related infographics that showed data-based associative dependencies between variables to expressive flowcharts. Diagrams at times were also products of an algorithmic process usually displayed as a palette of options that led to a process of optioneering and selection. These diagrams decomposed the design process into subsets and showed a relevant flow of information in the design process. Before jumping on to the algorithmic process in Grasshopper™, the students were asked to explicate the step-by-step logic of what they wanted to do. They were required to express a clear idea of how they were going to fulfill their design ambition. This step generated flow charts and pseudo codes. These pseudocode and flow charts are diagrams that show an informal description of the operating principle of a Grasshopper™ script. Finally, the generated pseudocode and flowcharts were assessed to determine if learners could follow the underlying algorithm or describe a system in terms of an algorithm.

Students explicitly expressed relations between various elements of their design palette; this was done to formulate a design strategy that responded to a specific design problem. Infographics were used to analyze and highlight the most powerful statistical relations between design parameters. The graphics in Figure 1 represent the quantification of users, linked to the mapping statistics as shown in the infographic. The students explained the relationship between spatial programs and user density integrated with respect to time. This helped prioritize spatial interactions within the typology.

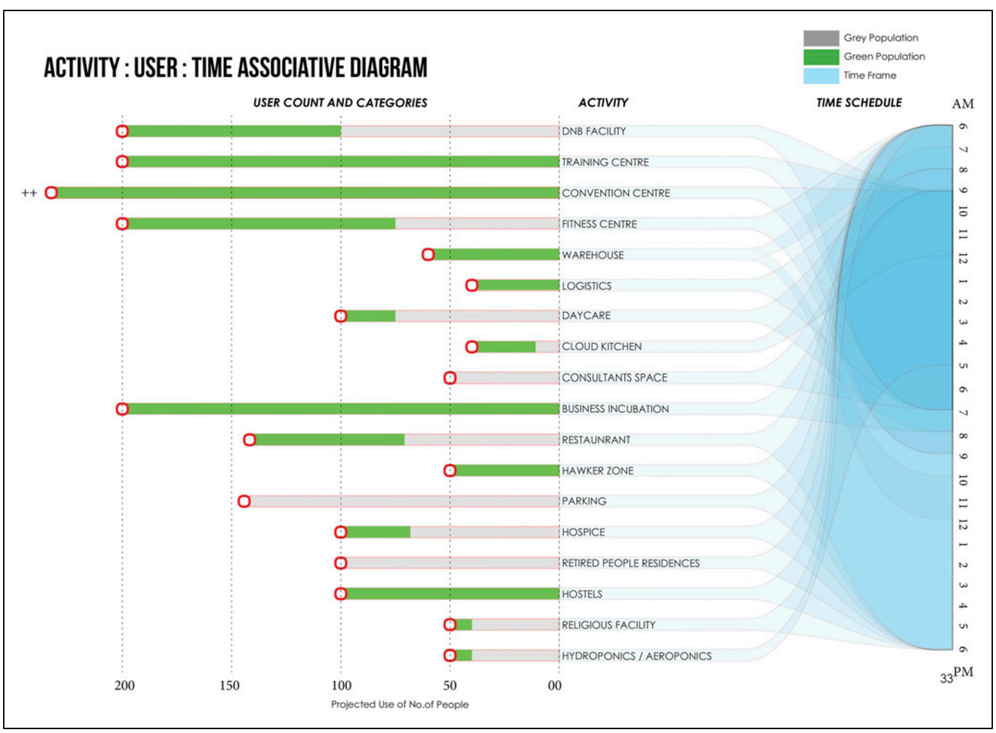


Figure 1. Data-based infographic to understand relations between the temporality of various activities and footfalls of users in a proposed hybrid program.

In this instance, the specific student group designed a programmatic hybrid that catered to the specific areas of aging and the young population concentration. Their mapping statistics showed an unprecedented concentration of daycare centers, hospitals, nursing homes, pharmacies, and several educational institutions and business centers. Thus, the infographic became an associative diagram bringing in an innate relationship among subsets of users. Graphically it is evocative of the green (youth) and the gray colors (senior citizens), each representing a specific age group characteristic. This explication thus helped them understand program density, the demographic distribution of activity, and the temporal use of functional areas.

These infographics prioritized a specific statistical relation that became the base to speculate further design strategies. With problems identified the next step was problem parametrization.

Problem parametrization and associative diagrams

Parametrization of a problem required the student to decompose the design goals into quantifiable and non-quantifiable entities. In this phase, the students expressed a systemic setup by clearly identifying inputs, processes, and outputs through diagrams called flowcharts. Flowcharts were used to represent algorithms visually; these diagrams had symbols to show the flow of data, processing, and input/output within an algorithmic script. Each design goal, namely, formal, compositional structural climatic, etc., became sub-systems linked through an abstract function. These abstract functions were action verbs that spelled spatial (geometric) transformation, a simulation relation, or an optimized selection. The following graphic is in Figure 2 shows such a graphical decomposition through an infographic. It shows the data-based relationship between functional, formal, and climatic design goals.

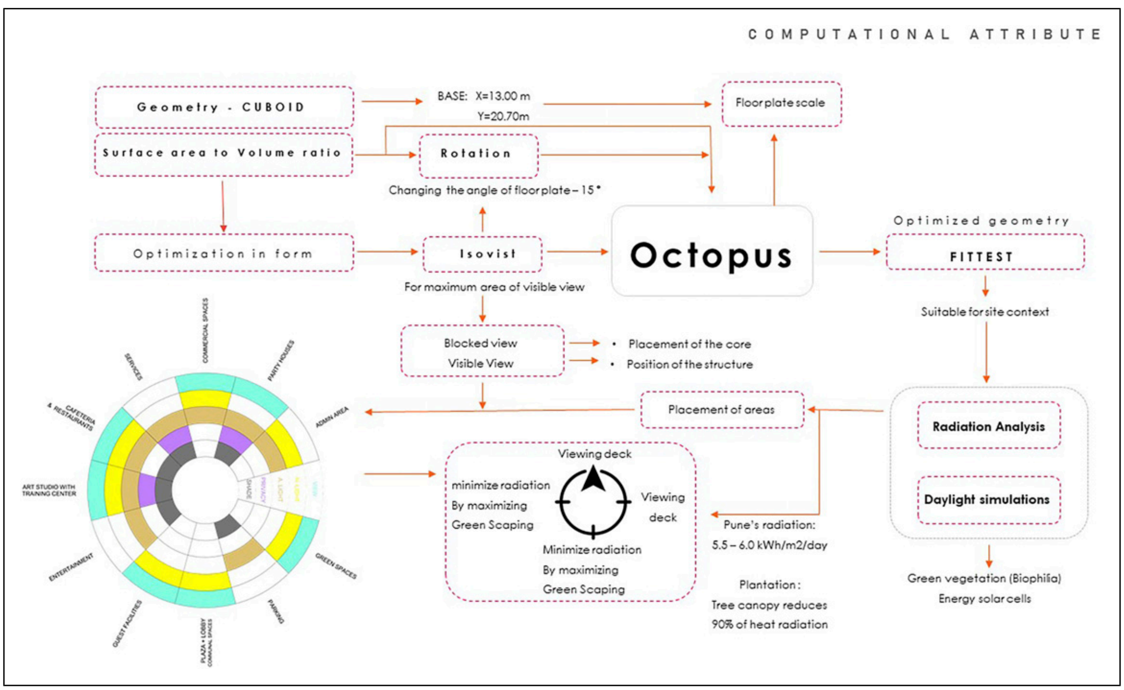


Figure 2. The diagram expressed as a flow chart/pseudocode shows an associative ecology explicitly showing external built-form geometry as a function of climatic analysis and afforded views.

The aim of representing the problem parametrization through diagrams was to prioritize controlling variables and filtering unimportant variables. The diagram yields a blueprint of the design process that shows the controlling features of the algorithms to follow. The image below explicitly shows a spatial program as a function of floor-to-volume ratio, this is parametrized in association with its climatic responsiveness studied via the "Ladybug plugin." The positioning of viewing decks in places was decided via the "Isovist" component that prioritized the best views. This associative relationship of various design elements stated the dependencies within a design system, allowing any change in the measure of a parameter to correspond to an exclusive output.

Each sub-constituent with its clear goal became set for the next step of algorithmic mediation. This led to the development of associative rule sets through specific Grasshopper™ scripts. The illustration in Figure 3 explains the conversion of user data, and mapping statistics that influenced the zoning on site. Urban adjacencies now influenced the site geometrically through its variable data. In one of the sites, a slum, an IT park, hospitals, and a riverfront park were used as influencers to decide the shape of the podium. The podium was to host hybrid public programs like the food court, public plaza, and a riverfront Park. Thus, it became imperative to determine the movement of various stakeholders. An algorithmic logic incrementally influenced the footprint of the podium, its scale, and position, and determined the pedestrian ingress and egress strategies. The intent was to allow the central space to be more visually and physically accessible from all the entry nodes.

The algorithm thus negotiated between walkable distances and visual access of different edge nodes to the central public space creating a palette of options. An evolutionary solver Galapagos was used to choose between algorithmic results. In this case, it determined the best fit for visual and physical access of pedestrian users to public programs. It also influenced the placements of vertical cores. The vertical cores were placed through an optimization algorithm that allowed the designers to control the distances between two vertical cores and visibility from the central public space. The ones that were meant to serve private spaces were spaced away from public reach and visibility.

Plurality of solutions

The algorithmic system allowed dynamic relations between sub-constituents of a design system and each element had a measure of influence in the associative system allowing multiple iterations. Figure 4 shows the optioneering through Octopus for optimum geometry that satisfies minimum heat gain, maximum view, and a usable functional floor-to-volume ratio. The generation and exploration of a larger number of possible design solutions and options at every stage allowed the students to articulate their choice decisively.

Performance validation and optimization

The genre of performance design models allowed students to validate the performance of their design models rendering credibility to their design process. The explication-abstraction and instrumentalization in prior stages helped students ascertain their morphological drivers and articulate the design process. At this point in their design process, students chose to harness the ability of performance drivers to articulate their design morphology as shown in Figure 5. Grasshopper™ offered many components that simulated the design's environmental, structural, and formal attributes and allowed students to estimate the performance outcomes of their designs through iterative evaluatory feedback. In some cases, it was used as a fundamental attribute of form-making. These simulations available in the form of plugins of Grasshopper™, allowed daylight, acoustical, structural analysis, material optimization, and other evaluatory feedback that informed design decisions in the process.

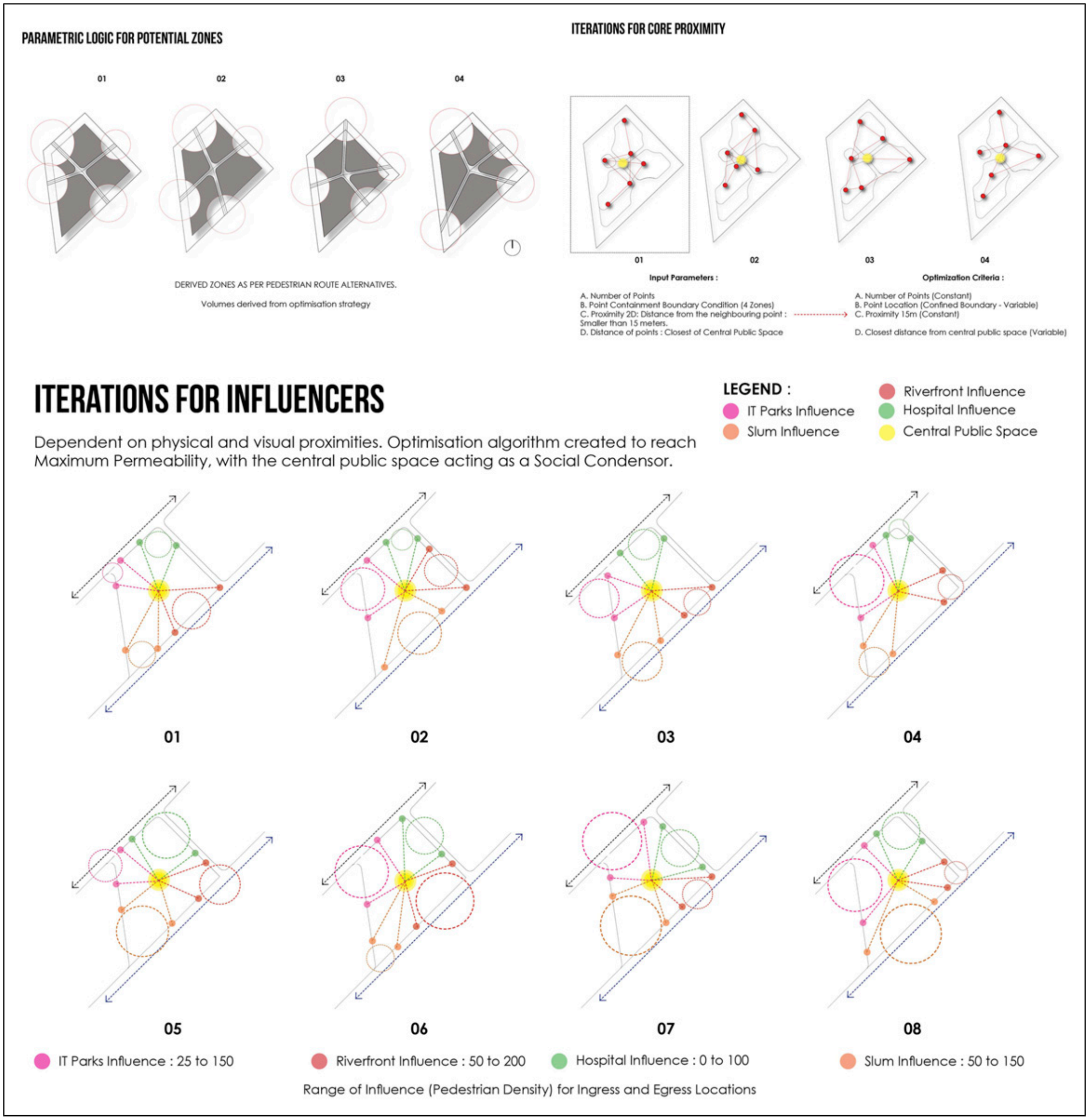


Figure 3. Understanding the influence of urban adjacency, varying radii are set to define the range of users, demarcating potential public zones, the shape of the podium, and the placement of cores based on distances and visibility logic.

Multicriteria optimization

In the due course of the design process, associative modeling systems also allowed students to engage in plural performative evaluation instead of consequential step-by-step validation of parameters through multicriteria optimization. The evolutionary solvers helped them to impartially score the multiple options that the Grasshopper ™script produced. The students used evolutionary solvers like Octopus to facilitate multicriteria optimization as shown in Figure 6. The associative modeling's attribute of producing multiple

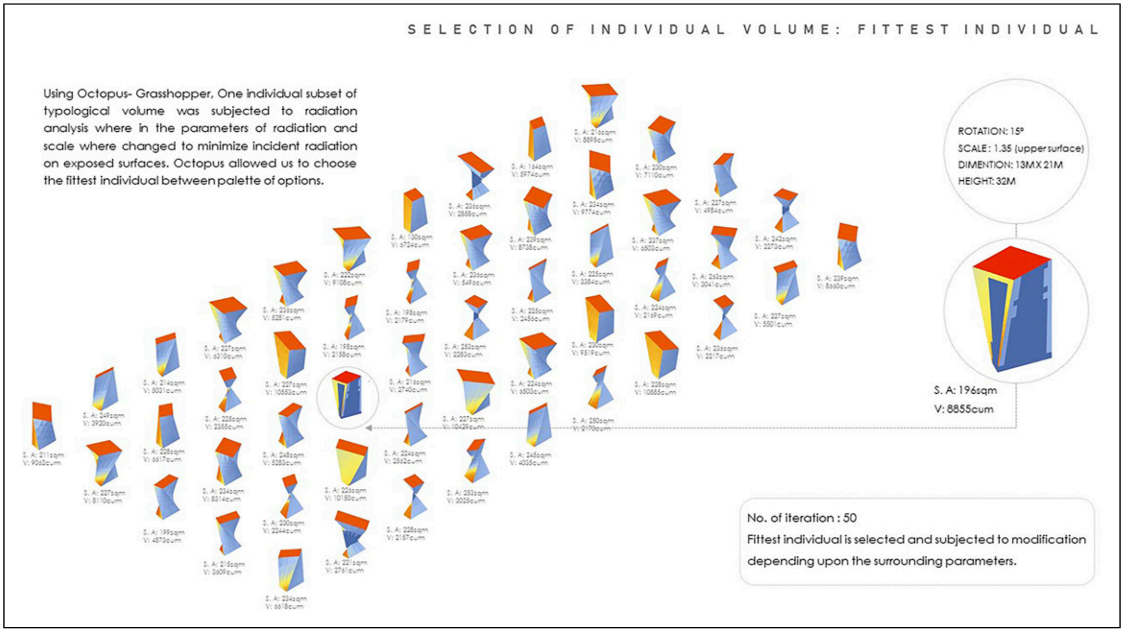


Figure 4. Optioneering through Octopus for optimum geometry that satisfies least heat gain, maximum view, and a usable functional floor-to-volume ratio.

options allowed exploration during the initial stages of strategic decision-making and the design's performative evaluation stage. Variations brought about by a Grasshopper™ script helped them navigate requirements of brief such as circulation, functional requirements, and physical and programmatic constraints and dependencies. At this stage, the intensity of supervisory engagement also helped them focus on aesthetic decisions, cultural context, etc. which allowed the students subjective freedom. Though outliers of a parametric design process the subjective decisions also contributed to the decision-making.

Discussions

This research points toward the distinctive design thinking that associative modeling medium affords the students in its due process. This class of parametric design thinking, namely, the associative parametric design signifies a major shift as it uses an algorithm. An algorithm is a computational procedure including a set of step-by-step rules to solve a problem through decomposition, abstraction, generalization, deduction, and induction; thus, the same process also finds its imprint in the system that efficiently uses these algorithms. The major attributes like explication, problem parametrization, and abstractions are obligations of the process as afforded by the associative modeling medium. Explication is the essential part of a parametric thought; parametric design through associative modeling allows the users to make the associated relationships between physical, geometrical, and analytical attributes of a design problem and thus brings in a fundamental change to the design thinking method.[16] Some principles within this class of parametric thinking are native to computational thinking, explication being one of them. It was noted that the processual discipline of parametric thinking demands changes in the traditional modes of design thinking toward problem-solving.

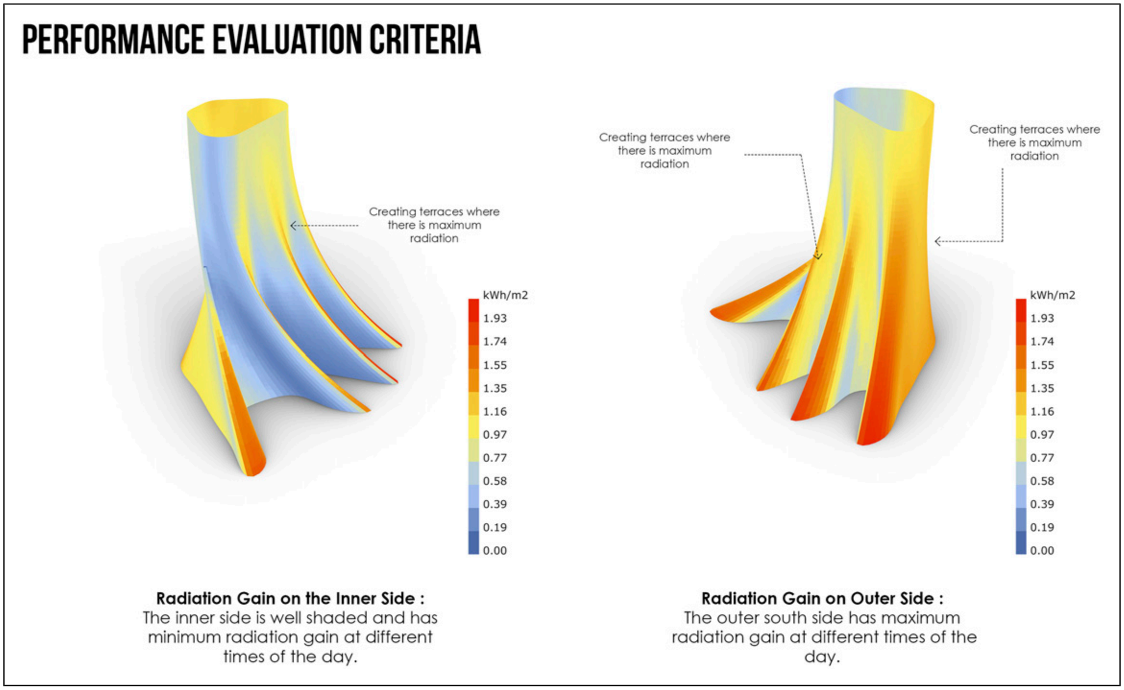


Figure 5. The graphic shows the use of daylight simulation using Ladybug to evaluate the heat gain response wrt the incident radiation on the built form.

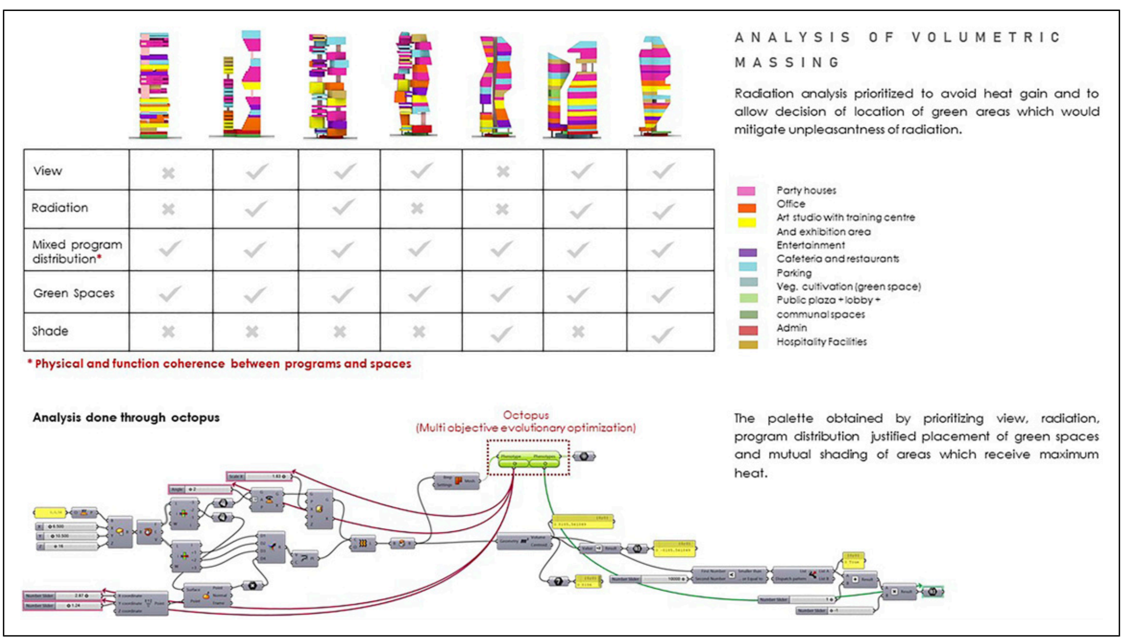


Figure 6. Optioneering as a product of multi-optimization criteria for exploratory massing options. Octopus as an evolutionary solver helps impartial scoring of parameters.

These changes as demonstrated above appear from the level of problem formulation as the problems must be interpreted and formulated to enable computers and other digital tools to solve them.

Cause effect of decomposition of a design system

Computation is not just about learning programming skills but more about structuring information and developing logic.[17] In the problem formulation stage, the studio used explication and abstraction as a method for understanding design goals. This explication helped the students understand the relationship between the programmatic, functional, and compositional parameters of the design brief. It helped them see the innate programmatic dependency of various functions across their hybrid typology defining its distinctive character.

Associative diagrams allowed the students to see the architectural design as a system that demonstrated a dynamic relationship between its sub-constituents. Each sub-constituent allowed the designer to perceive a design goal suited to it. Such explication also helped students to prioritize their design goals. When there are multitudes of parameters coinciding with design goals, it helps to explicate the design process and thus makes it an essential step in problem parametrization. These communicative diagrams helped them decide and convey design milestones.

Decomposition became the next stage that allowed the students to concentrate on the subset of this layered system. Decomposition demonstrated an interaction between its constituent parts. The associative system displayed the order of data flow in an explicit and editable form. Such associative diagrams allowed the students to logically organize and analyze data, bringing in innate relationships between constituents of subsystems.

The underlying construct of computational thinking is defining abstraction. "Abstractions are the 'mental' tools of computing. Computing is the automation of our abstraction."[18] Abstraction was thus used as the next step to decide the relation between subsets of this decomposed system, this becomes an important step in problem parametrization. Each design goal, namely, formal, compositional structural, climatic, etc. then became subsystems linked to each other through an abstract function. The abstract functions were action verbs like spatial/geometric transformation, a simulation relation, or an optimized selection. Problem parameterization involves the decision of quantifiable and non-quantifiable goals.[19] The parameters that were earlier implicit in the traditional design methods now had to be explicitly expressed, bringing more legibility to the process. Decomposition and abstraction are inherent processes that maintain a demonstrable and legible associative relationship between sub-constituents of a design program.

Cause effect of performance validation

Performance evaluation as an attribute of parametric design brings transparency to the validation of a built form against set criteria. Students used the exploratory process for evolving better and more performatively resilient structures. The computer vis a vis its performance models shoulder the cognitive burden by allowing simulation, evaluation, and generation reducing the subjectivity of a design process. The communicative result of simulation helps students justify their design decision. Evolutionary solvers Galapagos/Octopus allow students to use multicriteria optimization and arrive at optimized solutions.

Cause effect of optioneering

The significant advantage of algorithmic automation in parametric design is the variety of design options that designers can optioneer from a range of solutions. Processes such as these allow the medium to partner with the designer by engineering an option. It considers various options and then impartially scores by filtering in

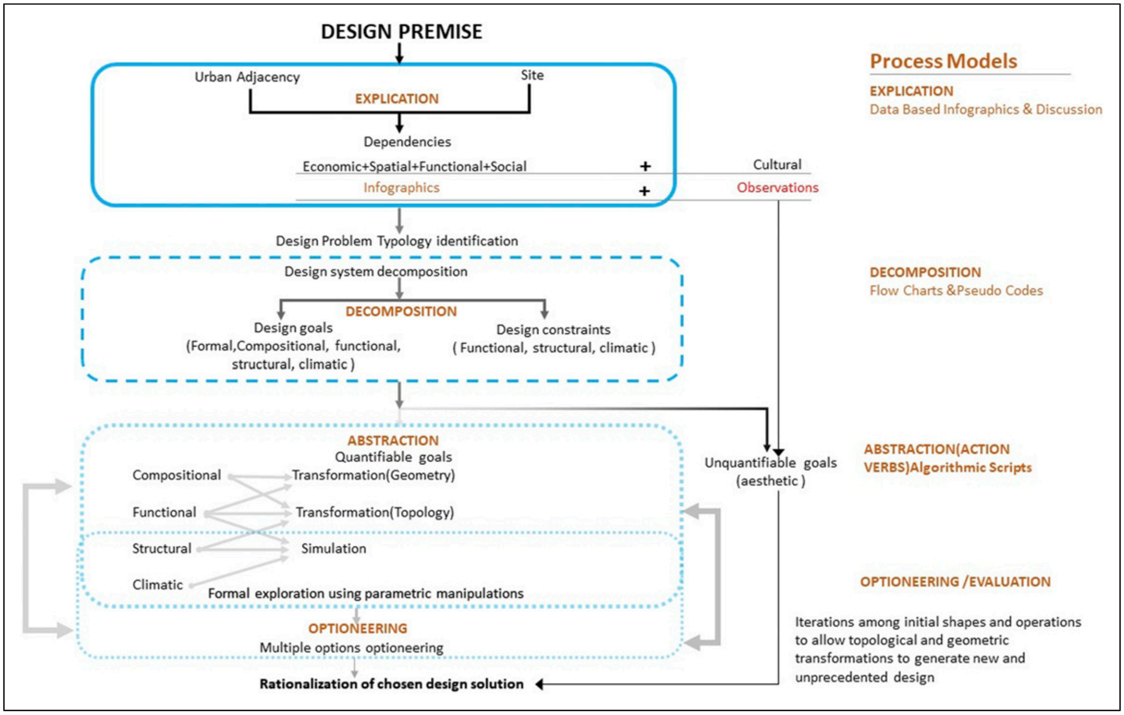


Figure 7. Diagram showing the author's perception of process interpretation and specific attributes of the parametric process. The incremental transparency indicates legibility and arrow thickness corresponds to the magnitude of iteration cycles. The subjective decisions are outliers but also contribute to design decisions.

accordance with input criteria. This is done through an in-depth and robust analysis of the range of options. The process of decision-making becomes legible. It also amounts to value addition by reduced manual work.

Conclusions

An associative modeling system as a subset of a class of parametric design tools displays striking characteristics that are native to computational thinking. When used for architectural design problem-solving, it demands some obligatory processes. At the problem decomposition stage, associative diagrams display the dynamic relationship between the sub-constituents of a design program. They help establish design milestones and explicitly convey the design procedure. Students' otherwise implicit decisions during the design process are now declared explicitly.

The parametric design thinking method mirrors a scientific thinking process as it allows a rigorous, impersonal mode of procedure dictated by the demands of logic and objective procedure. Once the design milestones are divided into quantifiable and non-quantifiable goals, the process sets the design free from the overpowering subjective bias and prejudice of the designer's narrative. Parametric design thinking stresses explication and allows the design process to be examined and edited at any stage during and even after the algorithmic development imparting flexibility. Design decisions are made through a recursive process that is cyclically refined by allowing constant feedback and testing as shown in Figure 7.

Performance evaluation attributes of the medium allow the functional, environmental, and structural merits to be tested extending the demonstrability of design decisions and making the design thinking process more legible. The extensive bandwidth of evaluation plugins helps in impartially scoring design decisions amongst a variety of solutions. This supports cognition in the architectural studio and allows the students to interact with the medium in a novel way. The process-based methodology imparts legibility to the design process and allows designers to extend beyond fixed singular design solutions. It also facilitates the explicit conveyance of the design procedure.

Rapid changes in computational design warrant a more extensive, empirical study toward expanding the digital paradigm taxonomy. The authors intend to continue their research by conducting empirical research in the field. They intend to study and measure the effect of digital mediums on the design cognition of architecture students in an experimental studio setup. The study will continue to expand the existing conceptual models of digital design thinking and contextualize the Indian contribution to the parametric design pedagogy.

Acknowledgments

The authors hereby acknowledge the work of Architect Kaushik Sardesai for his input throughout the semester as a co-faculty of the "Digital Design Studio" Sem II. The authors also acknowledge the students of the M. Arch 2019–2021 batch for their work in semester II of the "Meta Urban Hybrid" studio conducted at the M. Arch Digital Architecture Department at Dr Bhanuben Nanavati College of Architecture, Pune, India.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Dhanashree Sardeshpande https://orcid.org/0000-0002-7769-4560

References

1. Riccobono A. *Architectural design in the digital era. Identifying computer influences and new expressive trends in current architecture*. Palermo, Italy: ICAR/14,Universita Degli Studi Di Palermo; 2014.
2. Oxman R. Theory and design in the first digital age. *Des Stud* 2006; 27(3): 229–265.
3. Salomon G, Perkins DN and Globerson T. Partners in cognition: extending human intelligence with intelligent technologies. *Educ Researcher* 1991; 20(3): 2–9.
4. Kalay YE. *Architecture's new media: principles, theories, and methods of computer-aided design*. MIT Press; 2004.
5. POPTECH (Mar 12, 2010). Neri Oxman: On Designing Form [Video]. YouTube. https://www.youtube.com/watch?v=txl4QR0GDnU
6. Oxman N. *Neri oxman: on designing from archdaily.com*; 2012. Retrieved May 29, from. https://www.archdaily.com/238362/neri-oxman-on-designing-form
7. Lawson B. *How designers think*. Routledge; 2006.
8. Bordal SA. *Unfuzzing design: how progress is made towards unknown goals*. Kolding, Denmark: Designskolen; 2019.

9. Chokhachian A and Atun RA. A framework for exploring the role of parametric design on design procedure. In: International Conference on "Unspoken Issues in Architectural Education", Gazimagusa (Famagusta), North Cyprus, 2014
10. Oxman R and Gu N. *Theories and models of parametric design thinking*. ECAAEE: Vienna,Austria; 2015. https://www.researchgate.net/publication/279199673_Theories_and_Models_of_Parametric_Design_Thinking/link/558f187808aed6ec4bf526c4/download
11. Karle D and Kelly BM. *Parametric thinking*. Parametricism: Acadia Regional, University of Nebraska - Lincoln; 2011. https://www.academia.edu/43484505/Parametric_Thinking
12. Chronis A, Liapi KA and Sibetheros I. A parametric approach to the bioclimatic design of large scale projects: the case of a student housing complex. *Automation in Construction* 2012; 22: 24–35.
13. Chiu M-L. *The jump of digital design thinking: overviews of digital architectural design education CAADRIA proceedings*. 2006. http://papers.cumincad.org/data/works/att/caadria2006_027.content.pdf
14. Oxman TKEMR and Martens B. Ditching the dinosaur: redefining the role of digital media in education. *IJDC* 2004; 8: 01.
15. Babbar N. (2018). *Digital Permeations in Architectural Design Studios*. IJETSR 5(3), https://www.academia.edu/41988881/Digital_Permeations_in_Architectural_Design_Studios
16. Woodbury, Robert &Williamson, Shane & Beesley, Philip. (2011). Parametric Modelling as a Design Representation in Architecture: A Process Account. Proceedings of the Canadian Engineering Education Association. 10.24908/pceea.v0i0.3827
17. Soleimani A. *Computational design thinking and thinking design computing*. 2018. https://www.researchgate.net/publication/337069310_Computational_Design_Thinking_and_Thinking_Design_Computing
18. Wing JM. Computational thinking and thinking about computing. *Philos Trans R Soc A: Math Phys Eng Sci* 2008; 366(1881): 3717–3725.
19. Brown NC and Mueller CT. Design variable analysis and generation for performance-based parametric modeling in architecture. *Int J Architectural Comput* 2019; 17(1): 36–52.

Journal of Engineering Education Transformations

CURRENT ISSUE

Year: 2024, **Volume:** 38, **Issue:** 2

Search here ...

Examining the relationship between self-reflection and academic achievement in problem-based learning

Chetan Sahasrabudhe
Dr B N College of Architecture for Women, Savitribai Phule Pune University

Abstract— **Problem-based learning (PBL) has been an essential pedagogical strategy in teaching and learning Architectural Design since the early days of the discipline. As with any pedagogical strategy, multiple factors impact the learning outcomes in a PBL-based classroom. Among them, 'reflection' features frequently in the literature. This essay examines the relationship between reflection or more specifically, self-reflection and academic achievement in PBL. The examination is based on Reflective essays written by the students at the end of the semester. Reflective Essays are correlated with academic achievement in the subject of architectural design. The essay concludes that there is a strong correlation between self-reflection and academic achievement.**

***Keywords*— Architecture; Design; Problem Based Learning (PBL); Self-Reflection.**

***JEET Category*—Practice**

I. Introduction

DESIGN studio occupies a central position in the predominant pedagogical model of teaching architects. Lawson in his design expertise identified five features of a design studio (Lawson & Dorst, 2009). First, a studio is a place where students and teachers are in the same space for a long time. Second, the studio has a lot of unstructured time with some scheduled activities like 'crits' (short for 'criticism'). Third, the design studio is a place where students integrate learning from various other subjects like construction and structure. Fourth, in the studio, students learn by doing. The teachers set design problems for the students which the students solve. The idea behind this approach is to mimic the real-world practice of architecture, which is the fifth distinguishing feature of a design studio as argued by Lawson.

As a learning strategy design studios make use of problem-based learning (PBL) in general and pedagogy of creative problem solving in particular. The design studio lacks a rigid schedule and definite content to be 'taught'. This results in shifting the responsibility of learning in the studio onto the student. In other words, the design student must 'self-regulate' her design learning. Zimmerman has explained self-regulated learning as a three-stage cyclical phase process (Zimmerman & Moylan, 2009). The three stages are planning the learning or forethought, performing the task and third that of self-reflection.

The solutions to the design problem that students work on are assessed formatively (during the semester) as well as through a summative assessment (at the end of the semester). These assessments are primarily 'performance' oriented. Meaning, that the students are marked for the work that they produce and not for the processes that lead to the product. Such assessment does not assess either the forethought or the self-reflective phase of learning.

Both the stages, that of 'forethought' and 'self-reflection', have not received much attention in the context of architectural design education. The present essay focuses on self-reflection and examines whether the performance assessment of a problem-based design learning studio is correlated to student reflection

This paper was submitted for review on Month DD, YYYY. It was accepted on Month, DD, YYYY.
Corresponding author: Chetan Sahasrabudhe, Dr. B N College of Architecture for Women, Savitribai Phule Pune University, Maharashtra, India
Address: MKSSS's Dr. B N College of Architecture for Women, BNCA Campus, Karvenagar, Pune – 411052 (e-mail: chetan.s@bnca.ac.in).
Copyright © YYYY JEET.

II. Literature Review

Design studio pedagogy aims to take students on a path toward design expertise (Lawson & Dorst, 2009). To explain design learning, Lawson drew upon Dreyfuss's model of expertise and adapted it to design learning. Dreyfuss's model postulated that expertise acquisition goes through stages of development beginning from that of a novice, beginner, advanced beginner, competent, expert, master and finally visionary. Lawson further elaborated that the design student's transition between these stages is interrupted by 'dips and leaps-and-bounds' (Lawson & Dorst, 2009, p. 242). These transitions as Lawson says require reflection on part of the student designer (Lawson & Dorst, 2009, p. 216). A typical design studio assesses performance through a series of developmental performances and the final performance through the design portfolio. However as discussed above, mere performance is an incomplete pedagogical goal.

A more explicit connection between design learning and self-regulation was articulated by Powers (2017). Based on the PBL model as discussed by Savery (Savery & Duffy, 1996), Powers named four key elements of a design studio. These are

– 1. the studio, 2. Design problem, 3. Design teachers, and 4. Design learners. Powers states that for learning to happen, the students must be active participants and be able to regulate their learning. Powers further argues that while the first three of these elements receive adequate attention, the element of self-regulation receives the least attention although it is a critical component of problem-based learning.

Self-regulation as postulated by Zimmerman in his cyclical phase model consists of three iterative stages. These are, Forethought, Performance and Self-Reflection. An elaborated version of the cyclical phase model of self-regulation was published in 2009 (Zimmerman & Moylan). In this model, Zimmerman further elaborated on self-reflection as having two distinct aspects self-judgement and self-reaction. Self-judgement was discussed as having two further aspects namely self-evaluation and causal attribution. Self-evaluation is where the learner compares her performance with a standard. Causal attribution is where the student assigns causes like lack of ability, effort, time management etc. to her performance. As per Zimmerman, both evaluation and attribution are interdependent concepts. The second category of the self-reflection phase is self-reaction, which in turn is composed of self-satisfaction and adaptive/defensive decisions. Students prefer activities that produce satisfaction and avoid learning that leads to negative emotions. Adaptive decisions lead to choosing certain strategies of learning while defensive decisions may consist of procrastination, apathy etc. This activity of self-reflection cyclically affects the forethought phase on the path to gaining expertise. It, therefore, is a critical component of the self-regulated learning process.

In the field of design, the concept of self-reflection was extensively written about by Donald Schön (1982). Arguing a strong case for the role that reflection plays in education, Schön distinguished between two types of reflective practice. One is what he calls ‘reflection-in-action’ and the second; is ‘reflection-on-action’. ‘Reflection-in-action’ happens during the act itself. In Zimmerman’s terms, it is the reflection that happens during the phase of performance. According to Schön this type of reflection is only subtly different from ‘knowing-in-action’. Reflection in action has immediate significance for the task at hand. While ‘reflection-in-action’ is difficult to observe distinctly, what is relatively easier is to reflect on the ‘reflection-in-action’. As Schön says reflection-on-action can directly affect our future action or the forethought phase of Zimmerman’s model.

There have been many studies that relate self-reflection to academic achievement. These studies examine diverse student categories including high school students, students of occupational therapy, applied science and dental medicine students. A study by Lew (Lew & Schmidt, 2011) concluded that while there are positive effects of self-reflection they may not be measurable by academic test achievement. Even though the subjects were enrolled in a course which was organized based on problem-based learning, the authors state that although the ability of the students to self-reflect improved during the semester, there was no improvement in the test scores. A 2016 study from Iran (Ghanizadeh) examined 196 university students and concluded that self-reflection positively and significantly affected academic achievement. Cavilla’s study of high school students found a statistically insignificant correlation between academic performance and self-reflection (2017). A 2019 study of dental students found that there is a significant correlation between reflection and academic achievement (Loka, Doshi, Kulkarni, Baldava, & Adepu).

It appears that although there is an assumption that students who are better at self-reflection demonstrate better academic achievement, the actual research findings are divided. At best the research suggests a causal relationship at one end while on the other end the studies acknowledge the positive impact of self-reflection but do not support a causal relationship between self-reflection and academic achievement. However, there are not many studies that attempt to establish a correlation between academic achievement and self-reflection in the domain of architectural design discipline.

III. Purpose of the Study

There is little research on self-reflection in the context of architectural design education. I aim to examine the relationship between academic achievement and self-reflection. Along with this I also aim to understand intrapersonal factors that may contribute to academic achievement. Considering the qualitative and quantitative nature of the study, I use statistical analysis along with qualitative content analysis.

RQ 1 - Is there a relationship between academic achievement and the self-reflection skills that a student has?
RQ2 – What aspects do students consider important to design learning?

The findings may help educators in problem-based learning settings to improve student learning

IV. Methodology

A. Context

The study was conducted at a third-year design studio at a school of architecture located in Pune. The yearlong activity consisted of two courses Architectural Design IV and Architectural Design V. Out of a total of 56 credits of the year, these two courses account for 20 credits. 30% of weekly teaching time is allotted to the course. By its nature, the subject of design seeks integration and application of various other subjects. The faculty set up design problems for the students to work on. Architectural design course depends heavily on interaction between students and faculty as well as amongst students.

B. Participants

Forty students were part of the study. All the participants were female. Out of these fifteen participated in the voluntary writing of the reflective essay at the end of the year. The students were tutored by four facilitators as a team. As all participants were female, the study does not examine the impact of gender on the outcome.

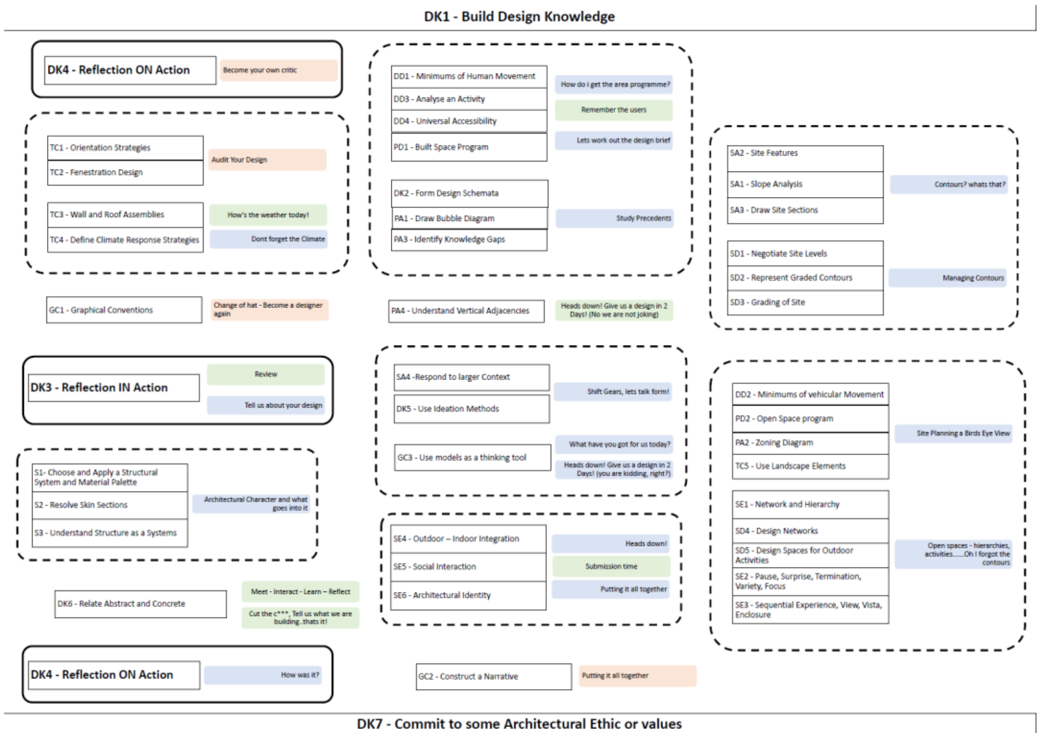


Fig.1. Graphic Syllabus which was shared with the students at the beginning of the Studio. The Syllabus mentioned the acts of reflection-in-action and reflection-on-action.

C. Measures for Quantitative Analysis

1) Academic achievement

The design portfolios produced by the students were assessed during the semester and at the end of the semester as per the University system through an oral examination. These marks consist of 50% marks given by the internal examiner and 50% marks given by the external examiner at the end of the semester assessment. An average score for both the semester-end exams was used for the study.

2) Self-reflection

For reflection-in-action, we (Studio Facilitators) relied on the critical incidence questionnaire (CIQ) developed by Brookfield (2017). This questionnaire was filled by students on a weekly or fortnightly basis by the students. However, the CIQ feedback was collected anonymously. It was not possible to correlate it with individual academic achievement and therefore has not been considered in the analysis.

The reflection-on-action component was requested from students as a voluntary submission. The students were asked to write letters to their juniors who would be joining the same studio after them. The studio team decided to ask for such a 'letter to your junior' rather than a specific reflective essay about self; for two reasons. First, research shows that self-reflection is a fraught task. As Malkki (2010) reports, an individual's natural tendency to maintain 'pre-existing structures' is a fundamental barrier to self-reflection. Self-reflection involves challenging self-assumptions which is problematic for the comfort zone that individual wishes to occupy. Externalizing the self-reflection in the form of a letter to someone else attempts to remove this barrier to self-reflection. Second, Nilson (2013) suggested that 'letters to the next cohort' as an assignment is more useful to the outgoing students because the assignment makes them reflect on 'where they slacked off and what it cost them, where they pushed themselves and how they benefited, how wisely they directed and monitored their studying, how diligently they planned and developed their assignments, and how effectively they budgeted their time during the term.'

The concepts of reflection-in-action and reflection-on-action were introduced to the students through a graphic syllabus (Fig 1). The graphic syllabus highlighted the role of reflective thinking about the expected studio learning. Other than the inclusion of the idea of reflection in the graphic representation of the syllabus, there was no attempt to introduce reflective thinking as a skill.

D. Data Collection and Quantitative Analysis

The data about academic achievement was collected from the exam results. The marks received for Design IV and Design V were averaged to a percentage value. At the end of the year, the students were asked to write a 'letter to their junior' who would be joining the studio in the coming year. As a studio facilitator team, we avoided giving the students a structure or a questionnaire for the writing of the letter. It was felt that doing so would bias the students in a particular way of thinking reflectively. Writing the essay was a voluntary submission and was not a marked assignment. The studio strength was 40, of which 15 students wrote the reflective essay titled 'letter to my junior'. The letters were coded, and themes were identified. The initial coding was compared to

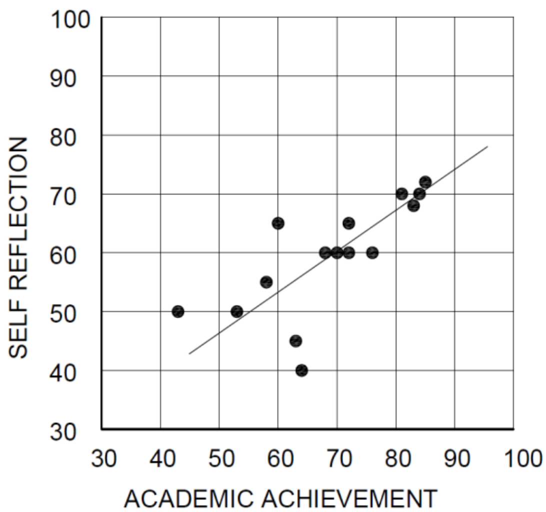


Fig. 2. Scatter plot of self-reflection scores and academic achievement

themes of self-reflection identified from Zimmerman's description of the self-reflection phase.

An evaluation checklist was prepared based on the categories (Table 1). The essays were marked out of 100 based on the checklist. To improve the reliability of the evaluation, two independent assessors were asked to blind-mark the essays based on the evaluation tool. A per cent agreement between the scores was calculated to be 74%.

A graph of the academic achievement (marks received at the end of semesters 5 and 6) and Self-reflection (Evaluated essay) was drawn as a scatter plot (Fig. 2). The plot showed a high degree of correlation between the two variables. Pearson's coefficient of correlation was calculated for the data which came to be 0.739, corroborating the scatter plot conclusion.

E. *Method for Qualitative Analysis*

The quantitative analysis led to answering of RQ 1 which investigated the relationship between academic achievement and self-reflection skills. A qualitative or inductive content analysis was done for the data to examine RQ 2 which was aimed at probing the aspects important for design learning.

Inductive content analysis is a qualitative method of analysis (Vears, 2022). This method is used to code data without using any preconceived categories. The essays were read multiple times and coding was done in an iterative manner until a saturation point was reached.

F. *Qualitative or Inductive Content Analysis*

The essays were coded for terms which were not covered in the evaluation check list prepared for the quantitative analysis. This analysis revealed various categories in an inductive manner. For something to be identified as a category, a criterion of 20% occurrence was used. For a sample size of 15 that the present study used, an occurrence of the concept in 3 or more essays was considered and analyzed. No grading was done based on frequency of occurrence as the sample size was deemed to be small for such an analysis.

TABLE I

CHECKLIST FOR EVALUATING THE SELF-REFLECTIVE ESSAYS

Evaluation checklist for self-reflection essays

Dear Assessor

Kindly assess the student reflective essays based on the following checklist. There are five aspects that you may use to evaluate the essay. Mark the essays out of 100. The marks allotted to each characteristic are indicated in bracket. The third column briefly describes the characteristics on the list.

Your assessment may be based on the characteristics mentioned, however please don't be limited by the list mentioned. The list is given as a guide for what to look for in the essays (letter to my junior)

Criteria	Marks	What to look for
Self-evaluation	25	Is the learner comparing her performance with a standard? Is there a mention of individual goal setting?
Causal Attribution	25	Is the student assigning causes to her performance? (Negative - lack of ability, lack of time, laziness) (Positive – inspiration, role models, classroom environment, faculty)
Self-Satisfaction	25	Is the student expressing satisfaction, happiness, sense of learning, progressing, achievement?
Adaptive Decisions	12.5	Are there any recommendations for learning strategies such as – time management, interacting, asking questions, learning new skills…
Defensive Decisions	12.5	Is there regret of certain decisions that did not work such as – losing track of time, aiming for perfection, not being regular, not understanding the overall picture, loosing opportunities to stay with the class…

These identified categories were labelled based on theoretical constructs from literature on Pedagogy. Subsequently, the categories were grouped under three broad themes: first, habits such as time management, second, attitude towards learning (performance orientation versus enjoying the work) and third, about the learning process (realizing importance of scaffolding and asking questions for learning).

V. RESULTS

A. *Quantitative Findings*

The scatter plot and Pearson's coefficient show a high level of correlation between the two variables of academic achievement and self-reflection. The students whose academic achievements are high have correspondingly high self-reflection scores.

Following is a list of illustrative quotes from the essays. These quotes are a sample of the criteria considered in the quantitative evaluation of the reflective essays –

1) *Self-evaluation*

Examples of goal setting and evaluating oneself against a standard.

"You are your own competition. Keep beating (sic) yourself and you shall succeed"

"It (setting goals) was a bit difficult approach to me, but I suggest you should give it a try"

2) Causal Attribution

These are examples of both negative and positive causes that students wrote about as causes of their academic achievement or lack thereof.

"Looking at other people's work always inspires me"
"Don't repeat the same mistake which I did of being lazy"

3) Self-Satisfaction

Feelings of happiness and sense of learning as expressed by students.

"Be focused on your work and enjoy the design process"
"I can say that I have learnt the most from doing case studies to design ideation, from overall design development to designing the smallest details"

4) Adaptive /defensive decisions

Students expressed regret about some of the decisions that they felt should have been made during the semester.

"Explore new presentation techniques"
"Please be regular with your work, it is very important"
"Speak up, talk about your design, ask questions about others' designs"
"Learn to communicate your thoughts and concepts through your design"

B. Qualitative Findings

While doing a content analysis of the essays, certain themes were found to be recurring. The themes along with example quotes from the essays are listed below

1) Time management

The importance of managing time was a frequently observed theme.

"Please be regular with your work"
"submit your work on time"

2) Enjoying work

Neuroscience recognizes that we have a 'pleasure brain'. Having fun and learning are closely related (Bain, 2012). The students who recorded enjoying the learning also scored better on self-reflection.

"Enjoy your journey"
"Enjoy this process of learning"
"I hope you will also enjoy it"

3) Scaffolding

As a technique of learning scaffolding was proposed by Vygotsky (Langford, 2005). As compared to learning by 'discovery'; scaffolding has an element of teaching intended in the concept. It is a stage-wise learning process that is supported by teachers.

"*Doing stage-wise design as per the schedule is the most important thing*"
'*we first learn the alphabets (sic), we are not worried about how to write a paragraph*"

4) Questioning / Discussing / Commenting

Asking a question in the classroom (Browne & Keely, 2007) and discussing (Brookfield & Preskill, 1999) have been considered important tools for a learner-centred classroom. Having a classroom atmosphere that promotes questioning and discussing would be a desirable goal of any teacher

"*Don't be afraid to ask questions*"
"*Always remember to speak up, raise your queries and opinions*"
"*Speak up, ask questions*"
"*Discuss your work regularly*"

5) Performance Orientation

The phrases quoted below, indicate that the students are more focused on performance in the final assessment rather than their learning. Research (Bain, 2012) indicates that students who have learning orientation are deep learners as compared to surface learners who focus just on getting good grades.

"*They* (the faculty) *like sketches"*
"*They* (the faculty) *have a lot of knowledge, so surely make a smart use of it"*
"*do the small exercises neatly"*

It is likely that the data from the 15 essays may not have been able to uncover a comprehensive set of aspects that students consider to be important for design learning. A larger data set collected over successive years will more likely reveal a comprehensive set of aspects. However, the analysis presented in this essay indicates the potential of self-reflective student essays in revealing aspects important for design learning.

VI. Conclusion

A strong correlation between 'self-reflection' and 'academic achievement' suggests that incorporating 'reflection-on-action' activities as part of the classroom may be beneficial for student learning. The second part, that of 'reflection-in-action' may be encouraged by encouraging the maintenance of a reflective journal.

Most of the themes as revealed by qualitative analysis (time management, scaffolding, questioning and discussing) are skills that can be incorporated into problem-based learning. The teachers may actively make these a part of the session plans. Lastly, the study provides teachers with a potential tool to improve student learning.

VII. Limitations

A follow-up study of the students during their remaining two years at the institute is likely to reveal whether the correlation between academic achievement and the habit of self-reflection continued in their senior years. The role played by the classroom practices of the faculty and the design studio environment has not been accounted for in the study.

VIII. Implication

Problem-based learning strategy is an established pedagogical tool. It is widely used in the teaching of architectural design. The practice of critical reflection through the writing of an 'end of semester' reflective essay can complement the pedagogical practice and positively impact academic achievement.

Acknowledgement

I acknowledge the active participation of my co-faculty – Sudhanva Kolhatkar, Shubhashish Subandh and Sandhya Nivsarkar during the conduct of the studio

References

Bain, K. (2012). *What The Best College Students Do*. Massachusetts: The Belknap Press of Harvard University Press.

Brookfield, S. D. (2017). *Becoming a Critically Reflective Teacher*. San Fransico, USA: Jossey-Bass.

Brookfield, S. D., & Preskill, S. (1999). *Discussion as a Way of Teaching - Tools and Techniques for Democratic Classrooms*: Jossey-Bass.

Browne, M. N., & Keely, S. M. (2007). *Asking The Right Questions: A Guide to Critical Thinking*. new Jersey: Pearson.

Cavilla, D. (2017). The Effects of Student Reflection on Academic Performance and Motivation. *SAGE Open, 7*(3).

Ghanizadeh, A. (2016). The interplay between reflective thinking, critical thinking, self-monitoring, and academic achievement in higher education. *Higher Education, 74*(1), 15.

Langford, P. E. (2005). *Vygotsky's Developmental and Educational Psychology*. New York: Psychology Press.

Lawson, B., & Dorst, K. (2009). *Design Expertise*. Oxford: Architectural Press.

Lew, M. D. N., & Schmidt, H. G. (2011). Self-reflection and academic performance: is there a relationship? *Advances in Health Science Education, 16*, 16.

Loka, S. R., Doshi, D., Kulkarni, S., Baldava, P., & Adepu, S. (2019). Effect of reflective thinking on academic performance among undergraduate dental students. *Journal of Education and Health Promotion, 8*(184).

Malkki, K. (2010). Building on Mezirow's Theory of Transformative Learning: Theorizing the Challenges to Reflection. *Journal of Transformative Education, 8*(1), 21.

Nilson, L. B. (2013). *Creating Self-Regulated Learners: Strategies to Strengthen Students' Self-Awareness and Learning Skills*: Stylus Publishing, LLC.

Powers, M. N. (2017). *Self-Regulated Design Learning: A foundation and framework for teaching and learning design*. New York: Routledge.

Savery, J. R., & Duffy, T. M. (1996). Problem Based Learning: An Instructional Model and Its Constructivist Framework. In B. G. Wilson (Ed.), *Constructivist Learning Environments: Case Studies in Instructional Design*. new Jersey: Educational Technology Publications.

Schön, D. A. (1982). *The Reflective Practioner: How Professionals Think in Action*. USA: Basic Books Inc.

Vears, D. F., & Gillam, L. (2022). Inductive content analysis: A guide for beginning qualitative researchers. *Focus on Health Professional Education: A Multi-disciplinary Journal, 23*(1), 17.

Zimmerman, B. J., & Moylan, A. R. (2009). Self-Regulation: Where Metacognition and Motivation Intersect. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of Metacognition in Education*. New York: Routledge.

ugccare.unipune.ac.in/Apps1/User/WebA/SearchList

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**International Journal of Architecture, Engineering and Construction**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	Action
1	International Journal of Architecture, Engineering and Construction	International Association for Sustainable Development and Management	1911-110X	1911-1118	View

Showing 1 to 1 of 1 entries

Previous 1 Next

International Journal of Architecture, Engineering and Construction

HOME | ABOUT | LOG IN | REGISTER | NEWS AND EVENTS | SEARCH | CURRENT ISSUE | ALL ISSUES | AEC FORUM

Home > **International Journal of Architecture, Engineering and Construction**

International Journal of Architecture, Engineering and Construction (ISSN 1911-110X [print] and ISSN 1911-1118 [online]), IJAEC, is published by the International Association for Sustainable Development and Management (IASDM) and North China University of Water Resources and Electric Power. IJAEC is a scholarly peer-refereed journal that promotes scientific, technical and managerial advances in the three intertwined disciplines of the built environment: Architecture, Engineering and Construction. IJAEC publishes original research papers, state-of-the-art review papers, novel industrial applications and insightful case studies in a broad scope of topics related to the three disciplines.

IJAEC also provides an AEC Forum, an interactive platform for international business organizations, public agencies, civil societies and academia to disseminate and exchange information, and to discuss on various issues in architecture, engineering and construction. Bookmark this Page

Editor-in-Chief
Xueqing Zhang, PhD, *Hong Kong University of Science and Technology, HKSAR, China*

Honorary Editor
Hojjat Adeli, PhD, *Ohio State University, United States of America*

Editor for Architecture
Ewelina Wozniak-Szpakiewicz, PhD, *Cracow University of Technology, Poland*

Editor for Engineering
Shunbo Zhao, PhD, *North China University of Water Resources and Electric Power, China*

Editor for Construction
Onishi Masamitsu, PhD, *Kyoto University, Japan*

USER

Username
Password
Remember me
Log In

JOURNAL INFO
- Editorial Board
- Editorial Office
- Production and Distribution
- Contact Us

BEST PAPER AWARD
- Best Paper Award

THEMATIC ISSUES
- Call for Thematic Issues

READERS
- Make a Search
- View Contents
- Recommend to a Friend/Library

AUTHORS
- Submit an Article
- Guide for Authors
- Ethical Guidelines
- Copyright Transfer Agreement

International Journal of Architecture, Engineering and Construction

Vol 8, No 4 (2019)

Table of Contents

Research Paper

International Journal of Architecture, Engineering and Construction
Vol 10, No 2, June 2021, 12021009, 1-11

Investigating the Impact of COVID-19 on Architectural Education from Students Perspective

Vasudha Gokhale* and Madhura Vaze

B. N. College of Architecture, Pune, India

Abstract: COVID-19 outbreak led to an extraordinary disruption to the educational landscape all over the globe. This research aimed to explore the impact of this global health emergency on students of architecture. It examines the psychological impact of the pandemic on the students and their preparedness for the expected post-pandemic new normal, representing the intense use of digital media in the context of architectural education. The methodology adopted included a questionnaire survey performed in architecture schools under the University of Pune India. To decipher acceptance of digital pedagogy, the technology acceptance model (TAM) is adopted. The study revealed that the pandemic imposed social isolation resulted in psychological disorders that adversely affect the transition towards digital pedagogy. The use of digital mode in architectural design studio was not preferred given the absence of interpersonal communication. It is found that the hurried shift in pedagogy from traditional to digital suffered from a lack of adequate resources that impeded knowledge dissemination. The findings contribute to the likely rapid pedagogic change in the architectural discipline capturing key aspects of digital pedagogy's success in the post-pandemic scenario. It will help academicians and policymakers to envision the post-pandemic educational landscape to move towards the predicted new normal.

Keywords: Pedagogy, locus of control, future anxiety, self-efficacy, temporal and spatial flexibility

DOI: http://dx.doi.org/10.7492/IJAEC.2021.013

1 INTRODUCTION

The Coronavirus 2019 (COVID-19) pandemic has created significant challenges for the global higher education community. Given the rapidly evolving situation due to the rapid spread of COVID-19 disease across the country education sector is experiencing a forced shift from offline to the online mode of teaching-learning where architectural discipline is no exception. The situation becomes as dynamic as to lead to a paradigm shift in the structure of architectural education. The shift from traditional teaching to online mode requires far-reaching institutional adaptations involving a significant transformation in the education process (Salama 2020). The crux of the problem is that the large scale and sudden shift of the learning process from classrooms to the home environment posed daunting challenges from a human and technological perspective. The unprecedented situation that education is facing amid pandemic outbreaks has a bearing on students' mental health and well-being. It is likely to affect their plans regarding higher studies and profession. This phenomenon indicated the need to understand the cognitive, behavioral, and social aspects as a part of the learning process that is taking place in architectural schools in India in the context of the current situation imposed by the pandemic outbreak.

This paper seeks to examine the myriad impacts of the COVID-19 outbreak on students of architecture. In the current situation, the accessibility of e-resources and its compatibility with students' targeted cohort needs is a matter of concern. The notion of the "new normal" as a new paradigm that includes digital media is discussed to provide insight for a smooth transition from traditional pedagogy to architectural education's digital mode. It has been argued that students' readiness to adapt to online education is of paramount importance as one of the major stakeholders to move towards a post-pandemic educational environment. Building on the conceptual and theoretical base, this research endeavors to decipher students' perceptions and their preparedness to predict the new or actual normal post-COVID architectural education. The study aims to provide a new understanding indicating future considerations for reshaping architectural education, responding to the post-pandemic educational landscape.

2 THE CHANGING PEDAGOGICAL IMPERATIVE

COVID-19 outbreak has imposed unforeseen circum-

*Corresponding author. E-mail: gokhale.va@gmail.com

stances that instigated the shift into digital teaching and learning due to the traditional format's anticipated uncertainties in the present context. In the current scenario pursuing teaching in a traditional classroom became difficult considering the need to maintain social distancing. In the given circumstances, digital pedagogy is recognized as an alternative for education to respond to this global health emergency (Verma *et al.* 2020). Many educational institutes switched to online teaching suspending classroom teaching to follow social distancing norms imposed by the Government to check the spared of COVID-19. As a result, the skyrocketing demand for distant learning overwhelmed existing portals and issues associated with the internet connectivity that hampered digital mode use. Schools of architecture recognized as the hub of social activity no longer remained physically accessible for students, resulting in the lack of interaction with peers and teachers, leading to social isolation. The transition to online teaching, where interaction takes place remotely, is coupled with numerous challenges that include communicating with the teacher and connecting with peers in virtual media, leading to anxiety and depression. Although adopted as an effective strategy for preventing disease spread, physical distancing interventions may have an adverse psychological impact on students in terms of reduced social support, increased loneliness, and depression (Reluga 2010). Besides, the pandemic's uncertain timeline snowballs anxiety and increases threat and panic (Banerjee and Rai 2020). For architectural course, face-face conservation, facial expression, and body language are significant aspects the lack of digital pedagogy that may affect the successful course delivery (Sun *et al.* 2020). Learner's attitudes play an important role in web-based education and teaching and learning methods. A positive attitude towards electronic media benefits the students and is likely to become part of the learning culture. Reflecting on this, it has become imperative to address students' expectations, interests, and needs, which are different from traditional classroom teaching (Ercan *et al.* 2014). Online teaching is considered an effective mode of learning; however, the associated non-verbal communication made it challenging for students (Khalil *et al.* 2020).

3 IMPACT OF PANDEMIC: PSYCHOLOGICAL PERSPECTIVE

An efficient and effective response to an emergency largely depends on the response mechanism's viability compared to the affected population's readiness or psychological state (Miller 2012). Due to quarantine, social distancing measures, and disruption in academic schedule, students are likely to suffer from psychological disorders such as future anxiety, stress, anger, loneliness, and boredom. Student's life has diverse roles and responsibilities, which often increase fears and anxiety about the future life. Future anxiety refers to the anticipation of the future with a sense of failure in light of self-realization and embodiment of aspirations. It is a state of fear, uncertainty, apprehension, and fear about undesirable events and changes likely to occur in the future (Akdeniz *et al.* 2020). A sudden disruption in education amid COVID-19 may result in the feeling of future anxiety that makes a student highly anxious and threatened about the future, the excess of which considered a psychological disorder.

Anxiety is a common phenomenon at a young age, which is an accepted interaction under specific circumstances. Students are often exposed to undesirable events that affect them emotionally, and they witness incompatibility with life courses and consequent arousal of agony, frustration, and stress (Matarneh and Altrawneh 2014). Anxiety is an anticipatory, cognitive, affective, and behavioral change that a person possesses in response to potential future threats and uncertainty (Grupe and Nitschke 2013). Given the country-wide lockdown and student safety concerns, most Indian Universities postponed examinations. The research indicated that many students were found worried and uncertain about getting an academic degree in time; besides, the possible cancellation of exams was found unfair to a certain extent (Satpathy and Ali 2020). The COVID-19 outbreak resulted in certain specific stressors that include worries about an individual and family's health. The fear and anxiety about an unknown disease multiplied for individuals having a family member or neighbor confirmed COVID-19 infection and consequent generation of depressive symptoms (Huarcaya *et al.* 2020). Major depressive disorder (MDD) is a commonly found mental disorder among students associated with role impairment, increased anxiety, lack of physical activity, and lower academic performance (Ebert *et al.* 2019). This phenomenon is likely to affect the student's ability to cope with the changing circumstances and respond to the forced immersion into digital learning, which is altogether different from traditional classroom teaching.

4 LEARNING IN DIGITAL MODE

Learning is recognized as a mutually interactive process between the learner and their environment. Students interact with classmates and teachers through various institutional contexts that reinforce students' learning and development in a college environment (Holly and Taylor 2009). Educational institutes have distinct cultures from each other, comprised of beliefs, values, and practices of the multiple stakeholders that result from congruency between values and practices and shapes its students' engagement (Carey 2018). Education aims to impart knowledge that enhances the competence of an individual (Zhang *et al.* 2015).

In the traditional way of education, knowledge generation manifests through the learning process that includes formal and informal learning in a school environment where socialization and interaction between students and teachers occur. In addition to formal or explicit knowledge, Weidman stressed students' need to acquire the tacit or informal knowledge in the context of a professional culture stimulated through interaction with their teachers and peers and shared experience they obtain in the learning environments (Weidman and Stein 2003). Social presence is an essential factor that affects a learner's satisfaction and success with an online course. It is the degree to which participants feel connected effectively in computer-mediated learning mode. Online resources transmit the vocal and nonverbal cues differently compared to face-to-face interaction, where social presence is more pronounced, enhancing the learning experience as a whole (Kim 2010).

The Digital learning process does not merely represent a learning system, but it is also a psychological phenomenon. Various psychological processes such as creative thinking and spatial cognition and motivation and an individual's learning style affect the learning process (Reffat 2005) The learning process has a strong interrelation with observable physical characteristics of the learning environment (Choi *et al.* 2014). Students entering a learning environment form a cognitive impression associated with an emotional response, whether physical or virtual. In both the teaching modes, meaningful interaction between learner and environment enhances the understanding and renders the learning experience enjoyable. Student's attachment to their learning environment is evident, the physical characteristics of which have significant behavioral and cognitive consequences. Students need a comfortable place for online learning to suit their needs to study for an extended duration (Maras *et al.* 2015). Physical discomfort interferes with learning, while a comfortable physical environment elicits a positive emotional response conducive to an enhanced learning experience (Harrop and Turpin 2013).

4.1 Academic Locus of Control (ALOC)

Classroom management is a process to monitor behaviors, relationships, lessons, and instructional settings for learners, becomes a complicated task in online learning. It is a preventive measure aimed to limit indiscipline, which needs efficient planning, relevant and exciting lesson plans, and effective teaching (Rufai *et al.* 2015). However, this aspect is not applicable in digital learning that calls for control of students' behavior independently. Online learners need to prepare their own structure around learning, determine the pattern of their engagement with course content, manage their time, and persist in the study despite competing life demands (Broadbent 2017).

The locus of control and computer self-efficacy have a bearing on learning outcomes within the technology environment. As per social learning theory, the locus of control is reinforcements that represent an individual's attitude. It refers to an individual's belief in their abilities to face and control life events. People with a strong locus of control believe that they are strong enough and control any positive or negative circumstances likely to occur in their life (Ogunmakin and Akomolafe 2013). Locus of control represents an innate trait that is a perpetual characteristic. In contrast, computer self-efficacy is a malleable trait that mediates the user's responses to stimuli within the usage situation and depends on the construct of perceived control, derived from the concept of locus of control (Zimmerman 2000).

4.2 Computer Self-Efficacy

As per the social cognitive theory, self-efficacy refers to a people's belief in their ability to accomplish a specific task or achieve a goal (Yokoyama 2019). Students' perceived efficacy towards using online resources dictates interaction with teachers and peers and determines their technology use behavior. Students' attitudes, digital literacy, social pressure, and competition significantly impact computer self-efficacy (Peechapol *et al.* 2018). The high degree of computer efficacy motivates students to participate in the virtual learning process and supports satisfaction. They tend to continue learning through online mode (Yavuzalp and Bahcivan 2020). Students who are experiencing online learning mode the first time may have apprehension about their self-efficacy, which is likely to affect their learning self-efficacy, computer self-efficacy, family and peer support determine learners' persistence in online education. The research established that self-efficacy has a profound impact on learning, motivation, and academic achievement. Notably high-level self-efficacy facilitates an individual to take up challenging tasks, pursue a longer duration to complete them, and exert extra effort to achieve the intended aim (Çelik 2015).

5 ADAPTABILITY AND ACCEPTANCE OF DIGITAL PEDAGOGY

A right learning environment supports positive emotions, which enhance the learning experience and the learning outcome where the learner's acceptance and intention towards digital technology become imperative (Strielkowski 2020). Technology acceptance depends on the beliefs and attitudes of the intended users, and it modifies achievement emotions, which in turn hinder or foster the learning process by and large (Pekrun *et al.* 2011). The research suggested that users' intention to continue using technology is determined by satisfaction, which is determined by system quality, information quality, service quality, perceived ease of use, perceived usefulness, and cognitive absorption (Roca and Chiu 2006).

The technology acceptance model (TAM) theorizes that technology usage depends on its perceived usefulness and ease of use, which dictates behavioral intention, attitudes, and usage behavior (Lee *et al.* 2003). Variables considered in TAM include perceived usefulness, ease of use, intentions, and attitude to use digital technology and external variables such as technology self-efficacy, subjective norms, and facilitating conditions (Scherer *et al.* 2019).

The physical environment characteristics in an educational setting directly impact teaching and learning activities, which need to be looked at from the student's perspective. The academic environment is invariable coupled with positive emotions such as pride, hope, enjoyment, and negative emotions such as anxiety, anger, hopelessness, and boredom, representing achievement emotions. As per the control-value theory, control and value, related appraisals mediate the learning environment, which impacts students' responses and emotions. The learning environment's characteristics in light of educational value and controllability are the primary sources of learners' participation in learning activities to achieve desired outcomes (Pekrun *et al.* 2011). Students' perception of value and control is different in the online and on-campus learning environment, affecting their achievement emotions, and learning outcomes (Stephan *et al.* 2019). Students often find online teaching mode more democratic and equitable as all the participants have an equal voice, and no one dominates the interaction (Kim 2010). However, the lack of physical interaction in online education disrupts continuity and flow due to the inherent limitation of technology and resources, which hamper the learning process. The flow theory postulates that an activity's unobstructed experience maintains a flow that helps students concentrate and make the learning experience exciting and enjoyable (Shin 2006). Flow experience refers to the state of absolute immersion and intense concentration in a particular activity that provides intrinsic enjoyment and a meaningful learning experience (Admiraal *et al.* 2011). It has been stated that obstacles in using technology imply to the user's mind and emotions rather than the technology itself (Zurloni *et al.* 2011).

6 DIGITAL DESIGN STUDIO PEDAGOGY

In the wake of advances in digital and telecommunication technologies, the phenomenon of designing in a virtual environment is reconfiguring traditional architectural design studio, which is the backbone of architectural education (Ciravoğlu 2014). Architectural education is moving towards digitalization, where students are using the simulation-based design process to incorporate experimentation and thinking through making (Tang and Marcu 2015). This process operates in the physical environment of the architectural studio. The construction of knowledge and learning takes place in conventional architectural studios by exchanging ideas, criticism, discussions on design amongst peers and faculties (Saquib 2019).

Architectural design studio education aimed at the initiation of creativity achieved with enhanced social interaction and collaboration (Sidawi 2013). The design studio is a social learning space where teaching and learning processes occur in the face-to-face mode in a physical space (Salama 2013). Students and teachers communicate and collaborate via asynchronous digital tools in the absence of spatial or geographical barriers in a virtual design studio. Such an environment facilitates students to communicate with teachers and peers and join or leave class at any time (Rodriguez *et al.* 2018). Architectural design studio operates in phases where interaction between phases becomes imperative. In this context, multiple intelligence theory presents an apt analytical frame (Kvan and Jia 2005).

Multiple intelligence theory suggests a particular pluralistic concept of intelligence that includes nine types of intelligence: Linguistic, Logical-mathematical, Spatial, Kinesthetics, Musical, Naturalist, Interpersonal, Intrapersonal, and Existential (Chang and Hung 2018). A useful virtual studio paradigm is based on the contention that human intelligence is multifaceted, and students require different types of intelligence in different measurements (Jommanop and Mekruksavanich 2019). Given the restricted face-face interaction, learning digital skills and student's proficiency in using digital tools in the design studio received paramount importance in the present context. Each stage of a disaster has a different degree of complexity in the context of organizational involvement, time demands, and functional needs, which in turn calls for action based on specific objectives (O'Sullivan *et al.* 2013). An unexpected extreme event is invariably associated with a surprise that tests a society's performance and often reveals the failure of the norms, rules, behavior, or infrastructure capacity to handle an emergency (Longstaff and Yang 2008).

7 RESEARCH METHOD

This research is aimed to investigate the impact of the COVID-19 outbreak on students of architecture. The study is conducted in architecture schools affiliated with the Savitribai Phule Pune University (SPPU), India. The survey instrument comprised a questionnaire, administered in 9 schools of architecture under the University of Pune. The analysis is based on 360 responses obtained from the questionnaire administered through the Google survey. The impact of COVID-19 is examined in terms of 5 psychological constructs adopted from the Major Depression Inventory representing depression symptoms

(Bech *et al.* 2011) and future anxiety (Al-Ferhat *et al.* 2019). To unfold acceptance of digital pedagogy from the student's perspective, the technology acceptance model (TAM) is adopted, assuming that acceptance of digital mode depends on the two core constructs, perceived usefulness and perceived ease of use, in addition to the locus of control and computer self-efficacy as external variables (King and He 2006). Student engagement in online learning is explored to depict students' perception about its use in the future; besides, the level of satisfaction is delineated, which is recognized as a pre-condition to adopt digital pedagogy (Fredricks *et al.* 2004).

The questionnaires were rated on five-point Likert scale to score the levels of the degree. Data is analyzed with arithmetic means and standard deviation. Criteria for mean value are considered as 4.51–5.00 indicate the highest degree, 3.51–4.50 high degree, 2.51–3.50 medium degree, and 1.51–2.50 low degree, 1.00–1.50 lowest degree. SPSS software is used to assess the relationship between the variables; the findings are presented in the next section.

8 MAJOR FINDINGS

In India, institutes were asked to promote digital learning to continue with the current course delivery by the Ministry of Human Resource and Development (MHRD) on 20th March 2020, with the suggestion to provide e-content free of cost to students. Lockdown was imposed on 25th March 2020 for 21 days, which is continued due to 103 schools of architecture closed down in Maharashtra, affecting 5,672 students (COA 2020). In response to guidelines by MHRD, the University of Pune directed all the affiliated institutes to start the use of digital media to continue the course delivery and pending assessment. Architectural school's initiative was quite visible, indicated by students' participation in online classes from March to September 2020. Analysis indicated that in March, 45% of students regularly attended online classes, 44% in April, 42% in May, with a gradual increase of 58% in June, and 83% in July. As shown in Figure 1, after 5 months, about 17% of students did not have an opportunity to attend online classes, which indicates a break in their academic schedule. This aspect affects their academic progress and results in dissatisfaction and unrest.

The lockdown was imposed when the academic session was about to over, and students were either submitted their assignments or about to do that. Pending assessments and uncertainty about the upcoming examination were another matter of worry for students. The breakup of students' responses to their concerns about submissions, exams, and assessments is shown in Figure 2. Analysis indicated that about 50% of students were "very much" worried about submission, assessments, and exams, 34% were worried much, 12% were worried to a certain extent; however, just 4% showed their reluctance about this aspect. The worries regarding academics increased students' concerns regarding their future who were already struggling to adapt to this unprecedented situation.

8.1 Impact of Digital Pedagogy

Students learning online are often found more stressed emotionally, suffering from several pervasive problems, anxiety disorders, depression, which profoundly impacts their academic outcomes. Student's perception regarding impact of digital mode of teaching is obtained in light of psychological problems they experience and their concerns about future. Student's responses for 5 variables representing psychological impact and 8 variables about future anxiety obtained. The mean score for psycholog-

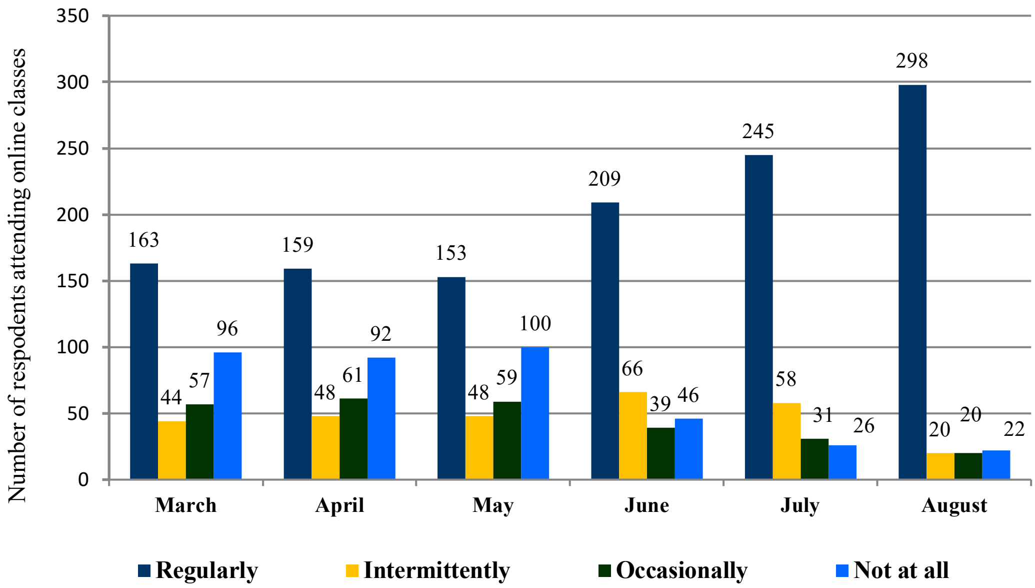


Figure 1. Participation in online classes

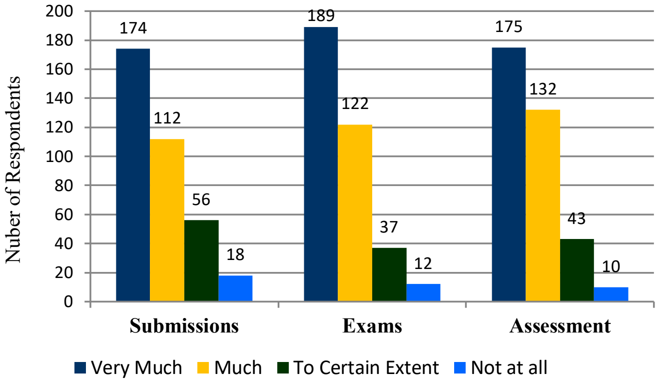


Figure 2. Student's concerns about academics

Table 1. Impact of digital pedagogy – psychological impacts

Psychological impacts	Mean	Standard deviation	Level
Nervous, anxious	3.09	9.82	Medium
Low interest	3.6	10.68	High
Less self-confident	3.525	30.99	High
Life isn't worth living	3.99	70.42	High
Trouble in sleeping	3.55	40.39	High

Table 2. Impact of digital pedagogy – future anxiety

Future anxiety	Mean	Standard deviation	Level
Career	2.49	32.24	Low
CORONA batch	3.19	31.47	Medium
Bad effect on studies	2.83	11.98	Low
Travel option	2.05	58.19	Low
Decreased budget	2.62	25.06	Low
Future study	3.06	16.11	Medium
Cope up with online learning	3.43	31.58	Medium
I will not be able to excel	3.72	48.80	High

ical and future anxiety variables and the level of impact are presented in Tables 1 and 2 respectively.

The mean score values revealed that students felt low self-confidence and interest in the day–to–day life and sleep disturbances at a high mean score; however, the feeling that "life is not worth living" indicates depression symptoms and indicates the high psychological impact on students. On the future anxiety scale, the mean score ranged from 2.05 to 3.72. Students' apprehension about "not able to excel due to lack of resources at their place" ranked first with a score of 3.72 that represents a high mean score. As indicated in the Tables 1 and 2, students were nervous and anxious to a certain extent. However, the feeling of lack of interest and self-confidence was pronounced. A disorder like trouble-sleeping is harmful to their optimal health.

8.2 Acceptance of Digital Pedagogy

It has been established that learning environments affect the cognitive, emotional, and motivational aspects of learning activity where the success of any pedagogical practice can be realized with its acceptance and effective use by intended users. As per TAM, acceptance of new technology has a bearing on two dominant features; ease in its use and its usefulness in the future. Student's response regarding the characteristics features; perceived ease, and usefulness of digital pedagogy, which affect its acceptance by the students is obtained as presented in Tables 3 and 4 respectively.

Table 3. Characteristic features of digital pedagogy – ease of use

Ease of use	Mean	Standard deviation	Level
Interaction	3.0	15.15	Medium
Better concentration	2.7	24.88	Low
Temporal and spatial flexibility	3.07	26.84	Medium

Table 4. Characteristic features of digital pedagogy – perceived usefulness

Perceived usefulness	Mean	Standard deviation	Level
Useful for design studio	2.3	37.41	Low
Useful for technical subjects	3.0	23.55	Medium

Perceived ease of use in terms of an opportunity to interact, flexibility in time and space was accepted partially. The mean value is within the medium range; however, the concentration level was not found better, as indicated by the low mean score. The usefulness of digital pedagogy for design studio scored a low mean score; however, the score range was medium for technical subjects. As indicated in the Tables 3 and 4, the student's perception about ease of use is marginal because maintaining concentration in online classes is difficult. The temporal and spatial flexibility and facility for interaction add to ease of use to a certain extent.

8.3 Participation in Digital Learning

Students' participation in digital learning depends on the quality of the learning experience and their capability to adopt the technology. An enjoyable learning experience represents high perceived competence accompanied by positive task-related value beliefs. Academic self-efficacy is the student's perception of their ability to perform a task formed through past experiences and their environment interpretation. The high positive level of academic self-efficacy provides enjoyment in the learning process, whereas a hostile relation leads to anxiety. Learning and participation in a virtual environment depend on students' ability to regulate their behavior and activities that depend on their locus of control. Reflecting on this, personality traits such as students' self-rated computer efficacy in terms of their proficiency in the use of various activities associated with online teaching and their experience in attending online classes that indicate their locus of control are further explored. The survey data is analyzed for variables representing computer self-efficacy and locus of control, as presented in Tables 5 and 6 respectively.

Table 5. Personality traits affecting adoption of digital pedagogy – computer self-efficacy

Computer self-efficacy	Mean	Standard deviation	Level
Computer software	3.9	64.71	High
Online meetings	4.33	81.19	High
Scanning and uploading	4.4	85.86	High
Computer programmes	4.28	78.57	High

Table 6. Personality traits affecting adoption of digital pedagogy – locus of control

Locus of control	Mean	Standard deviation	Level
Annoyed	3.0	17.07	Medium
Distracted	2.7	15.46	Low
Desperate	2.9	6.56	Low

Analysis indicated high computer self-efficacy as the mean scores were high; however, the locus of control variables scored low to medium. The student's self-rated computer self-efficacy, as shown in the Tables 5 and 6, is high. However, a lack of locus of control was reported. Because of the inefficiency of resources available, students get distracted, desperate, and annoyed at different scales depending on their personality traits. A Pearson correlation coefficient was computed to assess the relationship between variables related to computer self-efficacy and students' perceived usefulness for design and technical subjects, as shown in Table 7.

As indicated in Table 7, students' self-rated proficiency in using different formats for online meetings and uploading, scanning documents was found correlated with values $r = -0.116^*$, $p = 0.027$ and $r = -0.126^*$, $p = 0.017$, respectively. Students' proficiency in attending online meetings and scanning and uploading documents affects their perception regarding the use of digital media in design studios. The correlation between students' perceived ease of use and their willingness to use digital mode of learning and their overall satisfaction is examined; the result of statistical analysis is presented in Table 8. The opportunity provided by digital media for interaction and level of concentration offered was found correlated with student's willingness to continue online learning as per values $r = 0.471^{**}$, $p = 0.000$ and $r = 0.527^{**}$, $p = 0.000$ respectively. Similarly, students' satisfaction regarding online learning experience was correlated with ease-of-use variables with values $r = -0.487^{**}$, $p = 0.000$, and $r = -0.513^{**}$, $p = 0.000$.

Table 7. Relationship b/w computer self-efficacy & perceived usefulness of digital pedagogy

Variables	Correlation	Technical subjects	Design course
Software	Pearson Correlation	−0.097	−0.064
	Sig. (2-tailed)	0.066	0.226
	N	360	360
Online meetings	Pearson Correlation	−0.085	−0.116*
	Sig. (2-tailed)	0.109	0.027
	N	360	360
Scanning/ uploading	Pearson Correlation	−0.079	−0.126*
	Sig. (2-tailed)	0.136	0.017
	N	360	360
Computer programmes	Pearson Correlation	−0.073	−0.090
	Sig. (2-tailed)	0.167	0.087
	N	360	360

* Correlation is significant at the 0.05 level

Table 8. Relationship b/w ease of use intended future use of digital pedagogy and satisfaction

Variables	Correlation	Intended future use	Satisfaction
Interaction	Pearson Correlation	0.471**	−0.487**
	Sig. (2-tailed)	0.000	0.000
	N	360	360
Better concentration	Pearson Correlation	0.527**	−0.513**
	Sig. (2-tailed)	0.000	0.000
	N	360	360
Temporal and Spatial Flexibility	Pearson Correlation	−0.022	0.062
	Sig. (2-tailed)	0.676	0.239
	N	360	360

** Correlation is significant at the 0.01 level

9 DISCUSSION

The challenge was not completing course contents but exploring possibilities to cater to students' diverse needs through available resources considering the reality of economic, social, and geographical disparities. In this research, respondents were from 76 towns and cities located in 11 states of India, out of which the majority were small towns where internet connectivity issues persist.

The pandemic outbreak resulted in a paradigm shift in student's day-to-day living and pattern of learning. Students who used to wake up early morning and proceed towards college campus with joy and fun now found themselves in social isolation compounded with loneliness and sheer boredom. The gestures like the personal greeting, the high-five, the smile, the intimacy missed altogether, as an online classroom environment exuded good humor and bonhomie. Social networking, huddles, friendship, and bonding were on hold, weeding out the fun & euphoria of student life. Students' social isolation forced them to make fundamental changes, tussling with their cocoon's new learning format. Notably, students of architecture in India are not familiar with online teaching; still, they acquired many virtual media competencies to a certain extent. Students who were indulged in mastering drafting and presentation skills through software currently put their efforts into log-on, adjusting computer configuration to suit the bandwidth, using a webcam, file up and download, and sharing the screen. These processes exerted an excessive cognitive load on students and detracted them from the course contents and knowledge delivered.

Online learning necessitates more self-discipline and maturity to adopt a new learning way irrespective of technological and emotional barriers. It appears that students' proficiency in using electronic media varies greatly depending on their aptitude and inclination, where the successful use of a system results in a feeling of pride, and failure leads to frustration. Positive emotions such as enjoyment instigate and moderate students' interest and intrinsically and extrinsically motivate them to participate in the learning activity. Students' positive emotions, students rely on others for guidance to participate less and suffer from boredom, which distracts them from learning and detrimental to their wellbeing. The use of digital pedagogy depends on perceived ease of use and technology-related beliefs, and students' emotional experiences. This aspect indicated the need for more efforts to make online pedagogy user friendly and enjoyable. COVID-19 outbreak opened up numerous opportunities for education with accelerated use of digital technologies and encouraged students and teachers to become tech-savvy.

Students of architecture need to deal in a digital environment with multiple formats of information simultaneously, where constructs such as locus of control and computer self-efficacy play a crucial role. Although most architectural schools made efforts to start using digital media, the digital divide was noted. Given the practical and technical constraints that often emerge in electronic media use, including software incompatibilities and lack of required resources, students cannot perceive this format as suitable and enjoyable. The need to provide the required resources and living environment conducive to digital learning realized. Acceptability of virtual design studio suffers from preconception regarding face-to-face studio-based pedagogy, which results in limited use of asynchronous tools and hampers the shift from traditional to virtual mode. Students are often deprived of direct interaction and get immediate feedback from the teacher, which results in lesser engagement in the learning process. This shift towards digital pedagogy is coupled with a caveat that technology's use may not result in meaningful learning using the technology to perpetuate the traditional teaching method without considering the intricacy associated with the digital media. The utilization of digital technology in architectural education is of paramount importance; consequently, it is desirable to reflect these trends on the philosophy, objectives, curricula, course contents, and teaching methods adopted in architecture schools.

10 CONCLUSION

This research looked into the impact of the COVID-19 outbreak through the lens of the students of architecture. This research revealed that the adoption of digital pedagogy resulted in a high level of psychological implications in terms of diminished interest, declining self-confidence, depression symptoms, and health implications such as sleeplessness amongst students of architecture. The student's high level of feeling of the worthlessness of life reflects signs of depression. Social isolation measures bear deep psychological consequences on students, such as depression, anxiety, inertia, stress. Lack of digital competences, availability of resources at their disposal emerged as new stress-inducing factors for students. The uncertainty about studies triggered future anxiety amongst students, particularly those about to complete their course encountered with a dire reckoning how to cope with this situation. Students were found nervous and anxious to some extent. Findings suggested that fear of not being able to excel in the studies and incompatibility in acquiring digital skills was associated with students' psychological distress. Analysis indicated that the students were very much concerned about higher studies because of pandemic imposed travel restrictions, which resulted in apprehensions about their professional careers. The COVID-19 outbreak affected family income that made students face a likely decrease in parents' funds for their day to day needs. Student's high self-reported computer efficacy indicated student's proficiency in using digital tools. However, they lack in self-regulated learning that characterizes digital pedagogy. It has been found that lack of adequate resources, internet connectivity mediated the relationship between ease in using digital tools. It is noted that constructs such as a facility for interaction and better concentration representing "ease-of-use" of digital media affect students' willingness to use it in the future and their satisfaction level. The lack of locus of control intensifies in the lack of interpersonal communication, which is an invariable part of the traditional teaching approach. Analysis indicated student's dissatisfaction with the usefulness of digital media, particularly for the architectural design studio. This research revealed that although online media facilitates meaningful knowledge acquisition with spatial flexibility and time efficiency, students were not in favor of its design studio use. This phenomenon indicates the need to make the architectural studio more interactive in post-pandemic architectural education.

Although the paradigmatic trend that has started by surprise is believed by many, it will profoundly impact architectural education. This research established that online learning's social context is qualitatively different from face-to-face learning and has significant implications for online learning design in the context of architectural education. The emerging paradigmatic trends endorsed how architectural schools in India are shifting towards online mode. It will likely influence architectural education and become a new normal in the aftermath of COVID-19. This research is based on six month's experiences gained by students of SPP University Pune. This research recommends conducting further studies to continue exploring the issues raised in this paper in different academic institutions. Technology-enabled education is the future of architectural education; it is essential to identify critical challenges from diverse perspectives in the current scenario. Once identified, academic leadership can address these aspects through research and innovations in focus areas to prepare for predicted post-pandemic new normal in architectural education.

ACKNOWLEDGEMENT

The authors are thankful to Dr. Abhijit Natu for his help in data processing for this work.

REFERENCES

Admiraal, W., Huizenga, J., Akkerman, S., and Dam, G. (2011). The concept of flow in collaborative game-based learning. *Computers in Human Behavior*, 1(27), 1185–1194. https://doi.org/10.1016/j.chb.2010.12.013

Akdeniz, G., Kavakci, M., Gozugok, M., Yalcinkaya, S., Kucukay, A., and Sahutogullari, B. (2020). A Survey of Attitudes, anxiety status, and protective behaviors of the university students during the COVID-19 outbreak in Turkey. *Frontiers in psychiatry*, 1(11), 695–701. https://doi.org/10.3389/fpsyt.2020.00695

Al-Ferhat, B., Jarwan, A., and Zuraikat, M. (2019). The role of self-discrepancy in generating future anxiety among university students. *Humanities and Social Sciences Reviews*, 6(7), 425–435. https://doi.org/10.18510/hssr.2019.7668

Banerjee, D., and Rai, M. (2020). Social isolation in COVID-19: The impact of loneliness. *International Journal of Social Psychiatry*, 6(66), 525–527. https://doi.org/10.1177%2F0020764020922269

Bech, P., Rasmussen, N., Olsen, L., and Noerholm, V. (2011). The sensitivity and specificity of the major depression inventory, using the present state examination as the index of diagnostic validity. *Journal of Affective Disorders*, 1(66), 159–164. https://doi.org/10.1016/S0165-0327(00)00309-8

Broadbent, J. (2017). Comparing online and blended learner's self-regulated learning strategies and academic performance. *Internet and Higher Education*, 1(33), 24–32. https://doi.org/10.1016/j.iheduc.2017.01.004

Carey, P. (2018). The impact of institutional culture, policy and process on student engagement in university decision-making. *Perspectives: Policy and Practice in Higher Education*, 22(1), 11–18. https://doi.org/10.1080/13603108.2016.1168754

Çelik, E. (2015). Mediating and moderating role of academic self-efficacy in the relationship between student academic support and personal growth initiative. *Australian Journal of Career Development*, 24(2), 105–113. https://doi.org/10.1177%2F1038416215583563

Chang, Y., and Hung, J. (2018). The effect of multiple intelligences-based instruction on learning motivation and learning achievement in science courses. *US-China Education Review*, 8(8), 329–337. https://doi.org/10.17265/2161-6248/2018.08.001

Choi, H., Merriënboer, J., and Paas, F. (2014). Effects of the physical environment on cognitive load and learning: towards a new model of cognitive load. *Educational Psychology Review*, 26(1), 225–244 . https://doi.org/10.1007/s10648-014-9262-6

Ciravoğlu, A. (2014). Notes on architectural education: An experimental approach to design studio. *Procedia - Social And Behavioral Sciences*, 152(1), 7–12. https://doi.org/10.1016/j.sbspro.2014.09.146

Council of Architecture (COA) (2020). Status of Institutions. Available at <https://www.coa.gov.in> (accessed on 2020/08/01)

Ebert, D., Buntrock, C., Mortier, P., Auerbach, R., Weisel, K., and Kessler, R. (2019). Prediction of major depressive disorder onset in college students. *Depress Anxiety*, 1 (36), 294–304. https://doi.org/10.1002/da.22867

Ercan, O., Bilen, K., and Bulut, A. (2014). The effect of web-based instruction with educational animation content at sensory organs subject on students' academic achievement and attitudes. *Procedia – Social and Behavioral Sciences*, 1(116), 2430–2436. https://doi.org/10.1016/j.sbspro.2014.01.587

Fredricks, J., Blumenfeld, P., and Paris, A. (2004). School engagement: potential of the concept, state of the evidence. *Review of Educational Research*, 1(74), 59-109. https://doi.org/10.3102%2F00346543074001059

Grupe, D., and Nitschke, J. (2013). Uncertainty and anticipation in anxiety: an integrated neurobiological and psychological perspective. *NIH Public Access*, 7(14), 488–501. https://doi.org/10.1038/nrn3524

Harrop, D., and Turpin, B. (2013). A study exploring learners' informal learning space behaviors, attitudes, and preferences. *New Review of Academic Librarianship*, 19(1), 58–77. https://doi.org/10.1080/13614533.2013.740961

Holly, K. A., and Taylor, B. J. (2009). Undergraduate student socialization and learning in an online professional curriculum. *Innovative Higher Education*, 1(33), 257–269. https://doi.org/10.1007/s10755-008-9083-y

Huarcaya, J., Meneses, A., and Luna, M. A. (2020). Psychotic symptoms in COVID-19 infection: a case series from Lima, Peru. *Psychiatry research*, 1(1), 293–295. https://doi.org/10.1016/j.psychres.2020.113378

Jommanop, T., and Mekruksavanich, S. (2019). E-learning recommendation model based on multiple intelligence. *The 14th International Joint Symposium on Artificial Intelligence and Natural Language Processing (iSAI-NLP)*, Chiang Mai, 1(1), 1-6, https://doi.org/10.1109/iSAI-NLP48611.2019.9045576

Khalil, R., Mansour, A., Fadda, W., Almisnid, K., Aldamegh, M., AlNafeesah, A., and Al-Wutayd, O. (2020). The sudden transition to synchronized onlint e-learning during the COVID-19 pandemic in Saudi Arabia: a qualitative study exploring medical students' perspectives. *BMC Medical Education*. 20 (1), 1–10. https://doi.org/10.1186/s12909-020-02208-z

Kim, J. (2010). Developing an instrument to measure social presence in distance higher education. *British Journal of Educational Technology*, 42(4), 763–777. https://doi.org/10.1111/j.1467-8535.2010.01107.x

King, W., and He, J. (2006). A meta-analysis of the technology acceptance model. *Information and Management*, 1(43), 740–755. https://doi.org/10.1016/j.im.2006.05.003

Kvan, T., and Jia, Y. (2005). Students' learning styles and their correlation with performance in architectural design studio. *Design Studies*, 26 (1), 19–34. https://doi.org/10.1016/j.destud.2004.06.004

Lee, Y., Kozar, K., and Larsen, K. (2003). The technology acceptance model: past, present, and the future. *Communications of the AIS*, 1(12), 752–780. https://doi.org/10.17705/1CAIS.01250

Longstaff, P., and Yang, S. (2008). Communication management and trust: their role in building resilience to "surprises" such as natural disasters, pandemic flu, and terrorism. *Ecology and Society*, 13(1), 1–3. https://doi.org/10.5751/ES-02232-130103

Maras, D. Flament, M., Murray, M., Buchholz, A., Henderson, K., and Obeid N. (2015). Screen time is associated with depression and anxiety in Canadian youth. *Preventive Medicine*, 1(73), 133–138. https://doi.org/10.1016/j.ypmed.2015.01.029

Matarneh, A., and Altrawneh, A. (2014). Constructing a scale of future anxiety for the students at public Jordanian universities. *International Journal of Academic Research*, 5(6), 180–188. https://doi.org/10.7813/2075-4124.2014/6-5/B.27

Miller. J. (2012). Psychological capacity building in response to disasters. *Columbia University Press, New York*. ISBN:97802315196.

Ogunmakin, A., and Akomolafe, M. (2013). Academic self-efficacy, locus of control and academic performance of secondary school students in Ondo State, Nigeria. *Mediterranean Journal of Social Sciences*, 4(11), 570–571. http://dx.doi.org/10.5901/mjss.2013.v4n11p570

O'Sullivan, T., Kuziemsky, C., Toal-Sullivan, D., and Corneil, W. (2013). Unraveling the complexities of disaster management: a framework for critical social infrastructure to promote population health and resilience. *Social Science & Medicine*, 1(93), 238–246. https://doi.org/10.1016/j.socscimed.2012.07.040

Peechapol, C., Na-Songkhla, J., Sujiva, S., and Luangsodsai, A. (2018). An exploration of factors influencing self-efcacy in online learning: a systematic review. *International Journal of Emerging Technologies in Learning (IJET)*, 9(13), 64–86. https://doi.org/10.3991/ijet.v13i09.8351

Pekrun, R., Goetz, T., Frenzel, A., Barchfeld, P., and Perry, R. (2011). Measuring emotions in students' learning and performance: the achievement emotions questionnaire (AEQ). *Contemporary Educational Psychology*, 1(36), 36–48. https://doi.org/10.1016/j.cedpsych.2010.10.002

Reffat R. M. (2005). Collaborative digital architectural design learning within 3D virtual environments. *The 10th International Conference on Computer Aided Architectural Design Research in Asia*, Kumamoto, Japan.

Reluga, T. C. (2010). Game theory of social distancing in response to an epidemic. *PLoS Computational Biology* 6(5), 1000793–1000799. https://doi.org/10.1371/journal.pcbi.1000793

Roca, J. C., and Chiu, C. (2006). Understanding e-learning continuance intention: an extension of the technology acceptance model. *Human–Computer Studies*, 64(6), 683–696. https://doi.org/10.1016/j.ijhcs.2006.01.003

Rodriguez, C., Hudson, R., and Niblock, C. (2018). Collaborative learning in architectural education: benefits of combining conventional studio, virtual design studio and live projects. *British Journal of Educational Technology*, 3(49), 337-353. https://doi.org/10.1111/bjet.12535

Rufai, M., Alebiosu, S., and Adeakin, O. (2015). A conceptual model for virtual classroom management. *International Journal of Computer Science, Engineering and Information Technology*, 1(5), 27-32. https://doi.org/10.5121/ijcseit.2015.5103

Salama, A. M. (2020). Coronavirus questions that will not go away: interrogating urban and socio-spatial implications of COVID-19 measures. *Emerald Open Research*, 2(14), 25–28. https://doi.org/10.11120/tran.2005.02020016

Salama, A. (2013). Seeking responsive forms of pedagogy in architectural education. *Field Journal*, 1(5), 9–30. https://dx.doi.org/10.35241%2Femeraldopenres.13561.1

Saquib, M. (2019). Designing, conducting and evaluating the effectiveness of a public interest integrated design studio. *International Journal of Architecture, Engineering and Construction*, 8(3), 32–40. http://dx.doi.org/10.7492/IJAEC.2019.016

Satpathy, D., and Ali, E. (2020). A study on psychological well-being of final year management students during COVID-19 pandemic lockdown in India. *The International Journal of Indian Psychology*, 2(8), 1–25. http://dx.doi.org/10.25215/0802.201

Scherer, R., Siddiq, F., and Tondeur, J. (2019). The technology acceptance model (TAM): a meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Computers and Education*, 1(128), 13–35. https://doi.org/10.1016/j.compedu.2018.09.009

Shin, N. (2006). Online learner's "flow" experience: An empirical study. *British Journal of Educational Technology*, 1(37), 705–720. https://doi.org/10.1111/j.1467-8535.2006.00641.x

Sidawi, B. (2013). Design studio education to foster creativity: influential factors revealed by a case study of the University of Dammam. *International Journal of Architecture, Engineering and Construction*, 2(4), 280–291. http://dx.doi.org/10.7492/IJAEC.2013.025

Strielkowski, W. (2020). COVID-19 pandemic and the digital revolution in academia and higher education. *Preprints*, 1(1), 1–6. https://doi.org/10.20944/preprints202004.0290.v1

Stephan, M., Markus, S., and Gläser, M. (2019). Students' achievement emotions and online learning in teacher education. *Frontiers in Education*, 1(4), 109. https://doi.org/10.3389/feduc.2019.00109

Sun, L., Tang, Y., and Zuo, W. (2020). Coronavirus pushes education online. *Nat. Mater*, 1 19(6), 687–687. https://doi.org/10.1038/s41563-020-0678-8

Tang, M., and Marcu, M. (2015). Physics simulation and form seeking in architecture design education. *International Journal of Architecture, Engineering and Construction*, 4(4), 184–192. http://dx.doi.org/10.7492/IJAEC.%202015.019

Verma, A., Verma, S., and Garg, P. (2020). Online teaching during COVID-19: perception of medical undergraduate students. *Indian Journal of Surgery*, 1 (82), 299–300. https://doi.org/10.1007/s12262-020-02487-2

Weidman, J., and Stein, E. (2003). Socialization of doctoral students to academic norms. *Research in Higher Education*, 1(44), 647–656. https://doi.org/10.1023/A:1026123508335

Yavuzalp, N., and Bahcivan, E. (2020). The online learning self-efficacy scale: its adaptation into Turkish and interpretation according to various variables. *Turkish Online Journal of Distance Education*, 1(21), 31–44. https://doi.org/10.17718/tojde.674388

Yokoyama, S. (2019). Academic self-efficacy and academic performance in online learning: a mini review. *Frontiers in Psychology*, 1(9), 27–94. https://doi.org/10.3389/fpsyg.2018.02794

Zhang, S., Ding, X., Gao, Y., and Hu, Z. (2015). PPP Project management knowledge: empirical assessment of continuing educational needs in infrastructure development in China. *International Journal of Architecture, Engineering and Construction*, 4(2), 89–102. http://dx.doi.org/10.7492/IJAEC.2015.009

Zimmerman, B. J. (2000). Self-efficacy: an essential motive to learn. *Contemporary Educational Psychology*, 1(25), 82–91.

Zurloni, V., Mantovani, F., and Mortillaro, M. (2011). Addressing emotions within e-learning systems. *Information Science Reference*, 1(1), 1245–1258. https://doi.org/10.4018/978-1-60960-503-2.ch509

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for **"Current World Environment"**. Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	Current World Environment	Enviro Research Publishers	0973-4929	2320-8031	from January-2020 to Present	View

Showing 1 to 1 of 1 entries

Previous 1 Next

ISSN: 0973-4929, Vol. 18, No. (**1**) 2023, Pg.

Current World Environment

www.cwejournal.org

Post Occupancy Evaluation of Indoor Air Quality in Green Rated Commercial Interiors

SUJATA ABHIJIT KARVE* and **RUCHA NACHANE**

Dr. Bhanuben Nanavati College of Architecture, Pune, India.

Abstract

Good indoor air quality is crucial for the health, happiness, and satisfaction of the occupants. Since we spend so much time indoors, it is essential to maintain a reasonable level of indoor air quality. One of the elements contributing to the decline in indoor air quality was the interior materials. Having acknowledged this, green building rating systems have incorporated the use of low-emitting materials as a credit that may be gained. A system for assessing commercial interiors with a focus on interior materials exists and has been used by several commercial offices. This study aimed to understand the indoor air quality in green-rated commercial interior spaces that have won points for the use of low-emitting materials and indoor air quality. A post-occupancy review was conducted on an IGBC rated green commercial interior office space, in which various pollutant concentrations were measured and observations were made regarding space usage, cleaning processes, and maintenance. Almost 41.9% of the areas that were studied had CO2 values that exceeded the threshold. Additionally, the concentration of $PM_{2.5}$ was elevated in all locations, particularly during partial occupancy. The findings indicate that the use of low-emitting materials and finishes in office interiors helped to reduce the concentration of pollutants in the indoor environment. However, the concentrations of these various pollutants also depended on several other factors, such as the ventilation system, the use of electronic equipment, the frequency of cleaning practises, etc.

Article History
Received: 20 August 2022
Accepted: 15 February 2023

Keywords
Green Interiors;
Indoor Air Quality;
Indoor Pollutants;
Low Emitting Materials.

Introduction

The nature of air within a space determines the air quality inside and is linked to the health, wellbeing, and comfort of the occupants.[1] Pollutant concentration within the standard limits renders the air quality as acceptable. Since we spend over 90% of our time inside, maintaining excellent indoor air quality is crucial2. Building characteristics like its design, construction, operation, and maintenance play a role in the building's energy consumption

CONTACT Sujata Abhijit Karve sujata.karve@bnca.ac.in Dr. Bhanuben Nanavati College of Architecture, Pune, India.

© 2023 The Author(s). Published by Enviro Research Publishers.
This is an Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi:

as well as its indoor air quality. The buildings should be designed considering occupant's health and well-being in-addition to functionality, aesthetics, energy efficiency and sustainability.

WHO defines Air Pollution as *"contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere."*[3] *Indoor pollution is defined as "the presence of physical, chemical or biological contaminants in the air."*[4]

Internal sources that release chemicals are one of the primary causes of indoor air pollution. Sometimes due to these substances the quality of air inside may be worse than the air outside. The concentration of indoor contaminants may increase due to poor ventilation, and air circulation, lack of humidity control, off-gassing from interior materials and finishes like paints and coatings, adhesives and sealants, carpets, furniture, and cleaning reagents. The effects of pollution may be short term or long-term depending on the nature of pollutant and period of exposure. Long term effects are manifested through respiratory problems, heart conditions, and even cancer whereas short term effects can be seen in the form of fatigue, headache etc.[5]

The need for airconditioned spaces has led to the design of airtight buildings. Connection between indoor and outdoor for ventilation has diminished leading to an increase in pollutant levels within a building. The effect is seen on the occupant's health, wellbeing, and productivity making it a matter of public concern. This led to the concept of "sick building syndrome" (SBS) which is a term used to describe circumstances in which building occupants have severe health problems that appear to be related to their stay in a building but for which no cause can be found.[6] According ASHRAE (62-1989), a building is termed as sick when more than 20% occupants complain of irritation, headache, etc. and feel relieved once they go out. There could be several reasons of air pollution inside a space other than biomass fuel burning and most of the people are under the impression that they are safe indoors.[7] Various studies have studied the effect of polluted air in various building typologies but not many studies are available on office interiors and academic buildings in India.[8] Though WHO (2002) mentions that the highest number of diseases in India are caused due to indoor air pollution exposure, less attention has been given to its study as compared to outdoor air pollution.

The sealed environments in office buildings aid in increasing the concentration of chemicals or compounds in the air. The indoor air can get contaminated due to interior materials and finishes like paints, adhesives and sealants, furniture, carpets; human activities; poor ventilation. Various green building rating systems award credits for the use of specified the VOC's (volatile organic compounds) of interior materials with an intention to improve the indoor air quality. But there are insufficient studies related to analysing the effectiveness of this in achieving better indoor air quality. The purpose of this study was to analyse the indoor air quality of IGBC (Indian Green Building Council) certified green commercial interiors of office buildings through a post occupancy evaluation method. The study also tried to identify the factors that contributed to the indoor air pollution in these spaces.

Post Occupancy Evaluation

Post-occupancy evaluation is a diagnostic tool used to evaluate the quality of building in a systematic manner after the building is commissioned, used by the users, and occupied for some time.[9]

From an architectural perspective, the Royal Institute of British Architects defined Post-Occupancy Evaluation as *"the process of obtaining feedback on a building's performance in use after it has been built and occupied"*.[10] Post-occupancy evaluation (POE) allows facility manager to investigate the critical aspects of building for better performance and is related to the occupants of the building and their needs. POE can be carried out in three ways viz. indicative, investigative, and diagnostic.

Indoor Air Pollutants

Biological, chemical, and particulate pollutants make up the three main categories of air pollution. Indoor Air Quality guidelines as stated by WHO lists out the various sources of indoor pollution of which the following have been included in the current study, Total Volatile Organic Compounds, Formaldehyde, Particulate Matter ($PM_{2.5}$), Particulate Matter (PM_{10}) and Carbon dioxide.

Volatile Organic Compounds

Organic chemicals having high vapour pressure and low boiling point and those that can vaporize easily at room temperature are known as Volatile Organic Compounds. Infiltration through the building envelope or intake through mechanical ventilation allows VOC's from outside to enter the building.[11] VOCs' indoor sources include Building supplies and furniture like paints, adhesives, carpets, etc., cleaning supplies, disinfectants; insect repellents; carbonless copy paper, electronic devices like printers and copiers, craft supplies like permanent markers, glue, adhesives, and photography solutions, pesticides, aerosol sprays, and wood preservatives. A study conducted by Wensing *et. al*, (2008) found electronic devices can act as an emission source of VOC in indoor air.[12] A study conducted by Chan & Chao, (2002) found that during the daytime, building material, occupants, and outdoor sources are the main contributors of TVOC. Temperature, relative humidity, strength of the source, ventilation rate, and other variables all affect TVOC concentrations. Emission rate and diffusion increases with increase in temperature. During summers, there is an increase in TVOC concentration as compared to winter. Lower temperature and less than 30% relative humidity reduces the TVOC concentration in newly built structures. The off gassing of VOCs from materials lasts for at least two years.[13]

Formaldehyde

Formaldehyde is a flammable, highly reactive, colourless, strong – smelling pungent gas. Products made of pressed wood, such as particleboard, plywood, and fibreboard, glues and adhesives, permanent-press textiles, paper product coatings, and specific insulation materials can all be sources of formaldehyde inside. Increase in ventilation rates does not fully resolve indoor formaldehyde pollution.[14] There is an inverse correlation between the concentration of formaldehyde concentration in indoor air and the air exchange rate. It was concluded through experiments that emission factor increases with a rise in temperature and humidity.[15]

Particulate Matter

A complex mixture of solid and/or liquid particles suspended in air is referred to as particulate matter (also known as PM or particle pollution). They are of various size, shape, and composition. Exposure to $PM_{2.5}$ is considered as the top ten risks which leads to a lower life expectancy across the world as assessed by 'Global Burden of Disease' (GBD).[16] The negative role of fitted carpets was highlighted in the studies conducted by Ragazzi, Rada, Zanoni & Andreottola (2014) where it was seen that these carpets captured the dust and released it during the transit of people walking over it.[17] Large number of ultrafine particles (UFP) to fine particles are emitted by laser printers during the printing process which are maximum during initial cold start prints.[18]

Carbon dioxide (CO_2)

Carbon dioxide is a colourless, tasteless, odourless, and non- flammable gas. It is heavier than air and may cause oxygen deficiency as may accumulate at lower spaces. It is an indicator of inadequate air quality rather than as a specific indoor air pollutant. The outdoor air flow rate and the time spent by the occupant inside the building leads to higher indoor CO_2 concentration than the outdoor concentration.[19] The study by Azuma *et. al* (2018) was able to determine the ill effects on health due to short time exposure to carbon dioxide levels above 1000 ppm and prove that building related illness was linked to low-level exposure (700 ppm) of carbon dioxide.[20]

Green Rating Systems

Indian Green Building Council (IGBC)is a rating system which promotes the construction of green and sustainable buildings. It provides guidelines for the construction of environment friendly buildings which perform better in terms of economic and environmental factors. IGBC also focuses on occupant health and well-being, a prime factor while designing any building. It provides guidelines to improve the quality of air inside any space. The credits prescribed by IGBC for improving indoor air quality in interior projects are related to fresh air ventilation, CO2 monitoring, provision of indoor plants, minimising indoor pollutant contamination, low emitting materials and interior flush out.

Indoor Air Monitoring Methods and Guidelines

Currently there are no protocols or guidelines for indoor air quality (IAQ) monitoring for indoor spaces in India, contrary to ambient air quality standards of 1988. There is an inconsistency in the quantity of indoor air contaminants to be measured. Additionally, there is a lack of information regarding the monitoring criteria, recommendations for the necessary instrument types, and sample analysis techniques.[21] The bulk of techniques are determined by the chemicals of interest and the necessary sampling time. Each approach has a certain level of sensitivity and specificity. There is no single technique that can be used to monitor IAQ accurately.[22] There are numerous methods to measure organic compounds in an indoor environment, and the selection depends on the objectives of the study and the available resources.[23]

Standards for Evaluating IAQ

Occupational Safety and Health Administration (OSHA) guidelines that provide information on how to manage IAQ effectively, including how to reduce airborne pollutants, introduce and disperse enough make-up air, and maintain a comfortable temperature and relative humidity, the WHO guidelines, the WELL Building Standard®, for buildings of commercial type and institutional nature, the WHO guidelines, and the National Institute for Occupational Safety and Health (NIOSH) guidelines are among the standards for evaluating IAQ in buildings.

Methodology and Methods

The study to ascertain the indoor air quality in office buildings used the investigative post-occupancy evaluation method. The guidelines prescribed by "European collaborative action: indoor air quality &its impact on man" (1993) have been adopted for the monitoring purpose.[24]

Initially, office certified by IGBC were identified. Permission for the study was sought from the office through mail and official letter. Once the permission was received, the field study was carried out at the convenient date and time given by the office manager.

The monitoring and data collection was based on selection of spaces within the building, location within the selected spaces, sampling conditions and position of sampler. Spaces were selected based on the characteristics of the space like office spaces, cabins, conference rooms etc. Normal conditions of occupancy, activity of occupants, ventilation, temperature, and humidity were considered for the samples. The sampler was placed at the breathing zone position which is considered at 1m to 1.5m above floor level. Long-term sampling technique that lasts from several hours to few weeks was adopted for the study. The sampling duration was derived from "United States Environmental Protection Agency: Testing for Indoor Air Quality Section 01 81 09," which specifies three consecutive days for sampling and averaging the results of each three-day test cycle to determine compliance or noncompliance with regard to indoor air quality.[25] The readings were taken in the month of March, 2019. Two readings were taken for three consecutive days, first when the office opened at 9:00 AM, second when the office was partly occupied (around 10% occupied) and third when there was full occupancy at 3:00 PM. The readings taken at different timings helped to analyze the changes in pollutant levels due to occupancy and time of the day. The averages of the data collected for three days was analyzed and compared with The Well Building Standard® v1. The areas where the measurements went over the threshold limit were noted, and the likely causes of the rise in pollutant levels were investigated.

The Extech Indoor Air Quality CO_2 Datalogger and Air Detector Air Quality Pollution Meter were used for measuring the selected parameters. The Indoor Air Quality CO_2 Datalogger was used to measure CO2, temperature, and humidity. The test range for CO_2 was 0.000-9.999 ppm, for temperatures -10° C to 60° C and humidity range was 0.1 to 99.9 % RH. The Air Quality Pollution Meter was used to measure formaldehyde, TVOC, $PM_{2.5}$ and PM_{10}. The detection mode for HCHO and TVOC was diffusion type and for $PM_{2.5}$ and PM_{10} it was density (per litre). The acceptable limit as prescribed by the Well Building Standard was adopted for evaluating the IAQ as seen in Table no. 1 below.

Results and Discussion

A case of an office interiors certified by Indian Green Building Council were selected. The chosen case has received the certification from IGBC around 2-3 years ago.

The selected case was an IGBC Certified Green Interiors office space in Pune with a total area of 9209.83 Sq. ft. Measurements were taken at 31 locations in the office. Fig. 1 shows the locations where measurements were taken. Each of the locations that were chosen had unique features, including varied materials, person counts, furniture layouts, office desk counts, printer, scanner, and photocopier counts, windows, and natural ventilation. The data provided by the office was analysed to understand the materials used and credits achieved for the rating. As required by the rating system low emitting materials were used for interior paint, interior work adhesive, HVAC duct insulation adhesive, carpets and composite wood for furniture. The office had received complete credits related to interior materials and indoor air quality. All regularly inhabited spaces were designed with fresh air ventilation that meets the minimum ventilation requirements outlined in ASHRAE* Standard 62.1 - 2010. A minimum of 12% increased fresh air ventilation was provided in most spaces even going upto 66% increase in admin rooms and cabins.

Table 1: Acceptable limits for each pollutant as per standards

Pollutant Name	Acceptable Limit	Reference Guide
Total volatile organic compounds	500 or fewer µg/m3, or 0.5 mg/m3,	Building Design and Construction Reference Guide for LEED v4 by USGBC, 1.1.b For an indoor air quality assessment to receive credit, there must be evidence of total VOC levels below 500 g/m3.
Formaldehyde	Less than 27 ppb i.e. 0.03375 mg/m3	Building Design and Construction Reference Guide for LEED v4 by USGBC, 1.1.a For the Indoor Air Quality Assessment to receive credit, formaldehyde levels must be fewer than 27 ppb.
Particulate matter 2.5	Less than 15 µg/m3	1.2.a According to the EPA's 2012 NAAQS, PM2.5 concentrations must be less than 12 µg/m3 for the primary annual mean, 15 µg/m3 for the secondary annual mean, and 35 µg/m3 for the 24-hour averaged over three years.
Particulate matter 10	Less than 50 µg/m3	1.2.c The 24-hour mean concentration limit for PM10 is 50 µg/m3, according to the Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur by WHO
Carbon dioxide	Below 800 ppm	According to the Indoor Air Quality Guidelines by IDPH, adequately ventilated buildings should have an average carbon dioxide level of 800 ppm or less on each floor.

Total Volatile Organic Compounds

From the analysis of the data as shown in fig 2 below, it was seen that the average concentration of TVOCs was within the limit prescribed under the WELL Building Standards except for spots 12-14 (conference room 1). As per standards the prescribed limit is less than 0.5 mg/m3 which is seen in Fig 2 as the red dotted line. 9.67% areas of all the measured spots experienced higher TVOCs levels. The average lowest concentration of TVOCs was observed at spot 29 (in the café) with 0.245 mg/m3 whereas the average highest concentration of TVOC was at spot 12 (conference room 1 at the center of the table) with 0.689 mg/m3.

Based on the data collected as well as the observations conducted during field study, the probable factors responsible for increased TVOC levels in some of the areas were identified. Active computer processing leading to increased power use resulted in the increase of the total VOC emissions.[12] As the HVAC system was controlled by the users, the switching on and off the air conditioner was solely dependent on the user. It was observed that the HVAC system was switched off for most of the day at spot 23 – VP room, by the user. Due to the low ventilation rate the TVOC levels could have exceeded the limit. Also, printers emit higher levels of TVOCs[12] during the printing sequence due to which spots 19 and 20 could have experienced higher TVOC level.

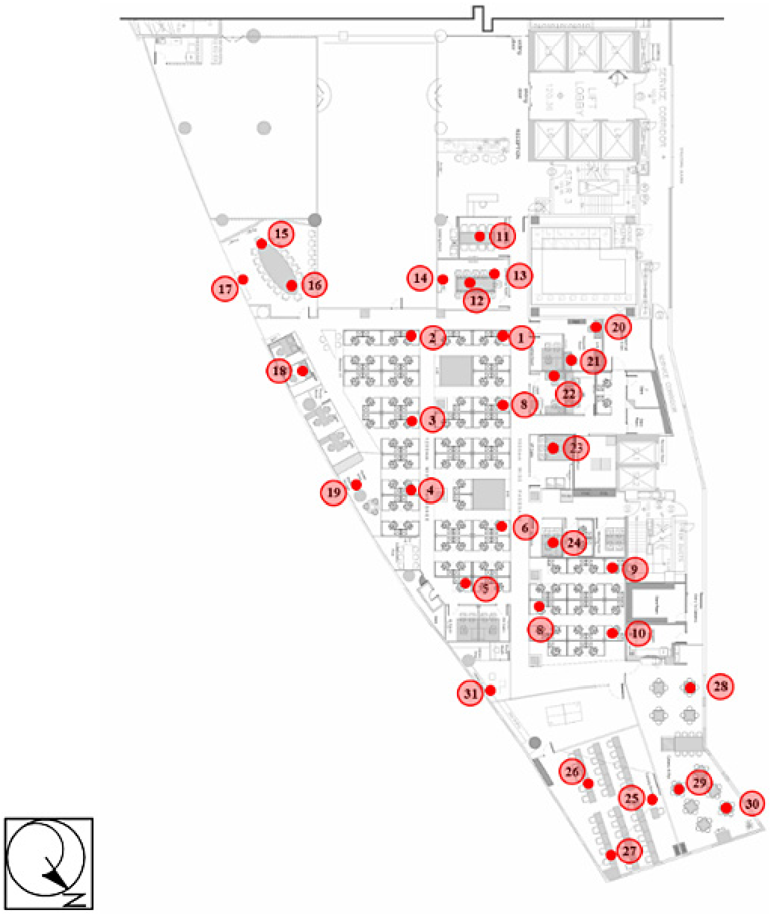


Fig. 1: Location of spot measurements for selected Case.

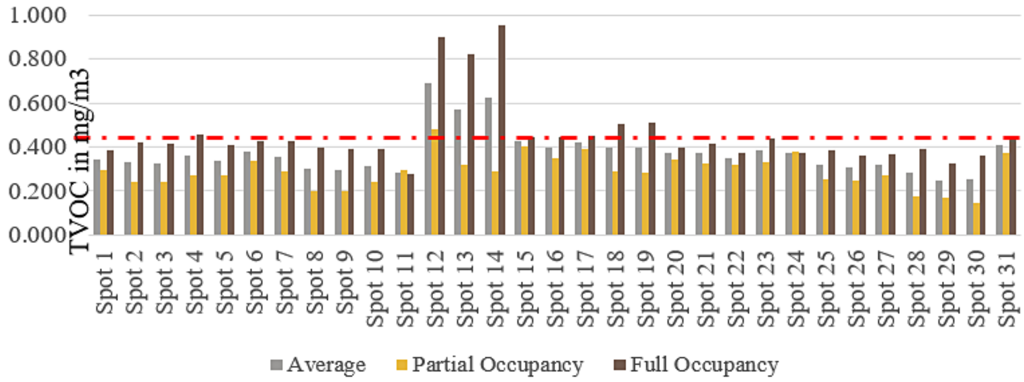


Fig. 2: TVOC readings at all sample locations at partial and full occupancy

Formaldehyde

Formaldehyde concentration at partial and full occupancy were measured as seen in Fig.3 below. As seen from the figure, The HCHO concentration exceeded the limit set by The Well Building Standard which has to be less than 0.03375 mg/m3, at most of the locations on all the three days. The prescribed limit has been shown as a red dotted line in fig.3 below. The workstation areas experienced HCHO levels higher than the prescribed limit for all the three days. The full occupancy readings exceeded the limit set for formaldehyde in all the spaces except for spots 11-18 (meeting room 1, conference room 1 and 2, and cubicle). 74.19% areas of all the measured spots experienced higher HCHO levels during full occupancy.

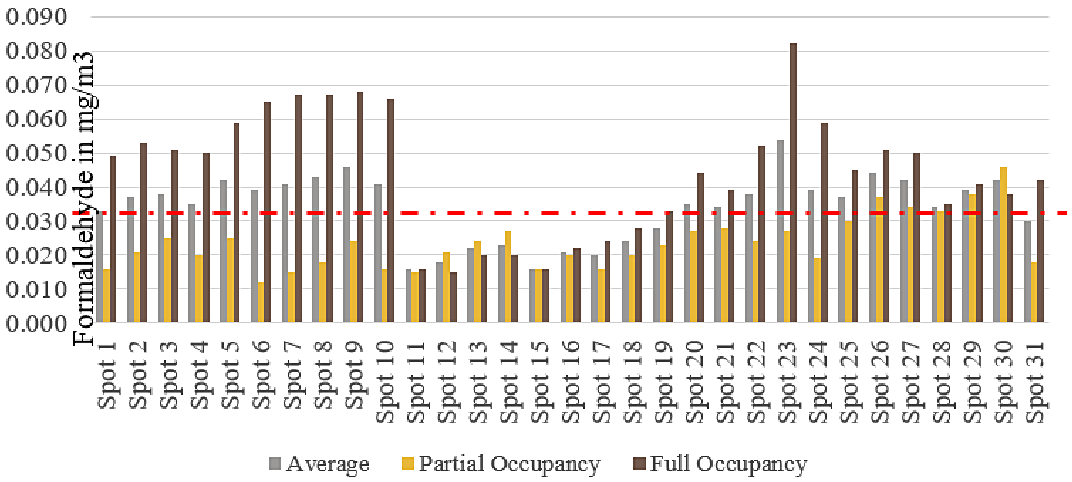


Fig. 3: Formaldehyde readings at all sample locations at partial and full occupancy

The findings were derived from the data collected and observations made on the field. It was observed that almost 90% of the occupants at the workstation were working on two computers which may have resulted in higher concentration levels at these locations. Emission rates of formaldehyde increase due to increase in temperature. The temperature observed at spots 28-30 were high and did not meet the standards set by ASHRAE 55-1-2010. High formaldehyde concentration at these spots could be due to the increase in temperature. Spots 11-17 were rarely occupied and hence the concentration in these spaces went higher only when there was occupancy and use of electronic equipment. Spot 11-18 are not frequently occupied so the HCHO emission from external factors are not seen in these areas. Only emissions from interior materials could be the probable source of formaldehyde. The formaldehyde concentration mainly depends on the materials used in the interior space. As low-emitting materials are used in the entire office, the emission from the materials would be low as compared to conventional materials. It is ambiguous to draw the conclusion that these factors influenced the low or high concentration levels of HCHO in Case 1 office spaces because the spot measurement did not really quantify the HCHO emissions from the office equipment and interior materials.

Particulate Matter – $PM_{2.5}$

As seen in Fig 4. which shows the concentration levels of $PM_{2.5}$ during partial and full occupancy, the average concentration of $PM_{2.5}$ exceeded the limit prescribed under the WELL Building Standards except for spot 16 - conference room 2 – near the entrance during partial occupancy. The prescribed limit as per standard is less than 15 µg/m^3 which is shown as a red dotted line in fig. 4 below. 100% areas of all the measured spots experienced higher $PM_{2.5}$ levels. But readings taken at full occupancy were within the prescribed limits as per the standards. One of the factors that govern the particle concentration is ventilation. In the absence of ventilation, the particle concentration increases as it gets accumulated. When the office opens in the morning it could have accumulated dust, bacteria and allergens present in the indoor air. The HVAC system circulates fresh air within the building and exhausts stale air outside, thus particulate matter concentrations are higher at the beginning of an office day than they are after occupancy. The sweeping and mopping of the office during the working hours also result in the lower $PM_{2.5}$ levels.

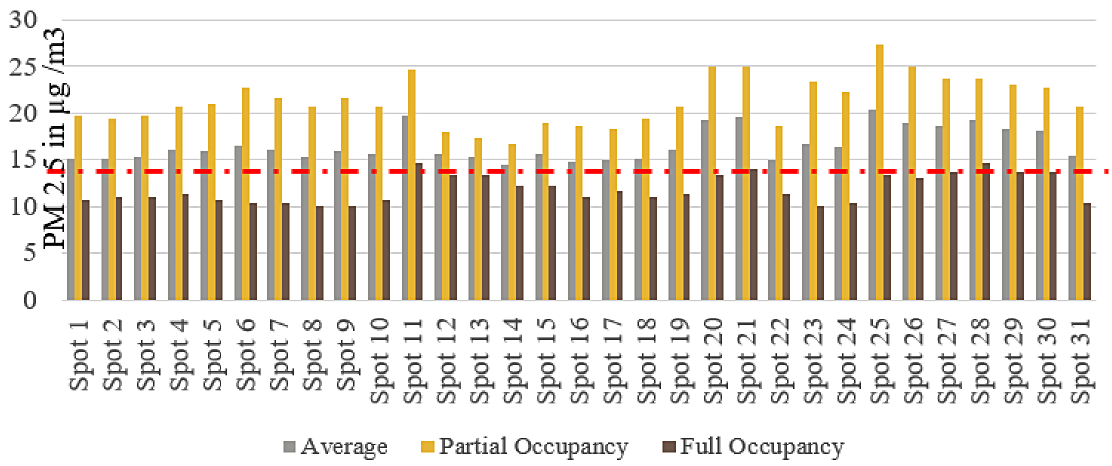


Fig. 4: Concentration levels of $PM_{2.5}$ in selected Case

Particulate Matter 10 (PM_{10})

The average concentration as also concentration at partial and full occupancy of PM_{10} was within the limit prescribed under the WELL Building Standards for all the spaces as seen in Fig. 5 below. The prescribed limit as per standards is less than 50 µg/m³. It was observed that due to the cleaning activities performed in the office, there was less accumulation of dust, bacteria and moulds inside the office.

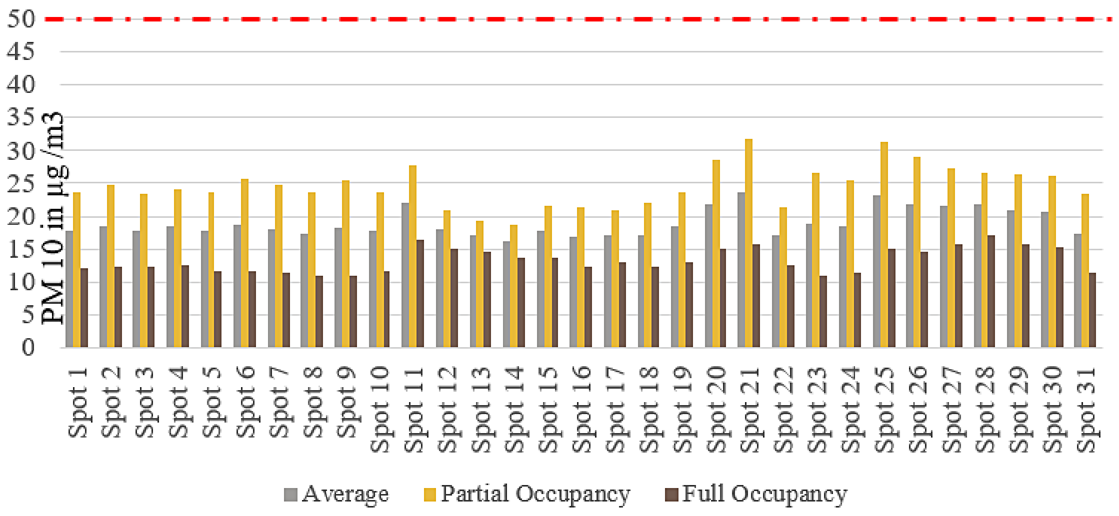


Fig. 5: Concentration levels of PM 10 in selected Case

Carbon dioxide (CO_2)

The average concentrations in all the office spaces exceeds the limit prescribed by v1 of The Well Building Standard® and the concentrations at partial and full occupancy too exceed the prescribed limits (Fig. 6). Although the CO_2 level exceeds the limit prescribed by The Well Building Standard®, it meets the standards set by ASHRAE. The standard limit for CO_2 is below 800ppm. 41.9% areas of all the measured spots experienced higher CO_2 levels.

From the data, it could be seen that as carbon dioxide is an occupant related pollutant, the level of such pollutants rises in the afternoon. The maximum average and maximum post-occupancy average were both high in VP cabin as the HVAC which was user controlled was kept off most of the time resulting in poor ventilation and fresh air intake. Even though the provided outdoor air flow rate exceeds the required minimum ventilation rate, the concentration of carbon dioxide exceeded in office spaces.

The office did not have the provision of timely flush out of the indoor air which can cause the level of pollutants inside to increase.

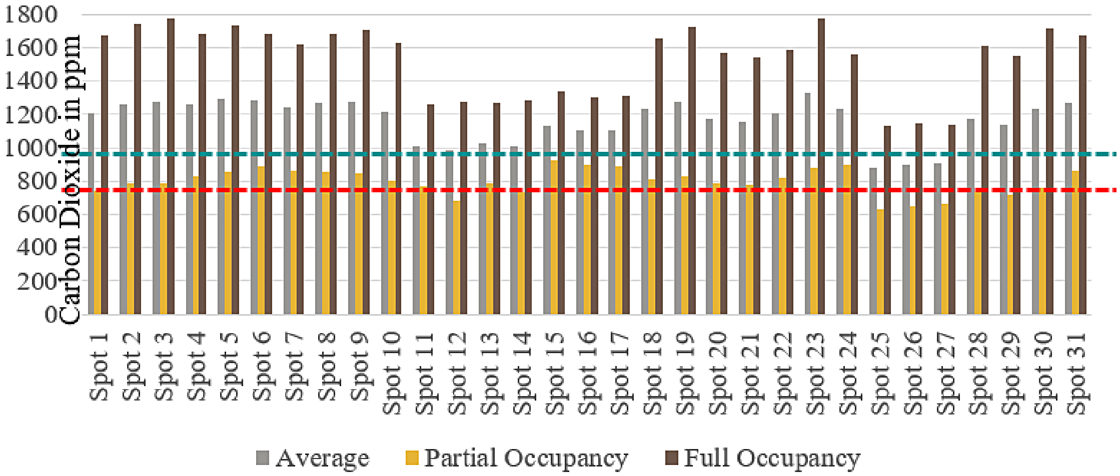


Fig. 6: Concentration levels of CO_2 in selected Case

Post the analysis of individual pollutants, statistical analysis was conducted with the help of SPSS statistical analysis tool to determine whether any correlation existed between the various pollutants and other factors like occupancy, temperature and humidity. An analysis of variance (ANOVA) was also carried out to test the hypothesis which stated that there was no difference in the value of the pollutant's pre-occupancy and post-occupancy.

A KMO and Bartletts test was conducted to check the sample adequacy. As seen in Figure 7, the sample is just adequate (.551) with a significance of .000.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.551
Bartlett's Test of Sphericity	Approx. Chi-Square	184.563
	df	28
	Sig.	.000

Fig. 7: KMO and Bartlett's Test for sample adequacy

The ANOVA test was conducted as a paired sample T-Test which tried to analyse the values of pollutants pre-occupancy and post-occupancy. As seen in Figure 8, there is a significant difference seen for volatile organic compounds ($p< .05 =.024$), $PM_{2.5}$ ($p< .05 =.036$), PM_{10} ($p< .05 =.048$) and CO2 ($p< .05 =.007$) values pre-occupancy and post-occupancy. Hence the null hypothesis was rejected and an alternative hypothesis stating that there is a difference in the values of volatile organic compounds, $PM_{2.5}$, PM_{10} and CO_2 pre and post occupancy.

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TVOC_pre_occupancy & TVOC_post_occupancy	31	.405	.024
Pair 2	FRML_pre_occ & FRML_post_occ	31	-.033	.858
Pair 3	PM2.5_pre_occ & PM2.5_post_occ	31	.378	.036
Pair 4	PM10_pre_occ & PM10_post_occ	31	.358	.048
Pair 5	CO2_pre_occ & CO2_post_occ	31	.478	.007
Pair 6	Temperature_pre_occ & Temperature_post_occ	31	.039	.835

Fig. 8: Paired sample T-Test

Correlations

		TVOC_avg	FRML_avg	PM2.5_avg	PM10_avg	CO2_avg	Temperature_avg	Humidity	Occupancy
TVOC_avg	Pearson Correlation	1	-.673**	-.446*	-.463**	-.269	-.534**	.552**	-.336
	Sig. (2-tailed)		.000	.012	.009	.143	.002	.001	.064
	N	31	31	31	31	31	31	31	31
FRML_avg	Pearson Correlation		1	.210	.233	.401*	.505**	-.406*	.260
	Sig. (2-tailed)			.256	.208	.025	.004	.024	.157
	N		31	31	31	31	31	31	31
PM2.5_avg	Pearson Correlation			1	.968**	-.430*	.556**	-.343	.053
	Sig. (2-tailed)				.000	.016	.001	.059	.776
	N			31	31	31	31	31	31
PM10_avg	Pearson Correlation				1	-.392*	.565**	-.311	.146
	Sig. (2-tailed)					.029	.001	.089	.433
	N				31	31	31	31	31
CO2_avg	Pearson Correlation					1	.054	.252	.120
	Sig. (2-tailed)						.775	.171	.520
	N					31	31	31	31
Temperature_avg	Pearson Correlation						1	-.621**	.393*
	Sig. (2-tailed)							.000	.029
	N						31	31	31
Humidity	Pearson Correlation							1	-.298
	Sig. (2-tailed)								.104
	N							31	31
Occupancy	Pearson Correlation								1
	Sig. (2-tailed)								
	N								31

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Fig. 9: Correlation Analysis

A correlation was also conducted to understand correlations between the various pollutants and factors like occupancy, temperature, and humidity. The average values of all the pollutants and factors were considered for this analysis. The analysis revealed that temperature was positively correlated with formaldehyde ($p<.05 = .004$), $PM_{2.5}$ ($p<.05 = .001$), PM_{10} ($p<.05 = .001$) and negatively correlated with total volatile organic compounds ($p<.05 = .002$) as seen in Figure 9 below. It was also seen that humidity was significantly correlated positively with total volatile organic compounds ($p<.05 = .001$) and negatively correlated with formaldehyde ($p<.05 = .024$). Occupancy did not have any significant correlation with any of the pollutants.

Conclusions

The analysis of the case study from data collected through on-site measurements and site observations indicate high levels of CO_2 concentrations despite enhanced ventilation provisions. The fresh air ventilation should adhere to ASHRAE standard 62.1-2010's minimum ventilation rates. As the office was an IGBC certified for Green Interiors, most of the spaces had been provided enhanced ventilation with a percentage increase ranging from 12% to 65%. User controlled HVAC systems if kept shut may lead to ineffective ventilation leading to higher CO2 concentrations. Ventilation also plays a role in regulating the level of concentration of $PM_{2.5}$ in the indoor spaces. Thus, the concentration levels of $PM_{2.5}$ are higher during partial occupancy i.e during mornings when the HVAC systems have still not been started. Concentration of formaldehyde was observed to be dependent on temperature and thus the areas of higher temperature showed higher measurements of formaldehyde concentrations. The volatile organic compounds (TVOC's) were well within the prescribed limits which can be attributed to the use of low emitting materials specified by the IGBC rating system. The increased values seen in some areas could be attributed to the higher use of electronic equipment like computers and printers.

The statistical analysis also reinforced earlier research which mentioned that lower humidity results in lower TVOC values but contrary to prior research, higher temperatures resulted in lower TVOC values. Similarly, higher temperature and humidity values resulted in higher emissions of formaldehyde was also as seen in earlier studies.

From the above case study, it could be concluded that low-emitting materials and finishes used in the office interiors helped to lower the concentration of pollutants in the indoor environment but the concentrations of these various pollutants depended also on several other factors like the ventilation system, use of electronic equipment, frequency of cleaning practices, occupancy etc. It should be mentioned that improving indoor air quality depends in large part on the ventilation system. Good air quality in indoor environments can enhance the health and wellbeing of the occupants. The study helped to prove that providing low-emitting materials was an insufficient strategy to improve the quality of indoor air if not supplemented with factors like effective and efficient ventilation systems as well as better cleaning practices.

Acknowledgement

no separate one as the author was the research team.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The Author(s) declares no conflict of interest between authors.

References

1. Sundell J. On the history of indoor air quality and health. Indoor Air. 2004; 14(s7), 51–58. https://doi.org/10.1111/J.1600-0668.2004.00273.X
2. Theakston F. WHO guidelines for Indoor Air Quality: Selected Pollutants. Germany: World Health Organization Regional Office for Europe; 2010. 444. https://apps.who.int/iris/bitstream/handle/10665/260127/9789289002134-eng.pdf.
3. Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York, 1997. https://stats.oecd.org/glossary/detail.asp?ID=1336

4. EPA United States Environmental Protection Agency. Indoor Air Quality. Epa.gov. https://www.epa.gov/report-environment/indoor-air-quality#:~:text=Health%20effects%20associated%20with%20indoor,%2C%20heart%20disease%2C%20and%20cancer. September 7 2021. 15/11/2022.
5. Erdmann C. A., Steiner K. C., Apte M. G. Indoor carbon dioxide concentrations and sick building syndrome symptoms in the BASE study revisited: Analyses of the 100 building dataset. A compilation of papers for the Indoor Air 2002 Conference in memory of Joan M. Daisey. 2002;129-134 21-
6. Goyal R., Khare M., P, K. Indoor Air Quality: Current Status, Missing Links and Future Road Map for India. *Journal of Civil & Environmental Engineering.* 2012; 02(04).
7. Datta A, R. Suresh, Gupta A, Singh D, Kulshrestha P. Indoor Air Quality of Non-Residential Urban Buildings in Delhi, India. *International Journal of Sustainable Built Environment.* 2017; 6(2): 412-420.
8. Peixian Li, Froese T.M., Brager G. Post-Occupancy Evaluation: State-of-the-Art Analysis and State-of-the-Practice Review. *Building and Environment.* 2018; 133: 187-202.
9. MacDonald P. Post Occupancy Evaluation – An Essential Tool to Improve the Built Environment. RIBA Architecture.com. 2020
10. Chan G. Y., & Chao C. Y. Quantification of Indoor TVOC Levels from Different Sources in
11. Mechanically Ventilated Buildings. *Indoor Built Environment.* 2002; 340-350.
12. Wensing M., Schripp T., Uhde E., Salthammer T. Ultra-fine particles release from hardcopy devices: Sources, real-room measurements and efficiency of filter accessories. *Science of the Total Environment.* 2008; 407(1): 418-427.
13. Holøs S. B., Yang A., Lind M., Thunshelle K., Schild P., & Mysen M. VOC emission rates in newly built and renovated buildings, and the influence of ventilation – a review and meta-analysis. *International Journal of Ventilation.* 2018.
14. Wu X., Apte M. G., Maddalena R., & Bennett D. H. Volatile Organic Compounds in Small- and Medium-Sized Commercial Buildings in California. *Environmental Science and Technology.* 2011: 9075-9083
15. Parthasarathy S., Maddalena R. L., Russell M. L., & Michael. Effect of Temperature and Humidity on Formaldehyde Emissions in Temporary Housing Units. *Journal of the Air & Waste Management Association.* 2011; 689-695.
16. L. Morawska, G. A. Airborne particles in indoor environment of homes, schools, offices and aged care facilities: The main routes of exposure. Elsevier - *Environment International.* 2017; 75-83.
17. Ragazzi M., Rada E. C., Zanoni S., & Andreottol, G. The role of particulate matter in offices for
18. urban air quality management. *The Sustainable* City IX. 2014; 1403-1412.
19. McKone T., Maddalena R., Destaillats H., Hammond S. K., Hodgson A., Russell M., Perrino C. *Indoor Pollutant Emissions from Electronic Office Equipment.* 2009.
20. Apte M. G., Fisk W. J., & Daisey J. M. Associations Between Indoor Carbon Dioxide Concentrations and Sick Building Syndromes in US Office Buildings. *Munksgaard.* 2000; 246-257.
21. Azuma K., Kagi N., Yanagi U., & Osawa H. Effects of low-level inhalation exposure to carbon dioxide in indoor: A short review on human health and psychomotor. *Environment International.* 2018; 121, 51-56.
22. Panagiotaras D., Nikolopoulos D., Petraki E., Kottou S., Koulougliotis D., Yannakopoulos P., & Kaplanis S. Comprehensive Experience for Indoor Air Quality Assessment: A Review on the Determination of Volatile Organic Compounds (VOCs). *Physical Chemistry & Biophysics.* 2014.
23. Crump D. (2001). Strategies and Protocols for Indoor Air Monitoring of Pollutants. *Indoor Built Environ.* 2001; 125-131.
24. Colombo A., De Bortoli M. European Collaborative Action 'Indoor Air Quality & Its Impact on Man' (formerly COST Project 613) : Determination of VOCs Emmitted from Indoor Materials and Products: Interlaboratory Comparison of Small Chamber Measurements. OPOCE. 1993
25. Testing for Indoor Air Quality Section 01 81 09. United States Environmental Protection Agency. 2007. https://www.epa.gov/sites/default/files/2014-03/documents/018109.pdf https://www.who.int/health-topics/air-pollution (accessed on 8/11/2021)

ugccare.unipune.ac.in/Apps1/User/WebA/SearchList

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**shodhkosh**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	ShodhKosh: Journal of Visual and Performing Arts	Granthaalayah Publications and Printers	NA	2582-7472	from October-2021 to July- 2024	Discontinued from July 2024

Showing 1 to 1 of 1 entries

Previous 1 Next

Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
Enhancing Connections in Visual and Performing Arts: Multidisciplinary Insights in Architecture and Planning
July-December 2023 4(2 ECVPAMIAP), 128–141

INVESTIGATING THE RELATIONSHIP BETWEEN STREET DESIGN AND URBAN VITALITY THROUGH 'SMART-CITY INITIATIVE' CASE OF PUNE, MAHARASHTRA, INDIA

Isha Etesh Aghera [1], Dr. Vaishali Anagal [2]

[1] Student, Fourth Year, Dr. B. N. College of Architecture, Pune, Maharashtra, India
[2] Associate Professor, Dr. B. N. College of Architecture, Pune, Maharashtra, India

Received 29 August 2023
Accepted 29 December 2023
Published 03 January 2024

Corresponding Author

Dr. Vaishali Anagal,
vaishali.anagal@bnca.ac.in

DOI 10.29121/shodhkosh.v4.i2 ECVPAMIAP.2023.711

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Copyright: © 2023 The Author(s). This work is licensed under a Creative Commons Attribution 4.0 International License.

With the license CC-BY, authors retain the copyright, allowing anyone to download, reuse, re-print, modify, distribute, and/or copy their contribution. The work must be properly attributed to its author.

OPEN ACCESS

ABSTRACT

The design and use of street furniture play a vital role in the design of public places and in making vibrant urban places. The street and seating area serves as a public meeting place for a variety of interactions and activities. This study aims to explore how street furniture can be designed based on its location, and how it can be improved by comparing real-world scenarios to theoretical principles. This study takes into consideration the context and surroundings of the streets developed under the Smart City initiative, as well as their interaction with the citizen's life. Accessibility, livability, and connectivity are the defining characteristics of urban vitality. The urban street design has become more prevalent in locations with obvious commercial activity. The study aims to investigate the elements of street design and street furniture and their effect on urban vitality and its relationship with the surrounding land use. This analysis is done using qualitative methods such as on-site observations, content analysis of photographs, and walk-along interviews with the users.

Keywords: Activity Street Mapping, Seating Space, Visual Image, Urban Vitality, Urban Affairs, Street Pattern

1. INTRODUCTION

The Ministry of Housing and Urban Affairs (MoHUA) and all state and union territory (UT) administrations collaborated to launch the Smart Cities Mission (SCM) on June 25, 2015. The SCM will increase infrastructure and services while keeping the environment clean and sustainable and boosting urban vitality Aijaz

(2021). As part of the Pune Smart City project, 27 km of streets have been designated for redevelopment, and 100 km are covered by the city's yearly budget. In Pune, the initial stage of these street design initiatives has already turned several roadways into lively public areas. By a large majority, Pune residents constantly cite traffic and transportation as their biggest concerns. The street-Road relationship generally prioritizes vehicular traffic and ignores the human quality of street life. By creating an engaging place for pedestrians, street furnishings provide an essential part in the growth of the city. In general, the streets are crowded by vehicles or people walking on the road. Providing a decent walkway and adding urban vitality to it can help to create proper street circulation. The seating space developed aids in increasing social interaction amongst individuals by providing a designated place free of cars. There has been an increase in the use of urban street design in areas where commercial activity is visible. By developing an urban vitality, it adds character to the street while also providing human comfort. The research is divided into four parts. The first is a representation of a literature review on methodologies for analyzing street furniture and urban vitality. The field study is carried out with activity mapping, on-site observations, and interviews with the users. This study aims to investigate the relationship between street design and the surrounding context and how street furniture brings vitality to urban streets.

2. LITERATURE REVIEW

Radwan & Morsi (2016) has attempted to show the importance of street furniture design and its functionality on the human level. It demonstrates the significance of blending street and urban design in city planning. To shed light on the aspects of street design and street furniture, as well as their impact on the surroundings and given practices from various countries. The study has concluded how designers seek to create fashionable street furniture while ignoring its practicality, and usefulness, and how the immediate surroundings, safety, and materials all contribute to the overall experience. Yücel (2012) aims to look at the significance of urban furniture and its connections to public areas. Urban furniture may be utilized in both unpopulated and densely populated sections of a city. As a result, urban furniture has become an integral element in cities. It is also mentioned in the paper that designs that do not reflect the sense of urban identity may leave pleasant impressions of the space, but in the foreseeable future, they are short-lived designs that do not represent the historical nature of the city and cannot effectively develop a contemporary urban image.

Urban furniture design encourages more social interaction. Street furniture plays a crucial role in city beautification and aesthetic balance. Additionally, it describes the vibrant environment that attracts individuals who will spend hours there for social purposes Allahdadi (2017). In reality, more factors such as group activities, being visible and participative, and serving as a gathering spot for people to visit one another impact the development of social interactions in public areas. The primary purpose of city furniture is to improve the quality of life for city dwellers by giving them access to comfortable living areas in their urban environment Şatir & Korkmaz (2005). There exist regions with a wider focus that argue for emphasizing an integrated strategy for research on city furniture and urban designs, when two sides of a roadway are rearranged, the point of view demands that cars and pedestrians' perceptions should be evaluated.

Solanki (2021) expressed how much an increase in attractiveness could encourage urban vitality. Attractiveness, one of the walkability factors, appears to be crucial in enhancing urban vitality and is closely tied to urban regrowth. While

Urban furniture is a broad group of objects with various shapes, sizes, and purposes that are used in urban settings. Additionally, it also examines both practical and visually appealing solutions as well as the building materials that are most frequently used Grabiec et al. (2022)

'The impact of urban form on urban vitality' Atak (2020) argued that residential areas' urban form influences whether urban vitality is encouraged or not. However, streets must be locations where people are meeting, interacting, and engaging in social activities in order to establish livable and sustainable cities. Urban vitality promotes street utilization, people to communicate, and the development of areas that are safe and easy to navigate on foot.

Aram et al. (2019) examines how UGSs (Urban Green Space) are used to produce a cooling effect. The intensity of the heat is significantly reduced by urban green spaces and pause points in urban areas. According to the paper, the increased buildup of greenhouse gases in the Earth's atmosphere has caused abrupt changes in global temperature patterns and the climate. Hence, as a result, all UGSs, including parks, are crucial for lowering UHI, producing cooling, and giving residents thermal comfort.

Every citizen in a city comes into contact with the street at least once a day, either physically or with a visual connection. The purpose of the study is to identify the needs of users in Pune and the type of street environment they like Patki (2017). Additionally, the research is based on the comfort and satisfaction of the user. Basar (2021) Finding and analyzing actual designs of urban furniture that uses renewable energy is the goal of the study. As a result, it aims to reduce excessive energy usage in city parks, minimize negative environmental effects, and utilize appropriate renewable resources as a material for urban street furniture.

The main design, visual, and physical aspects are evaluated in this study, along with how they affect the activity pattern, and user behavior. Pedestrian preferences are closely related to the variety and perceived comfort of the surroundings, which includes things like facades, colours, aspect ratios, upkeep, and greenery Balsubramanian et al. (2022). While the suggestion arouses that some design interventions concerning two public realm Streets and Nodes that cater to various user groups in a commercial and residential region, respectively. The standard user theory, which is highly correlated with the kind of functionality and character of the streets, applies to the urban streets in many Indian cities. Every module's design is centered on user comfort, street-appropriate size, and nature Bhaghyalaxmi et al. (2014)

Street furniture is seen as a crucial component that can be seen in urban space, that helps people live better lives in urban settings. Usually, the presence of street furniture encourages pedestrians to visit by providing a necessary comfort. This paper's major goal is to examine the criteria that should be taken into account while designing by analysing the demands of users of street furniture in urban settings Dhaou et al. (2022)

In relation to the Internet of Things and digitalization, the study presented in this article reflects the applicability of design and evaluates the performance of street furniture products. It helps in understanding the present situation with urban furniture design and the distinctive requirements in the digital context. The paper explores the effects of the variables on the security of urban furniture from the viewpoints of urban development, economics, and user groups. The findings demonstrate that urban furniture, a traditional design field, may be further modernized and improved against a backdrop of digitalization and the Internet of Things. It offers new perspectives and assistance for human use and advanced urban development Yang et al. (2022). Bhat (2022) This research is focused on understanding the primary open-space criteria on the basis of which the context's microclimate may be improved. Khorasgani et al. (2023) continues by introducing the articulated landscape characteristics, relationships with places, and associated components and elements.

3. METHODOLOGY

In this study, we qualitatively analyzed the relationship between street design and urban vitality at the city level using visual data to determine where, why, and to what measure we may improve urban vitality.

Two important streets in the city of Pune were selected for this study: Fergusson College Street (F.C. Street) and Jangali Maharaj Road (J.M. Road). They were chosen intentionally for their similarities and differences: First, they were transformed from non-walkable footpaths and street parking areas. Second, they were transformed with similar approaches, such as removing parking, inviting recognizable colorful paintings, green plants, and various types of outdoor urban furniture, such as chess tables, bike racks, and so on. Later, interviews were conducted with persons strolling down the street or utilizing street furniture to learn about their experiences. This analysis is done through the visual data comparison and observation along with street activity mapping. Pune under the smart city initiative has implemented the smart streets project having the potential to redevelop. The analysis and observation can be documented by comparing different locations like JM Road and F.C. Street and doing activity mapping along with understanding the context and surroundings.

Lynch (1960) According to Lynch, every city has a comparable collection of pictures in the minds of those who have experienced it. Based on Lynch's five characteristics that influence such images, some of them are considered viewpoints on the research area. There are pathways that the observer can go along. This is the aspect of the city that influences people's perceptions of it the most. JM Road and FC Road serve as a path where there is a concentration of uses by people. Landmarks are a different kind of point reference that can only be observed from the outside. Typically, it is referred to as a physical thing, such as a sign, mountain, building, or store. Given the Goodluck Cafe has been located on FC Road since 1935 (Refer to Figure 1), it serves as a landmark for people. The legibility of a city often depends on landmarks since they serve as crucial indicators for everyone in the city to find their way around.

3.1. A CASE STUDY OF PUNE – F.C. STREET

FC is an abbreviation for Fergusson College, which is an institution. F.C. Street is a fully functional commercial street. It provides you with commodities from practically every category, including cuisine, clothing, culture, business, and science. (See Figure 1) A number of educational campuses such as Gokhale Institute, Fergusson College, Marathwada Mitra Mandal's College, Modern College of business administration, and Agharkar Research Institute abutting the streets. Young users are attracted to F.C. Road for two major reasons: food and clothes.

Figure 1

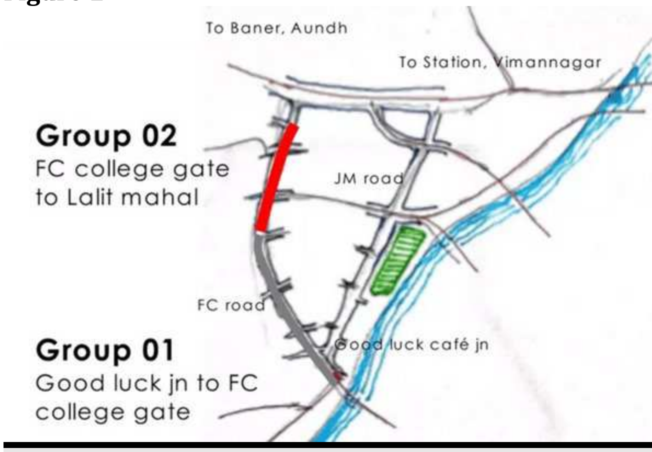


Figure 1 Map of F.C. Street and J.M. Road
Source Street Design Workshop Slideshare. (n.d.)

Figure 2

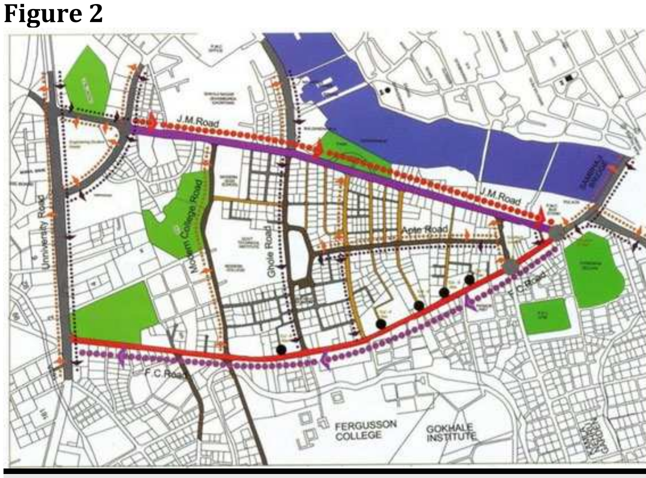


Figure 2 Map of F.C. Street and J.M. Road
Source Prasanna Desai architects Oasis Designs. (n.d.)

Pune smart city development corporation Ltd. created a roadway that will cater to people of all ages as part of the smart city program. There is enough space division in terms of vehicular roads, pedestrian pathways, cycling paths, and sitting areas. At regular intervals, an equal amount of green landscape area is provided. The prominent observation is the usage of urban street furniture has increased in regions where commercial activity is prominent while Seating is not available in certain areas where shops or restaurants are located.

The research is carried out by conducting interviews with people walking down the street or using street furniture to learn about their experiences. Further, the context and surroundings in which it was studied, as well as its relationship with the citizen's life were analyzed. Questions were asked of people while they were using the street furniture.

1) Are you able to freely move around the street without any obstructions? (For example - street lights, bins, signage poles, etc)
2) Do you enjoy walking down this street?
3) How frequently do you visit this street?

(To determine regular users) - once a week/once a month/first visit

4) Why have you visited this particular street today?
   (e.g., passing through, shopping, or eating)
5) What is it about this street environment that you enjoy?
6) Is there enough shade to sit here during the day?
7) Which specific place do you avoid sitting in?
8) Do you sense a cultural and artistic and peaceful presence near the seating space?

The number of people interviewed was nine. And a random process was used to choose individuals for the interviews. Through this method, it was discovered how frequently visitors visit this place and their reasons for visiting. The necessity for it as determined by its location heavily influences how street furniture is used. Regardless of gender, the majority of visitors were young people in their early 20s who came for a variety of reasons but mainly for shopping and food.

The responses elicited are as below:

Table 1

Table 1 Field Observations & Interviews (Case Study: F.C. Street)		
1.		• **Gender:** Male • **Age:** 55-year-old • **Visiting Time:** Every day for one hour • He is a heart patient who lives near FC Street. • He likes this street because it has everything he needs, from food to peaceful shaded pathways
2.		• **Gender:** Female • **Age:** 23 to 24-year-old • **Visiting Time:** Once a week • They are all friends who meet on FC Street. They usually visit in the morning or evening, but they have also visited in afternoon, and they always find shade when they sit wherever.
3.		• **Gender:** Female • **Age:** 26-year-old • **Visiting Time:** Twice a week • She was looking for a place to wait for her friend, and the paar under the tree was the only one she could find that day. Except for this one, there was no seating on the entire footpath opposite the FC College.
4.		• **Gender:** Female • **Age:** 28-year-old • **Visiting Time:** Twice a week • She came to the street for shopping the day I interviewed her. • She would not prefer this designed block because it lacks tree shade and proper shade. And the blocks are spaced apart so that only one person can sit.

5.		• **Gender:** Female • **Age:** 21-year-old • **Visiting Time:** Once a month • She had visited this place for shopping. She prefers seating area near the FC College to this one because there is no tree shade, no landscape, and no buffer zone bifurcation created between the road and footpath.
6.		• **Gender:** Female • **Age:** 25-26-year-old • **Visiting Time:** Twice a month • They go to FC Road to shop and catch up with each other. They prefer the seating area outside FC College to the one near Wadheshwar because it is better maintained.

Source Author

Figure 3

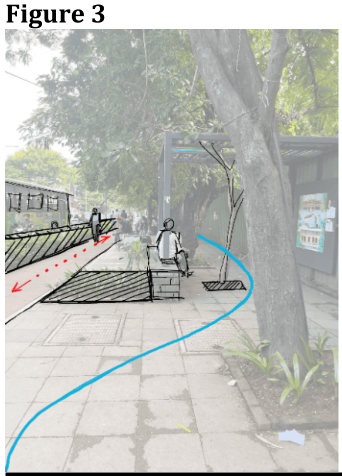


Figure 3 Landscape Behind Seating Space

Source Author

Figure 4

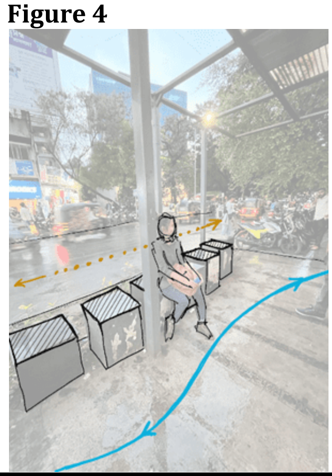


Figure 4 Urban Furniture at Different Height

Source Author

Figure 5

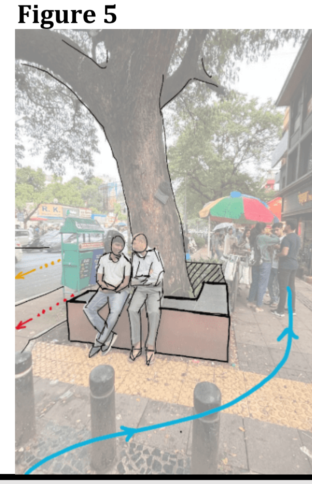


Figure 5 Seating Space Under the Tree Shade

Source Author

Table 2

Table 2 Visual Analysis and Observations from F.C. Street

No.			Observations
1.	Street-Road Connection		This image provides a clear illustration **between the sidewalk and the road**. The **separation** is created through landscape and bollards. The **roadside plantation** provides good privacy as well as safety for those using the footpaths.

2.	Dark avoided Space		The entire pathway is shaded by **large old trees** that provide shade throughout the day. However, in some places, it creates a negative **dark space** that might have been avoided at night. Part of the reason could also be the green corrugated sheet on one side.
3.	Parking area		A roadside plantation was **missing** in some places where urban furniture was **not there** due to commercial shops. Instead, a two-wheeler **parking space** was accommodated and replaced in that area while still taking the height of the walkway into consideration.
4.	Garbage		There were separate containers for **dry and wet garbage** set at equal intervals throughout the whole roadway. They were set just alongside the walking path.
5.	Seating space near Commercial shops	 	There is a **commercial section** with a busy pedestrian on the **opposite** side of the urban furniture street design. The only seating on that side was **beneath the tree**, which could only accommodate 8-10 people. People had to **cross the road** after shopping and dining to use the sitting area provided.

3.2. A CASE STUDY OF PUNE – J. M. ROAD

Jangali Maharaj Road (JM Road), like FC Road, is a one-way street with a traffic flow. As a result, proper vehicular and pedestrian movement is observed. The street is planned with cycle tracks and large pedestrian paths to allow people to wander across safely. Each street designated as a public open space must strive to integrate with all parks, restaurants, landmark buildings, heritage, retail shops, and so on, to create a cohesive, all-inclusive connected streetscape for the city.

Figure 6

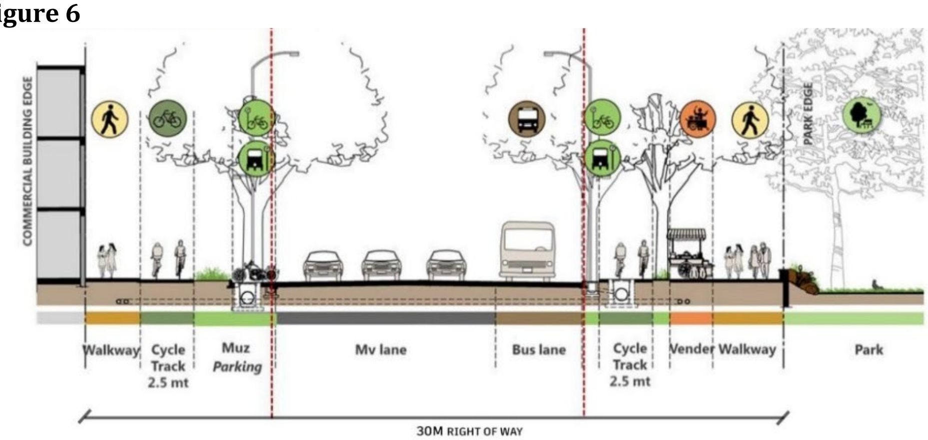


Figure 6 Section of Jangali Maharaj Road
Source Oasis Designs. (n.d.)

Figure 7

Figure 7 Sketch of Jangali Maharaj Road
Source Author

Figure 6 shows the section across JM Road Street helps us understand how green space separates spaces and widen the pathways. In Figure 7, the segregation of Vehicular and pedestrian and vehicular movement leads to safety and encourages walk-ability on urban streets.

The landscape has been used to provide separation for walking paths, footpaths, and cycling routes. This landscape division allows for a sitting area in between. While the trees along the walkway cover the entire width of the road and give shade on bright days. The activity was more concentrated on the commercial side, with fewer seats occupied. While on the other side of the road, opposite the business area, is a garden where people of various ages come at various times to relax and socialize. PMC did not just widen the walkways but also provided seating spots and fun game areas on the roadside for children. There is a famous Sambhaji garden on the side of the pathway, which will affect the usability of the space more with different age groups. While there is a residential area beside a road with no commercial use, the design of urban furniture is lacking and the design is impeding the walkway constructed in a very small space. "As residents can see the visible change on JM road, many elected members are making demands to replicate the model in their areas. It is not possible to beautify all the roads by considering the space available in those areas but wherever possible PMC will try to execute the same", said Raut – Indian Politician Tomar (2018)

Table 3

Table 3 Visual Analysis and Observations from J. M. Road

No.			Observations
1.	Landscaping near street furniture		Urban furniture bench is surrounded by **nature and landscape,** making us forget that we are sitting on the side of the road. There is a **tree canopy** above and a **plantation barrier** for a sidewalk. Making it an absolutely ideal location for an evening stroll.
2.	Isolated space w.r.t shrub plantation		The sidewalk is **lined with shrub plantations** on both sides, creating an isolated space for walking and jogging. It also separates the seating area from the road.
3.	Safety from vehicles through a landscape		There is a special landscape path that **separates** the seating area and the footpath along with the road. It creates a **barrier** for people looking over the road via urban furniture. It also helps to **reduce noise** from vehicles. From the footpath.
4.	Signages	 	J.M. Road has more visible and **clear signage** at proper intervals while walking. All of the signage is set precisely, making it **easier to understand** the space.

5.	Play area		There are **chess tables** for people to come and utilize the space for walking and seating and not only for using the commercial area but use an outdoor play area.

Source Author

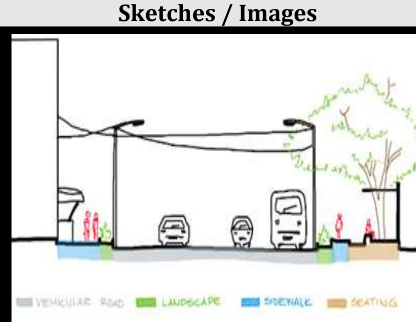
4. FINDINGS AND DISCUSSIONS

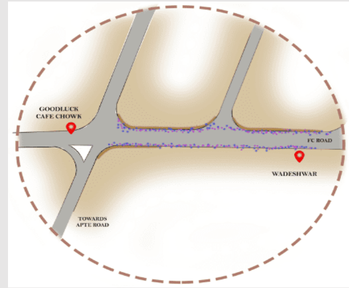
After the implementation of the smart city project, the street has become a place rather than a space of only vehicular movement. The frequency of visiting the streets has increased although not for the activities surrounding the streets, but people are using the streets as places to meet, chat, and interact. The vehicular and pedestrian movement are segregated so this gives safety for the pedestrian. It's intriguing to explore the unique relationship between street furniture and urban vitality. Sitting inside a city setting offers a chance to pause as well as a physical and more personal connection to a place than one would have while standing or moving around it. The greatest areas for benches are places with high pedestrian traffic, such as shopping mall walkways, transit stations, plazas, and areas outside of institutions and organizations; regions with minimal activity are considered to be in bad places to redesign the street. The street furniture incorporates landscaping to add life and shrub plantings at the edge to protect people from moving vehicles. Bus stations, bike paths, and seating places are also present. The adjoining-built form identity has a significant influence on the street. In terms of tactile blocks, accessibility, etc., the street conditions also benefit those with special needs and benefit all age groups. Proper comprehension of signage for various tasks to optimize user flow and mobility. In Pune, where there is a lot of traffic, bollards are mostly used to prevent vehicles from driving on pavements. Dustbins, bus shelters, etc. are sufficiently distributed around the sidewalk. The urban street pattern was created using a variety of spatial, visual, and sensory approaches.

F.C. Road and J. M. Road have a similar approach in terms of the street pattern but differ in terms of use and context. The commercial area just adjacent to the street is the same in both locations, however the area utilization directly outside the store changes.

Table 4

Table 4 Common Observations and Findings

Common Observations	Sketches / Images	Findings
1. Street **Section**		The street section demonstrates how green space divides areas and broadens routes while providing safety.

2.	Activity **Mapping** (Time- 5:00 pm to 7:00 pm) Male: 120-160 Female: 150-180		The vital urban environment and perceived safety lead to **gender equality** in the use of active streets because of the commercial use
3.	**Seating** space near the **commercial** area -		Providing **seating near commercial areas** improves the usability and functionality of the street, as well as the value of the commercial space.
4.	**Bollards -**		Bollards are only positioned to facilitate cycling activity in order to prevent the flow of road cars onto the sidewalk. It leads to a safe environment and increases people's walk-ability and urban vitality
5.	**Integration of art in the street**		The seating space is semi-covered with tree shade above which helps on sunny days. A few artistic paintings are kept to enhance the space along the landscape.

Source Author

5. CONCLUSIONS

This study examined the relationship between space usage patterns on urban vitality and street furniture, taking into account the physical characteristics of the street environment, and basing its findings on observations and human experience. Beyond simple comfort, these furnishings' main purpose is to give a location personality and individuality and to entice people to use outside areas. When waiting for transportation, street furniture might provide sitting and shelter, for instance. It may also improve a site's aesthetic elements, image, and identity if properly planned and created. In recent years, high quality in the design of street furniture has drawn attention to landscape design in addition to its functional aspects. Emphasis is now placed on the fusion of function and aesthetics with new materials and technologies, creative concepts, and artistic applications in the user-friendly urban landscape. With the help of street furniture, a city may develop a stronger sense of community and become a place where people can meet, interact, and share in daily life. Having badly designed street furniture highlights a city's disorder, lack of cohesion, and sense of community. In recent years, cities have focused on establishing urban interactive space as well as well-planned roadways in order to better regulate vehicular circulation and commercial space utilization. Instead of not offering one, locations, where commercial space is not available, should build an alternative street plan and furnishings based on its context and surrounding.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

REFERENCES

Aijaz, R. (2021). India’s Smart Cities Mission, 2015-2021: A Stocktaking.

Allahdadi, M. (2017). Effectiveness of Urban Furniture Designing to Enhance Social Interactions.

Aram, F., Gracia, E.H., Solgi, E., & Mansournia, S. (2019). Urban Green Space Cooling Effect in Cities, 5, 4. https://doi.org/10.1016/j.heliyon.2019.e01339.

Atak, S. (2020). The Impact of Urban form on Urban Vitality: Comparative Analysis of Two Cases in Yenikale Neighbourhood.

Balsubramanian, S., Irulappan, C., & Kitchley, J. L. (2022). Aesthetics of Urban Commercial Streets from the Perspective of Cognitive Memory and User Behavior in Urban Environments. Frontiers of Architectural Research, 11(5), 949-962.

Basar, A. G. (2021). Sustainability in Urban Furniture Design; The Use of Renewable Energy Sources, 7, 1.

Bhaghyalaxmi, M., Srikanth, S., & Arjun, K. S. (2014). Urban Streets and Nodes: A Case of Bangalore, 5, 7.

Bhat, S. S. (2022). Understanding the Fundamental Purpose of Urban Green Spaces: Insights from Central Bengaluru, India. ISVS E-Journal, 9, 4.

Dhaou, O. B., Vasváry-Nádor, N., & Gall, A. (2022). Designing Street Furniture: A Protocol to Enhance the Quality of Life in Urban Spaces.

Grabiec, A. M., Lacka, A., & Wiza, W. (2022). Material, Functional, and Aesthetic Solutions for Urban Furniture in Public Spaces. https://doi.org/10.3390/su142316211.

Khorasgani, A. M., Villalobos, M. H., & Eskandar, G. A. (2023). Sustaining Historic Cities: An Approach Using the Ideas of Landscape and Place. ISVS E-Journal, 10, 1.

Lynch, K. (1960). The Image of the City, The MIT Press.

Oasis Designs. (n.d.). Pune Streets Program.

Patki, A. P. (2017). Relationship between Street Furniture in Pune and User’s Convenience, 5, 2.

Radwan, A. H., & Morsi, A. A. G. (2016). The Importance of Integrating Street Furniture in the Visual Image of the City.

Solanki, R. (2021). Street Furniture is Important for Attracting City and Public Spaces, 10, 3.

Street Design Workshop Slideshare. (n.d.).

Tomar, S. (2018). Pune's Footpaths Get a Welcome Makeover.

Yang, Z., Zhang, L., & Zhihui, W. (2022). Research on Performance Evaluation of Urban Furniture Function Design Based on Internet of Things Digitization.

Yücel, G. F. (2012). Street Furniture and Amenities: Designing the User-Oriented Urban Landscape.

Şatir, S., & Korkmaz, E. (2005). Urban Open Spaces With Examples & the Classification of Urban Furniture, 2.

ugccare.unipune.ac.in/Apps1/User/WebA/SearchList

SAVITRIBAI PHULE PUNE UNIVERSITY

Home

UGC

Search

UGC-CARE List

UGC-CARE List

You searched for "**shodhkosh**". Total Journals : **1**

Search:

Sr.No.	Journal Title	Publisher	ISSN	E-ISSN	UGC-CARE coverage years	Details
1	ShodhKosh: Journal of Visual and Performing Arts	Granthaalayah Publications and Printers	NA	2582-7472	from October-2021 to July- 2024	Discontinued from July 2024

Showing 1 to 1 of 1 entries

Previous 1 Next

Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
Enhancing Connections in Visual and Performing Arts: Multidisciplinary Insights in Architecture and Planning
July-December 2023 4(2 ECVPAMIAP), 142–150

INVESTIGATING THE CHALLENGES BETWEEN DESIGNS TO THE REALITY OF DIGITALLY FABRICATED STRUCTURES

Shraddha Makarand Parange [1], Dr. Vaishali Anagal [2]

[1] Student, Fourth Year, Dr. B. N. College of Architecture, Pune, Maharashtra, India
[2] Associate Professor, Dr. B. N. College of Architecture, Pune, Maharashtra, India

Received 29 August 2023
Accepted 29 December 2023
Published 03 January 2024

Corresponding Author
Shraddha Makarand Parange,
shraddhaparange1608@gmail.com

DOI 10.29121/shodhkosh.v4.i2 ECVPAMIAP.2023.706

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Copyright: © 2023 The Author(s). This work is licensed under a Creative Commons Attribution 4.0 International License.

With the license CC-BY, authors retain the copyright, allowing anyone to download, reuse, re-print, modify, distribute, and/or copy their contribution. The work must be properly attributed to its author.

ABSTRACT

Digital fabrication is not only the relation between design and construction but also the relation between thinking and making, which would be established by the use of modern technologies. The study aims to investigate the challenges formed between the two aspects of parametric architecture 'Design' and 'Fabrication' in India. There are various factors on which this gap depends. These factors would be the cost of construction, building material required for fabrication, and time required for construction compared with the conventional methods of construction. The objective of this study is to understand how digital fabrication will change the way of construction in India, which won't be restricted to the classroom or only the computer-based design but will work in onsite construction with many different materials with no waste of time and money. The earlier literature focuses on a single aspect which may be either design or fabrication. There are fewer papers available that address both of the aspects comprehensively. The research would get an overview of different perspectives of people towards parametric architecture. This is done by conducting surveys of different practicing architects, students who have done their masters in digital architecture and now practicing, and contractors who are working on parametric construction. The survey was conducted by sending a questionnaire to different practicing architectural firms all over India, the students who have pursued Master's degrees in digital architecture and professors teaching Master's degrees in digital architecture who had an interest in parametricism. The data received was analyzed using descriptive statistics. The qualitative data received through the questionnaire was analyzed by identifying patterns and then categorized according to the different answers.

Keywords: Parametric Architecture, Digital Fabrication, Parametricism

1. INTRODUCTION

The architectural magazines publish many articles about architects and their work on parametric architecture. The majority of work done in India, regarding Digital architecture, was concerned with the digital design of small-scale manufactured structures such as pavilions, public seating, elements in bungalow façades, or occasionally form exploration using parametric architecture tools (oneistoex, 22, Melih Gürcan Kutsal 22). Furthermore, the websites of architectural firms post numerous rendered images of skyscrapers and massive townships with very futuristic designs, but images of structures built using parametric designs are rarely seen. Many small-scale pavilions and installations have been observed in India, whereas many completed buildings built outside of India have been discovered to be digitally designed.

There may be different approaches of designers and fabricators to parametricism, which had different depending factors, and these factors generated a gap between thinking and making. This research attempts to identify the reasons behind the generation of this gap. The inclination towards parametricism may involve the fascination or inclination towards technology, futuristic forms, and different skillset of software. A questionnaire Survey was conducted to investigate:

1) What is the situation of Parametric Architecture in India based on design and fabrication aspects?
2) How are practicing architects responding to the term digital fabrication in India?
3) What is the current focus of parametric practices in India in current times?

1.1. UNDERSTANDING PARAMETRIC ARCHITECTURE

The term parametric has mathematical origins, but it has a different meaning in architecture. In Greek, para means besides, and metre is derived from metron, which means measure. When these two words are used together, they refer to a collection of numerical or other measurable factors that define a system or establish the conditions for its operation Koumari (2022). The experimental nature of parametric modelling is known as form-finding. The method of metric architecture is based on algorithms that enable the various parameters. These parameters are subject to some rules, which determine the relationship between design inputs and design outputs. This relationship produces complex geometries and structures.

One of the earliest examples of parametric design is Antonio Gaudi's upside-down church models; in his designs for the churches of Colonia Guell and Sagrada Familia, he created a string model (Figure 1). Digital fabrication was first used to create physical models for the restorations of Saint John the Divine Cathedral and Sagrada Familia Burry et al. (2001). That was weighted down to create complex vaulted ceilings and catenary arches. By adjusting the weight positions, he could change the shape of the catenary arches and see how it affected the entire model. He then placed a mirror on the model's bottom to see how it should appear upside down. (Figure 2).

Figure 1

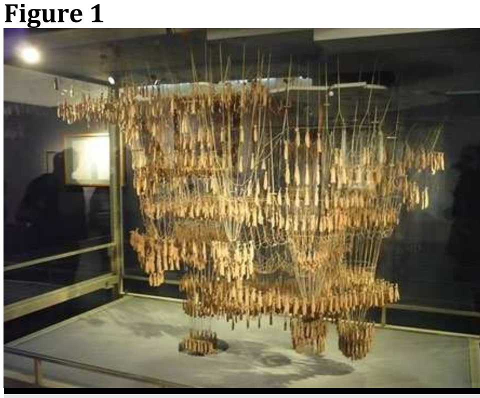


Figure 1 Upside Down Model of Sagrada Família

Figure 2

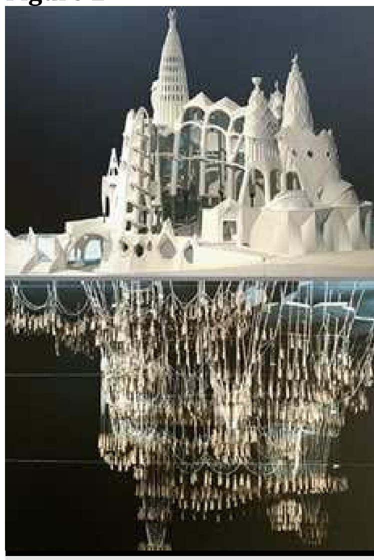


Figure 2 Visualization of Model with Mirror at Bottom of String Model

Parametric design deals with the designing of futuristic forms with help of different software. These forms mainly include forms with curvy nature, parabolic shapes, and flowing shapes of arches. There is large technical growth in the software field and now anyone with knowledge of coding can design this software. But the most used software for digital architecture is Rhino + Grasshopper designed by McNeill and associates.

Figure 3

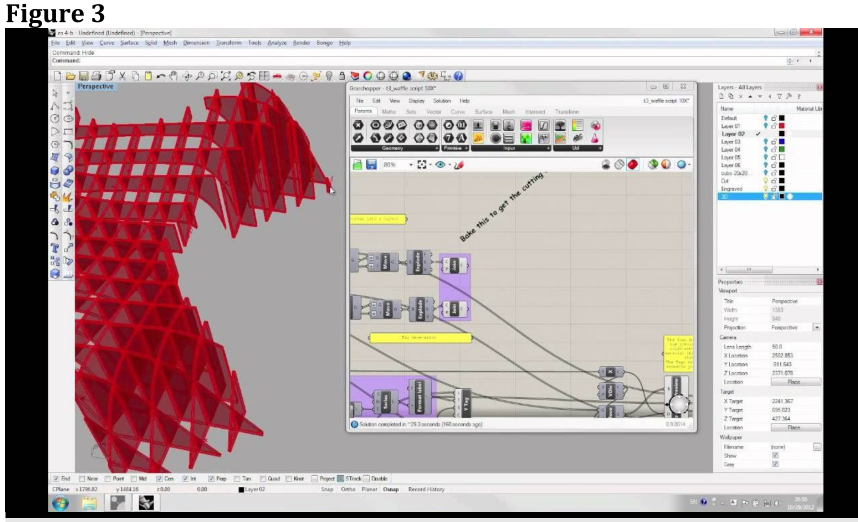


Figure 3 Picture Showing Design Process of Model on Rhino Software with Grasshopper

Structures designed with the help of parametric software are produced using a variety of digital fabrication techniques, such as additive, subtractive, and robotic fabrication. The most common digital fabrication procedures used in architecture are; additive procedures, subtractive procedures, formative procedures, joining procedures Hauschild & Karzel (2011), and robotic fabrication. Gallo & Pellitteri (2018)

3D printing, laser cutting, robotic building, and digital fabrication using AR and VR technologies are the tools used for these techniques. Digital fabrication is now being used in India, but so far it has only been for small-scale items like pavilions, benches, hangings, or furniture used for display purposes. However, parametric architecture's potential applications may completely change with digital fabrication. There are many architectural firms in this particular industry in India; these firms/studios have experience with parametric design and want to concentrate on digital design.

2. THEORETICAL BACKGROUND

A new, epochal global architectural style known as parametricism encompasses all design disciplines, including urbanism, interior architecture, product design, and furniture design, Integrating fashion design and graphic design Chokhachian (2014). Additionally, throughout the past fifteen years, many uses of digital media in architecture have had an impact on the entire area of building and design. Digital media were initially only used as a medium for representation. New digital technology has provided architecture with a new instrument for conceptual design in digital media. Schnabel (2007).

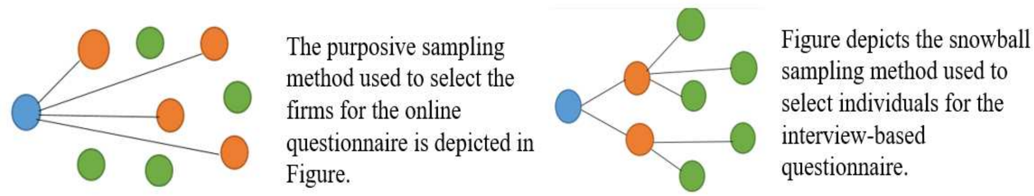
According to Luigi Moretti, the definition of parametric architecture is the Affirmation of the Architect's decision-making and expression freedom, but only if it does not interfere with the characteristics determined by the analytical investigations. In an article published in Moebius, the concept of Parametric Architecture is thoroughly developed by Moretti (1971), two years before his death, renews the need for a new architecture, rigorous in the definition of form through the use of Mathematical logic, computer techniques, and methods of operational research Viati (2010), necessary to overcome the empirical state of the current architecture.

As a result, parametric architecture is becoming increasingly popular. Geometric primitives such as squares, triangles, and circles are avoided in metric architecture, as are simple repetitions of elements and the juxtaposition of unrelated elements or systems. The key point is that parametricism requires that any element or subsystem that enters the evolving composition engage in intensive, adaptive relationships with what is already there Chokhachian (2014). Digital fabrication in architecture opens up previously unattainable possibilities for form, material, process control, and optimization in construction Kumsal et al. (2021). Which encourages both young and experienced architects to investigate these structures.

Form-finding has become an important strategy for shape determination since designers discovered that CAD programs could manage complexity beyond human capabilities. Architects can now design using a multi-parametric form-finding approach that incorporates geometry, dynamic forces, the environment, social data, and any other desired data. Kumsal et al. (2021). this new conversation between form and process has resulted in new architectural tectonics. As a result, there are various perspectives on form finding (design) and bringing these complex structures to life (fabrication). This study attempts to identify the various factors that influence the main two phases of parametric digital fabrication.

3. METHODOLOGY

At the commencement of the study, various articles were read, and a questionnaire was developed based on the articles in architecture magazines and research. There were both open-ended and closed-ended questions on the questionnaire. The qualitative questions provided a good understanding of the various thought processes of architects. Purposive sampling was used to conduct the survey, which allowed for the collection of qualitative responses from the best-fit participants, resulting in relevant data for research. The participants were chosen based on their interest in working in the design process or the construction of parametrically designed structures, as well as their post-graduate training in the parametric discipline.



3.1. METHODS AND TOOLS

The data collected from the questionnaire was based on theoretical knowledge. This data from the survey was collected from different architecture firms, professors, and master's students who had completed a Master's in digital architecture. The architecture firms were from all over India and professors and students were from BNCA digital architecture. A total of 65 questionnaire forms were sent to the above group of people, from which a total of 5 responses were obtained. To understand the origin of interest in whether design or fabrication questions were framed. If someone has no interest in the initial phase of design then there is no scope for fabrication. The following pie chart shows the area of interest in architects about parametric structures.

Figure 4

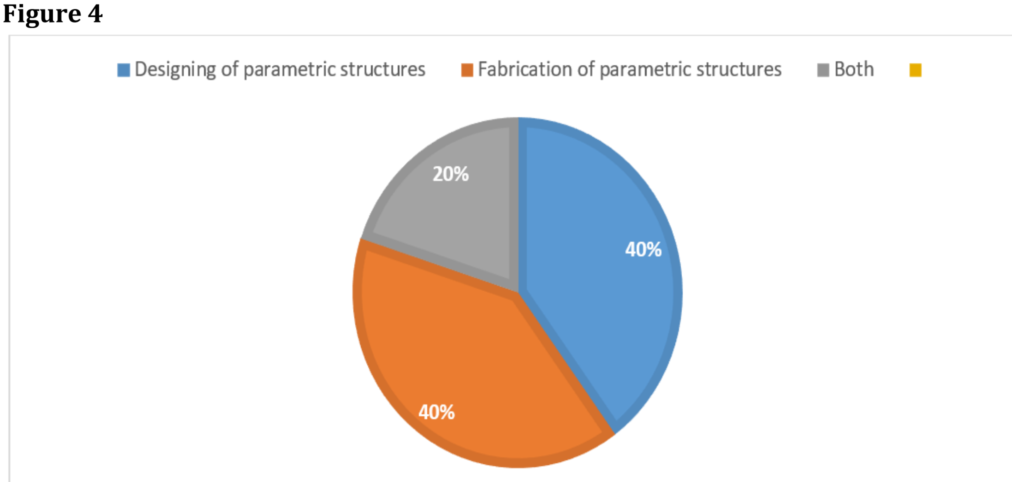


Figure 4 Pie Chart Showing Interest of Work in Parametric Architecture Related to Either Design or Fabrication Process

Interest developed in the design process was due to various reasons prominently because parametric designs consume less period to design concerning the conventional methods of design. Also, this helps in the exploration of new fluid forms rather than being stuck to the cuboidal geometries. Parametric software reduces time consumption while the designing process and is easier to manage the complexity of these forms. As shown in Figure 5

Figure 5

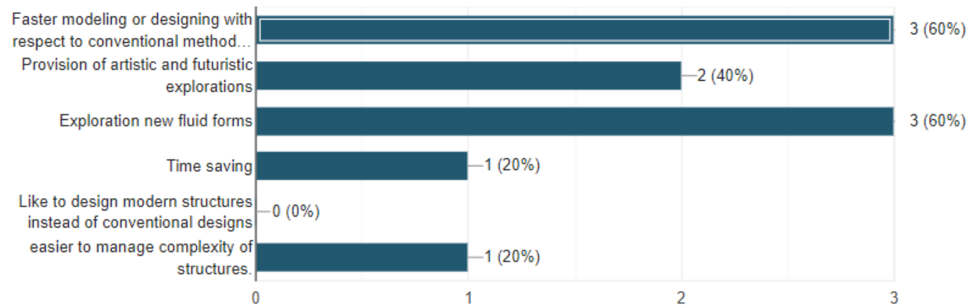


Figure 5 Bar Graph Showing the Interest of Respondents in Design of Parametric Structures

This design thinking and making process is accompanied by software support. Many Software programs are available for parametricism in India even so, only some of them are being utilized for designing, according to the responses received mainly rhinoceros software is used for designing and for fabrication process software such as free cad, metal cut, and the coral draw is used.

Figure 6

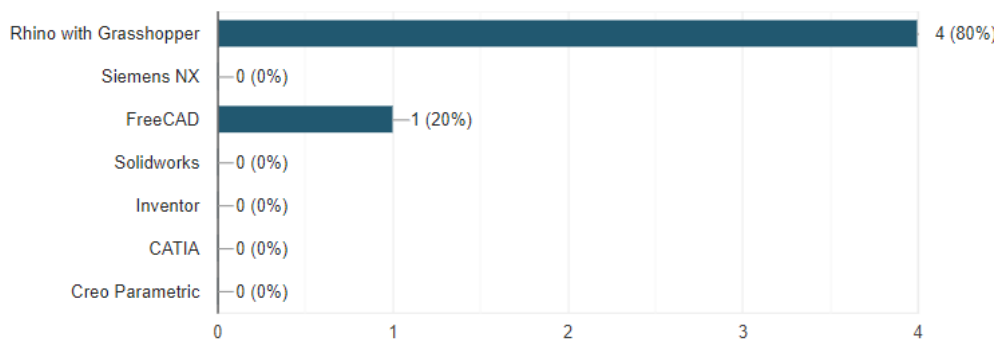


Figure 6 Bar Graph Showing Use of Software in Parametric Designs

As these software are being utilized by respondents the skillset of these software has an impact on the design and fabrication process. According to the responses, on a scale of 1 to 10 the skillset ranging from 3 to 7, are mainly in the design process whereas the skillset above 7 is in the field of fabrication as well. As shown in Figure 7.

Figure 7

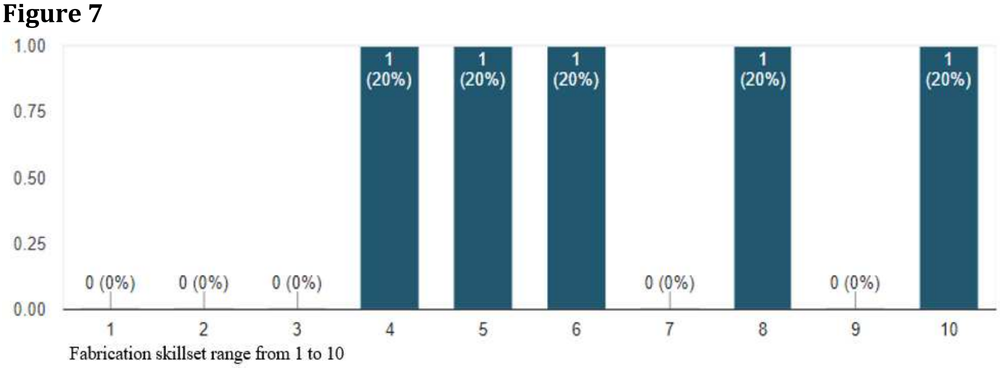


Figure 7 Bar Graph Showing Skillset About Software

For designing and fabricating the skillset for the exploration of this field, prior software experience is essential. Which may also be the cause of the lesser level of fabrication expertise. This software has inbuilt fabrication features yet there are reasons for not building them according to the responses received, lack of fabrication techniques and Complicated designs are what stop users from exploring. Also, financial constraints make it more impractical in a developing economy like India. These constructions can only be built with experienced labour, which places restrictions on the design.

Figure 8

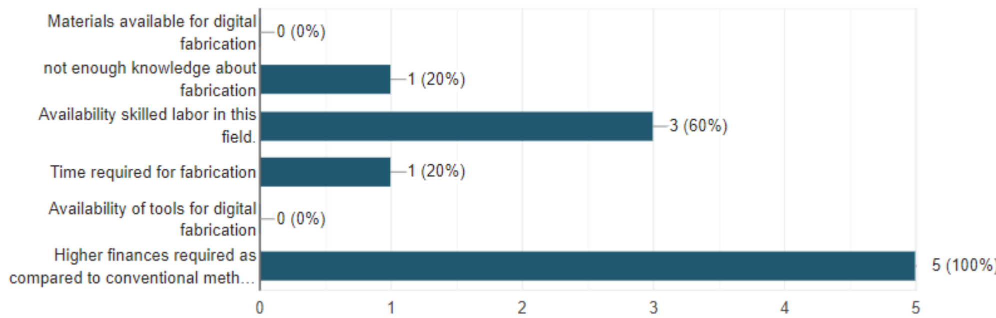


Figure 8 Bar Graph Showing Factors Restricting the Fabrication Process

As various rendered images of these futuristic structures are seen on the websites of architecture firms (Rat Lab, Wall Makers, Ant-Block studios, etc.) different factors would limit fabrication such as economic factors and lack of technology. Some People in India still have a mentality when it comes to these non-conventional constructions, and because they still follow Vaastu Shastra, the reason project remains in the planning stages. People have started accepting these structures for public buildings, but not yet completely in the housing sector, it has been observed that in the interiors of houses parametricism is welcomed but not completely in buildings. In current times, as a status symbol or because of fancy designs a group of people tends to accept these structures. It also depends on the age group, financial condition, and locality of clients. Many people are encouraging/insisting on futuristic structures as compared to a decade back.

Respondents who had moved on to the construction phase also mentioned several problems that included the availability of experienced labor as they find difficulties in understanding drawings, clientele who would support such a financial giant, and fabrication facilities available. The choice of materials available for digital fabrication is crucial because, traditional structures were made of concrete, which was simple to work with because it was just to pour the concrete into the mold to give it shape. In terms of aesthetics, it can be cast into almost any shape, allowing architects and engineers to achieve complex geometry. Xiao et al. (2022).

However, with parametric forms, this is extremely difficult because the individual unit has a unique shape, making it challenging to achieve the desired form. And the materials available at this point such as clay, and plastic have limited structural height with the digital tools available which would not be sufficient for taller buildings. Materials that are capable of folding and bending would give the desired shape in these structures like steel. Here tools and designs are ready but due to some material constraints structure is still in the design phase only. The precision needed to fabricate these structures is attained with the aid of robots and 3D printers, which is not feasible with human precision. Robots are primarily employed in parametricism for precision.

4. RESULTS AND DISCUSSION

The qualitative data collected from the interview of architects practicing digital fabrication, and a survey taken from students who have pursued master's degrees in digital fabrication and Firms practicing in the field of parametricism helped to understand the factors affecting the fabrication process of parametric structures. Initially, the design process requires a moderate skillset in software.

Respondents only want to investigate parametric design and software throughout the design phase, and then they want to proceed to the fabrication stage. Since the development of computer programs such as Grasshopper and Rhinoceros, freedom in the design of parametric architecture has become available. They enable automatic simulation and optimization of problem solutions, greatly expanding the possibilities for creating complex structures and forms Pimenova et al. (2019). Modern construction concepts include the parametric field. This fascinates architects, which is why it's becoming more popular among professionals. It represents a fresh way of approaching structures. Therefore, designers seek to research forms and software in particular and want to become experts in their profession. It is not very difficult to begin the fabrication process because this software has capabilities that generate the fabrication coding while creating itself. However, there are several limitations, mostly financial capital and materials, which have limited the ability of architects to construct.

Additionally, the clientele has a distinct perspective on this structure, which also hinders large-scale fabrication. Although architects create small-scale prototype models for form exploration and models for pavilions, some ideas may not move forward with large-scale production due to cost restrictions.

Although many people now accept the parametric design, there are still some instances where the acceptable design cannot be implemented due to the materials available.

5. CONCLUSIONS

The investigation indicates that several factors cause this gap in the design and fabrication process. From the perspective of the clientele and the designer, these variables would change. Designers' key concern is that they want to first use software to study the design itself and then they want the form exploration of these structures. The financial capital needed to build these buildings is higher than for traditional structures, for example, from the fabricator's point of view, Clients aren't presently approving such large sums for these setups. Some of them agree, but not for substantial structures. Parametric designs are limited to building façades, interiors, and small-scale projects like temples, gardens, schools, railway platforms, or the roofing profile of some structures but not on large-scale buildings.

The designs and production techniques are often ready, but because of these issues, they are only available in digital form and not in reality. Numerous architects in India have already created parametric forms for pavilions, landscape features, public structures like airports, parking structures, and residential building interiors. In India, where the mentioned difficulties are constraining the design to the reality of parametric structures, this would take some time for these structures to be fully accepted. However, it's not as though people do not accept them.

Positively, digital fabrication expands the possibility for these structures to be built and appeals to many practicing architects. If these structures are constructed, they would certainly contribute to sustainable environmental changes in society.

In terms of accepting these fluid forms, India is currently in a phase of coherence. Future years will certainly bring various opportunities for large-scale digital fabrication.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

The author thanks the interviewees and respondents who contributed and responded to the questionnaire survey and for the rich insights they provided.

REFERENCES

Burry, M., Burry, J., & Faulí, J. (2001). Sagrada Família Rosascomputer-Aidedputer Aided Dialogue Between Designer and Craftsperson (Overcoming Differences in Age, Time, and Distance).

Chokhachian, A. (2014). Critical Attitude Toward the Footstep of Googie Architecture on Parametric Architecture.

Gallo, G., & Pellitteri, G. (2018). Luigi Moretti, from History to Parametric Architecture.

Hauschild, M., & Karzel, R. (2011). Digital Processes: Planning, Designing Production. Basel/Berlin/Boston: Birkhauser.

Kumsal, A., & Şen Bayram, A. (2021). Digital Fabrication Shift in Architecture.

Pimenova, E. V., Grigoryan, M. N., Ivanova, P. V. (2019). The Parametric Architecture Tall Buildings Implementation Aspects, IOP Conf. Ser.: Mater. Sci. Eng.

Schnabel, M. A. (2007). Parametric Designing in Architecture, Sydney.

Viati, N. A. (2010). Un nuovo linguaggio per il Pensiero Architettonico. Ricerca Operativa E Architettura Parametrica. In: Luigi Moretti. Razionalismo e Trasgressività Tra Barocco e Informale, Electa, Milan, 409-19.

Xiao, Y., & Hack, N., & Kloft, H. (2022). Digital Structural Design and Shotcrete 3D Printing Strategies for Lightweight Reinforced Concrete Beam-Grid Structures.

Problems and Chan... GRADE 3 REVISION movies eng hind or... HP Utomik New Tab www.sinhgad.edu Gmail News Maps

Visit Our Old Website Register Login

Pushpa Publishing House

Advances and Applications in Statistics

The Advances and Applications in Statistics is an internationally recognized journal indexed in the **Emerging Sources Citation Index (ESCI)**. It provides a platform for original research papers and survey articles in all areas of statistics, both computational and experimental in nature.

IDENTIFYING FACTORS SHAPING ARCHITECTURE OF RESIDENTIAL REDEVELOPMENT - APPLICATION OF FACTOR ANALYSIS MODEL IN ARCHITECTURAL RESEARCH

P-ISSN: 0972-3617

Vaishali Anagal

Abhijit Natu

Vol. 90, Number 2, Pages 161-188

Advances and Applications in Statistics
© 2023 Pushpa Publishing House, Prayagraj, India
http://www.pphmj.com
http://dx.doi.org/10.17654/0972361723068
Volume 90, Number 2, 2023, Pages 161-188 **P-ISSN: 0972-3617**

IDENTIFYING FACTORS SHAPING ARCHITECTURE OF RESIDENTIAL REDEVELOPMENT - APPLICATION OF FACTOR ANALYSIS MODEL IN ARCHITECTURAL RESEARCH

Vaishali Anagal and Abhijit Natu

Dr. B. N. College of Architecture
Pune, India

BKPS College of Architecture
Pune, India

Abstract

The researchers in architecture domain are often intrigued by the role of various factors in shaping residential architecture. The researchers studying vernacular architecture, traditional architecture, housing in historic precincts and contemporary housing have often discussed how various factors affect the architecture of single-family housing. The architecture of multi-family housing, especially the architecture of redevelopment of multi-family housing, is seldom discussed in literature. Majority of research are qualitative owing to the nature of variables. This research aims to identify the factors that shape the

Received: November 22, 2022; Revised: October 2, 2023; Accepted: October 19, 2023
2020 Mathematics Subject Classification: 62H25.
Keywords and phrases: redevelopment, multi-family housing, factor analysis.

How to cite this article: Vaishali Anagal and Abhijit Natu, Identifying factors shaping architecture of residential redevelopment - application of factor analysis model in architectural research, Advances and Applications in Statistics 90(2) (2023), 161-188.
http://dx.doi.org/10.17654/0972361723068
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
Published Online: November 15, 2023

architecture of redevelopment of multi-family housing. The research employs qualitative method to identify the variables at exploratory stage and quantitative method to extract the meaningful factors using factor analysis at the later stage. This research demonstrates application of factor analysis in architectural research. It also informs how literature study and exploratory research can be constructive in interpreting the results of factor analysis based on which the strongest and most appropriate solution of factor analysis can be selected for drawing conclusions. This research quantitatively brings forth these factors and this is a significant contribution of this research.

1. Introduction

There is abundance of literature from the statistics discipline on the use of factor analysis, the process of carrying out factor analysis, how to determine the adequacy of sample size and how to retain and eliminate the factors after factor analysis. However, there are two important steps to be followed before and after the factor analysis. One is the identification of variables which explain the phenomenon under study before the factor analysis is carried out and another is naming the extracted factors and interpreting the results after the factor analysis. Both of these steps need a strong theoretical underpinning. This research paper presents the literature review from the discipline of architecture from which the variables shaping the residential architecture are explored. It also presents a literature review on the procedures of factor analysis and considerations during the procedure. It further presents a step by step procedural application of factor analysis in the study of residential redevelopment and illustrates how theoretical underpinning is essential to label the factors and substantiate the role the factors in explaining the phenomenon under the study.

2. Variables Affecting Residential Architecture

We find ample research and literature on domestic architecture pertaining to single-family housing as compared to the architecture of multi-family housing. Literature is studied to understand the variables shaping residential architecture. A number of researchers in India and abroad seem to be interested in investigating the role of the socio-cultural aspects in shaping the residential architecture. House as a reflection of culture has been examined by many researchers. The researcher in [1] affirms that socio-cultural values across different cultures in Japan and England have shaped house forms in those countries. In her empirical based research, [1] emphasizes that different privacy concerns in different cultures shape the house forms differently. The researchers in [2] believe that the concept of house is beyond its physical attributes. They argue that spatial configurations reveal social or cultural meanings. The author in [3] investigates the role of social structure and social interaction in the spatial patterns of residential buildings within historic settlements from Scottish Atlantic Iron Age. It is argued that social structure shapes and in turn, gets structured by the spatial organization of the buildings. While analyzing traditional architecture of single-family homes in Nigeria, the author in [4] argues that socio-cultural influences shape the residential architecture to what she calls as 'folk architecture'. She also takes a detailed account of colonial influence on 'folk architecture' during the British rule. The reference [5] considers multiple factors influencing architecture of traditional houses in the historic city centre of Midyat-Mardin, Turkey including its location, climate conditions, geological situation and availability of local materials, historical context of the place, cultural influences and demographic characteristics of the households like family structure and economic situation.

While investigating the role of the socio-cultural factors in shaping domestic architecture of 19th century in the city of Pune, India, the reference [6] argues that the household's characteristics like family background, education, occupation, social status and lifestyle have a bearing on the kind of house one chooses to build. In the study of new urban houses in China, the reference [7] explains how social factors affect design of urban houses. They elucidate the effect of demographic factors like, family size and structure, family situation, age of the head of the family, change in income level and social factors like changing needs due to change in lifestyle of occupants and change in work life on the spatial needs and space configuration of urban houses. An empirical study of transformations in Nigerian low-cost houses in Logos by [8] revealed that the decision to transform the house was highly related to tenure type (ownership/rented), length of stay, marital status, attainment of education and socio-economic characteristics of households. The researchers in [9] signify that domestic architecture represents the culture, beliefs and traditions of the people in the region. They study the influence of technology, concerns of privacy and safety, traditions, lifestyle, religion, social interaction and demographic factors such as family size and structure on architecture in Kerala, India. The authors in [10] discuss the changes in the traditional architecture in two rural areas of Poland in the context of turbulent political situations. They argue that social, economic, legal and planning factors have influenced the architecture in rural areas of Poland under the study. Their study reveals how housing needs evolved over time out of changes in expectations, social patterns, change in income levels and legal regulations and how these factors have a bearing on the architecture in the rural areas of Poland. The researcher in [11] examines the architecture of multi-family housing in two different contexts - one from the Basque Country and the other from France to understand whether the residential architecture of multi-family housing in these two estates reflected the specific characteristics of construction technology and town planning prevalent in these two cities. He emphasizes that architecture of multi-family housing in both the cases is driven by construction technology and town planning norms. The variables identified from the literature included site configuration, shape, topography, soil conditions [5], site context/regional/local context [5], climate [7], economics/cost [6-9], demographic characteristics of users [4, 6-9], user's needs [2, 7-9], user's aspirations/preferences [7, 8, 10], change in lifestyle [7-9], socio-cultural aspect [2-8, 10], construction technology and materials [4, 6, 9], codes and regulation [10, 11].

3. Factor Analysis

Factor analysis is a group of statistical methods carried out to investigate the relationship between a set of variables measured through questions or items. Factor analysis is used in various fields including social sciences, education and psychology [12]. ‘*The old adage that factor analysis is as much an art as a science is no doubt true*.’ This quote by [13] highlights the complexity of use of factor analysis in research. There are number of decisions that need to be taken by the researcher while conducting factor analysis. The quality of these decisions determines the accuracy and quality of factor solution [14, 15]. These decisions are:

(1) How to determine the minimum sample size?

(2) How many factors to be retained and what factors to be retained?

(3) How to select best or strongest solution of factor analysis that can give better interpretation of results?

(4) What type of rotation method to be used?

To answer these questions, a literature study on factors analysis was carried out which is presented below.

3.1. Adequate sample size for factor analysis

Examining sample adequacy is an essential part of factor analysis to evaluate whether the constructs achieved through factor analysis are strong enough to be interpretable [16]. The researchers in [17] underline the importance of determining sample size for any empirical study. They emphasize that determining sample size especially for factor analysis is very complex because of subjectivity involved in procedures. For a novice researcher, it is always a dilemma to take a decision regarding the number of samples to be collected and whether the collected sample is sufficient to carry out factor analysis or not [12]. There is a plethora of literature that describes the sample size required for carrying out factor analysis. However, there is a huge disparity in the sample size adequacy suggested by various researchers/experts and their criteria of suggesting adequacy also vary greatly [12, 18, 19]. The criteria defined by sample adequacy by various researchers include: (1) number of cases or samples itself [12], (2) the ratio of cases/subjects to number of variables (STV ratio) involved in factor analysis [12], (3) communalities of variables [19], (4) overdetermination of factors - number of variables and their loading in each of the factors [12, 18, 19] etc. and off course, (5) KMO test in SPSS indicating data adequacy [12].

3.2. Number of cases

The researchers in [18] take a detailed account of recommendations regarding the sample size that are considered adequate in literature. As cited in [18], the recommendations regarding the data adequacy in terms of absolute number of samples vary greatly in the literature and range from 100 to 200 to 250 to 300. The reference [20] recommended having 51 more subjects than the total number of variables, whereas [21] suggested a rough rating scale for sample adequacy as 100 = poor, 200 = fair, 300 = good, 500 = very good, 1,000 or more = excellent. The article [22] argues that a reliable factor solution can be obtained for a smaller sample size which is less than 50 for a data set with higher communalities and higher variables to factor ratio to which they term as ‘well-conditioned data set’.

3.3. Subject to variables (STV) ratio

Similarly, the suggestions regarding number of participants (subjects) to number of variables (STV) ratio range from a ratio of 3-6 to 5-10 as recommended by various authors [18]. With such great variations in these recommendations in literature, it is a tough task to determine data adequacy for one’s own research. The authors in [18] argue that with such inconsistency in these recommendations, these are hardly useful for researchers conducting empirical studies. They [18] also point out that some notable literature on factor analysis by authors like [20, 23] do not offer any recommendations on minimum sample size required for factor analysis.

3.4. Communalities

Some literature suggests considering a measure of communalities of variables to determine whether the data collected is ‘strong’ enough for carrying out factor analysis. If data is ‘strong’ with higher communalities and higher factor loadings in each factor, then minimum sample size does not matter [24]. The researchers in [18, 24, 25] could yield similar solutions with smaller data sets as they could yield with large data set when the communalities of variables were higher. The STV ratio was 3.0 for smaller size of sample in case of study conducted by [24], whereas it was 1.3 and 3.9 in two different studies conducted by [25]. With the help of empirical studies, reference [18] argues that the recommendations regarding sample size on the basis of absolute number of sample size and STV ratio are misleading and there are other factors that need to be considered while determining data adequacy.

The researchers in [12, 18] point out that the major reason of recommending larger sample size is reducing the sampling error and recovery of population factor. The authors in [24] emphasize that the representativeness of sample is more important than sheer number of samples to get a reliable factor solution. The researchers in [26] argue that the impact of sampling error gets reduced with high communalities of variables. The literature by various researchers like [27, 28] emphasizes on the effect of communality values on the quality of factor solutions in terms of replicability and recovery of population factors. Thus, factors with variables having low communalities affect the recovery of population and demand more sample size to overcome the issue to sampling error [29]. According to [12, 18], how large enough should be the sample will be determined by two factors - communalities of variables and overdetermination of the factors. In another research, reference [29] argues that when communalities are high, other factors like overdetermination of factors or sample size have a little effect on recovery of population factors.

Table 1. Level of communality

Communality range	Level of communality
0.6 and above	High
0.2 to 0.8	Wide
0.2-0.4	Low

According to [18], the values of communalities over 0.6 are considered to be high, the values that range between 0.2 to 0.8 are considered to be wide and those below 0.4 are considered to be low (see Table 1). Higher communalities of variables result into minimizing sampling error and better recovery of population and have a positive effect on the quality of factor solutions. The researchers in [28] regarded the communalities more than 0.8 as high communalities. However, it is unlikely to get such high communalities in real data. Generally, the communalities observed in real data range between 0.4 to 0.7, which are within low to moderate range [30]. The average communality in social science research was found to be around 0.55 (as cited in [31]). The reference in [18] recommends sample size less than 100 as acceptable sample size for an average value of communalities above 0.6, whereas sample size between 100 to 200 as acceptable size for an average value of communalities between 0.5 and 0.6. Still the question remains what researchers should do with the variables having low communalities. The article [32] recommends that variables with low communalities less than 0.2 (meaning that the variable has unique variance) are to be eliminated from the analysis since factor analysis focuses on considering common variances rather than unique variances.

3.5. Overdetermination of factors

Factor analysis is a technique of deducting number of variables into few significant factors that can offer meaningful insight regarding the phenomenon under study. In factor analysis, some variables get grouped together under a certain factor and explain the dimensions of that factor. Each variable will have a value of factor loading that measures the contribution of that variable in explaining a particular factor. High factor loading of a variable indicates that dimensions of factor are well explained by a certain variable [26].

Overdetermination of factors indicates the extent to which each variable well explains each of the factors [26]. Overdetermination of factors is defined by the two criteria: the value of factor loading of each variable and the number of variables grouped under each factor [26, 29].

For achieving higher overdetermination of factors, the number of variables should be several times more than the number of factors resulting into higher variables to factors ratio (p:r ratio) and also, the factor loadings of each variable should be higher. The recommendations regarding p:r ratio too vary in the literature. The researchers in [21] suggest p:r ratio to be 5:1 to achieve highly overdetermined factors. In the study conducted by [29], they observed that there is a close interaction among 3 factors - sample size, communalities and p:r ratio. The effect of sample size is insignificant for any p:r ratio, if communalities are higher. The effect of sample size increases for different p:r ratios, gradually for wide communalities and substantially for lower communalities. On the other hand, if communalities are lower, the role of p:r ratio and sample size become crucial for better recovery of population. A greater p:r ratio is helpful in case of low communalities of variables to reduce the impact of sample size. The researchers in [29] recommend p:r ratio between 3:1 to 7:1; thus having more number of variables that are valid and reliable to represent fewer factors. The authors in [33] echo the same stating that the effect of sample size can be reduced with a strong and stable solution having fewer factors. The researchers in [29] suggest that the adequacy of sample size can be gauged post factor analysis based on the criteria of communalities and p:r ratio. The reference [12] resonates that the sample size can be determined based on the stability of solution. Therefore, sample adequacy can be defined after the factor analysis is conducted.

Apart from p:r ratio, factor loading is also an important criterion for defining overdetermination of factors. The reference [34] recommends ignoring factors with lesser factor loadings by suppressing values of factor loading less than 0.3 based on the suggestion by [35]. It also insists on having at least three variables with factor loading more than 0.4 in retained factors. The relationship between the sample size and significance of factor loading is explained by [36]. According to him, factor loadings more than 0.512 are significant for a sample size of 100, factor loadings more than 0.364 are significant for a sample size of 200, while factor loadings more than 0.298 are significant for a sample size more than 300.

3.6. Kaiser-Meyer-Olkin (KMO) and Bartlett's test

One way of examining sample adequacy is carrying out KMO test in SPSS. The value of KMO correlation ranges between 0 and 1. KMO test value above 0.6-0.7 is recommended to be adequate by various authors as cited in [37]; whereas the value above 0.5 is considered suitable for factor analysis by [30].

Bartlett’s test of sphericity examines the presence of correlations among variables. For a useful factor analysis, at least some variables should have significant correlations. For factor analysis to be suitable, significance level of Bartlett’s test of sphericity should be less than 0.05 [38].

3.7. How many and which factors to be retained?

Factor retention is an important step in factor analysis [39]. A lot of literature suggests that the retention of factors to be determined should be based on factor loading of each variable and the number of variables grouped under each factor. The article [37] suggests that grouping of minimum 3 variables in a factor are required to qualify it as a meaningful factor. The authors in [26] recommend including factors having 2 variables with caution and only if their factor loadings are more than 0.7. Higher factor loadings indicate variable’s significant statistical contribution in a factor. A variable having low factor loadings (less than 0.3) does not correlate with the factor and does not explain vital dimensions of the factor. Hence, such variables can be removed from the analysis. However, for removing any variables, theoretical understanding of variables is more important than its statistical values [12].

Some researchers in [16, 21] recommend a thumb rule of the factor loading of 0.50 or higher for the minimum loading of a variable without any cross loadings. When a variable has factor loading of 0.32 or higher on more than one factor, it is assumed to be cross loaded. The researchers in [12, 40] suggest to remove the variables with low factor loadings and variables with cross loadings with value more than 0.4. If factor structure has too many cross loaded variables, then it becomes difficult to interpret and factor solution is considered to have flaws [41]. The authors in [42] recommend conducting factor analysis again after removing these weak variables to get a stronger factor solution.

In this light, reference [42] further brings it to notice that retaining more factors is less harmful for interpretation than eliminating useful or meaningful factors. However, it warns that retaining too many factors may result into weak solution having factors with lesser factor loadings. Regarding the number of factors to be retained, reference [42] suggests not relying on a solution with only one or two factors, since it may not represent structure appropriately. Similarly, reference [41] considers the factors having less than 3 variables to be weak and unstable. Thus, both the overextraction and under extraction of factors are believed to be considerably detrimental since they lead to weak solution (with poor factor loadings) [39].

Eigenvalue is another element based on which the number of factors to be retained are determined. Generally, the factors having eigenvalue more than 1 are retained after extraction [30, 34] for its ease for interpretation. Another criterion for determining number of factors is scree plot which is used in conjunction with the eigenvalues. In the scree plot, the factors that are above the break or elbow of the curve are retained for interpretation [26].

3.8. Method of rotation

The goal of rotation in factor analysis is to get a well-defined pattern of factor loadings and to achieve simple structure of factors [43]. In other words, rotation is done to achieve clearer factors that can be better interpreted [12]. When factors are rotated, it helps to maximize the high loadings of each variable on fewer factors as much as possible. Thus, a solution achieved through rotation offers a simple structure of independent constructs where interrelated variables within a construct can be easily interpreted (as cited in [12]). Major body of literature indicates that oblique rotation is used for factors which are correlated, whereas orthogonal rotation is used for factors that are not correlated with each other [30, 34, 43].

Authors in [37] resolve researchers dilemma regarding how to choose a rotation method between oblique and orthogonal rotations. They suggest carrying out oblique rotation initially and checking for correlations among the factors. If correlations in the factor correlation matrix are equal to 0.32 or more, then oblique rotation is appropriate since factors are correlated. If correlations are below 0.32, then orthogonal rotation can be carried out [14, 37].

Among the methods of orthogonal rotations like varimax, quartimax and equimax, varimax is most widely used method in factor analysis [30, 34, 43]. The reason for preferring varimax over quartimax is that varimax maximizes the number of variables with higher factor loadings on each factor and makes weak factor loadings even smaller. In the quartimax rotation, a number of factors are reduced (as cited in [26]) and maximum variables get concentrated in the first factor.

3.9. Interpretation of factor solution

This is a critical step after the factor analysis is carried out. The variables grouped in a factor are examined to check whether they form a meaningful construct. Based on the meaning/inputs, these groupings of variables offer for the research, a factor is assigned a label or name. This process of naming a factor is subjective and demands theoretical underpinning and an inductive process [42]. The reference [12] reiterates the importance of conceptual and theoretical explanation of both the variables and factors extracted.

The challenges faced during this phase are expressed by [26] by noting that there is a possibility the labels or names given by researcher may not reflect the variables within the factor accurately. The cross-loadings of variables may pose difficulty in interpreting the factor appropriately. The authors in [12] emphasize that factor analysis is an iterative process and can be continued till a mathematically sound and theoretically substantiated solution is achieved. Thus, the factor solution should be meaningful and considerably pertinent for the research.

4. Research Gap

A private-led redevelopment of multi-family housing is an on-going phenomenon in Indian cities [44-46], also in other parts of the globe like

Korea [47], Japan [48], The Netherlands [49], and Australia [50]. The factors shaping the architecture of these multi-housing redevelopment projects are seldom discussed in the literature. Most of the researches have considered one or a few of the spatial and non-spatial variables and have examined their effect on residential architecture. Also, most of these studies are carried out in reference with the vernacular residential architecture and colonial period. Thus, discussion on factors shaping architecture of redevelopment projects remains a major research gap. Investigating the effect of climate, socio-cultural background of users, and historical context on residential architecture have been topics of inquiry for many researches. Qualitative methods like interviews and case study methods are widely used to study the residential architecture and have taken more descriptive approach lacking strong inferential results. Quantitative methods to study the factors shaping architecture of residential redevelopment are seldom used in the research. Identifying the variables that shape the architecture of redevelopment of multi-family housing and understanding their relationship quantitatively was identified as a research gap.

5. Methodology

In the initial stage of the research, the variables affecting residential architecture were deduced from the literature. Simultaneously, exploratory research was carried out to understand real world situation in the realm of redevelopment of formal housing with the focus on redevelopment of multifamily housing. The city of Pune, India, where a private led-redevelopment of multi-family housing is escalating in last couple of decades is considered as a case study for this research. As a part of exploratory research, in-depth interviews were conducted with architects, developers experienced in the field of redevelopment and also, with the committee members of co-operative housing societies which have undergone redevelopment from the city of Pune, India. These interviews were conducted using a ‘guide’ and a researcher as a key instrument [51]. The professionals’ survey was administered over architects who have worked on feasibility reports of residential redevelopment and or have designed redevelopment projects as well as it included developers who have executed redevelopment of multi-family housing. The data collected were analyzed using factor analysis of independent variables and conclusions are drawn by interpreting the results of factor analysis in the light of literature and qualitative data collected through interviews.

5.1. Sampling strategy

The architects from Pune city with valid Council of Architecture, India (COA)'s registration were the population under the study. The architects having experience between 10 to 30 years were selected from the list of architects from COA website based on their date of registration with COA. A total of 100 responses were received. The average experience of the respondent architects in terms of number of redevelopment projects was around 12. A list of developers who deal in residential redevelopment was prepared with the help of architects and committee members of redeveloped co-operative societies. Out of 25 developers contacted, 12 developers responded to the survey form. Thus, a total of 112 responses were received in professionals' survey.

6. Variables Emerged from the Exploratory Research

The in-depth interviews with architects, developers experienced in the field of redevelopment and committee members of six co-operative housing societies which have undergone redevelopment shed light upon the process of redevelopment, technical and financial feasibility of redevelopment project as well as some pertinent variables affecting the project feasibility and the architecture. The variables considered in this research are presented below.

Independent variables derived through literature

(1) Codes and regulation (DCR, redevelopment guidelines).

(2) Cultural background and lifestyle of the original residents.

(3) Site surrounding (natural features like lake, river, hill etc. or urban settings like slums, commercial area, high rise buildings etc.)

(4) Family size and structure of the original residents.

(5) Needs, aspirations and spatial preferences of original residents.

(6) Family income of original residents and attitude to pay for space additional to the space offered by developer.

(7) Climatic parameters.

(8) Location of the plot (locality).

(9) Shape of the plot.

(10) Area of the plot.

(11) Socio-cultural and socio-economic contexts of the neighbourhood.

Independent variables derived through exploratory research

(12) Title of land (Freehold/lease/land under Urban Land Ceiling Act (ULC)).

(13) Type of the redevelopment (self redevelopment/developer led redevelopment/govt. led redevelopment).

(14) Difference between sale rate and construction rate.

(15) Sizes of original condominiums.

7. Data Collection and Analysis

The spatial and non-spatial variables affecting architecture were enlisted from literature and a list of variables was finalized after the exploratory research after deletion of non-relevant variables and addition of variables which pertain to the issue of redevelopment (see Section 6). The perceived effect of 15 spatial and non-spatial variables on the architecture of residential redevelopment was to be analyzed. This effect was ranked on an ordinal 5-point Likert type scale (5-extremely affects to 1-does not affect). Therefore, a factor analysis was conducted to obtain fewer and more meaningful factors.

The adequacy of sample size was checked on all of the parameters described in the literature review of factor analysis which is presented below. Initially, KMO and Bartlett's test was carried out to check data adequacy. The KMO measure of sampling adequacy was 0.774 which being closer to 0.8 indicated that data was adequate for factor analysis [12, 52]. The significance level of Bartlett's test of sphericity was 0.00 (see Table 2) which indicated that there is a presence of correlations among variables [38].

Table 2. KMO and Barlett's test - factors affecting architecture

KMO and Bartlett's test		
Kaiser-Meyer-Olkin measure of sampling adequacy		**0.774**
Bartlett's test of sphericity	Approx. chi-square	490.804
	df	105
	Sig.	**0.00**

Table 3. Cronbach's Alpha- factors affecting architecture

Reliability statistics	
Cronbach's alpha	Number of items
0.812	15

The Cronbach's alpha was 0.812 which indicated that the data was internally consistent and reliable [53] (see Table 3).

In this research, the absolute number of samples was 112. There are 15 variables in this research. Therefore, the STV ratio comes to 7.47 which satisfies recommendations of data adequacy by some researchers, it gets disqualified on the criteria set by some other researchers as cited in [18]. Therefore, the factor analysis was carried out to check communalities, factor loadings and overdeterminations of factors as suggested by [18].

In this research, out of 15 variables, 11 variables have high communalities, 2 variables have communalities that hover around 0.5 which can be considered to be wide range; whereas 2 variables have low communalities. The average communality of all variables is 0.597 (see Table 4) which indicates that the data is relatively strong considering that this is a research in the social science domain [29]. Therefore, sample size considered in this research can be considered adequate based on communalities.

Table 4. Communalities - spatial and non-spatial variables

	Communalities			
		Initial	Extraction	Range of communality
1	Development control rules	1.000	.360	Low
2	Title of the land	1.000	.639	High
3	Type of redevelopment	1.000	.636	High
4	Difference in the construction rate and sale rate	1.000	.500	Wide
5	Needs and aspirations of original households	1.000	.324	Low
6	Family income and attitude to pay for extra space	1.000	.686	High
7	Family size and structure	1.000	.775	High
8	Location of the plot	1.000	.572	High
9	Location of the plot	1.000	.686	High
10	Area of the plot	1.000	.676	High
11	Sizes of original condominiums	1.000	.605	High
12	Cultural background and lifestyle of original residents	1.000	.664	High
13	Site and surrounding	1.000	.718	High
14	Climatic parameters	1.000	.484	Wide
15	Socio-cultural background of the neighbourhood	1.000	.579	High
	Extraction method: Principal component analysis			

Other than communalities and KMO test of sample adequacy, the overdetermination of factors is examined based on factor loadings and variables to factor ratio after carrying out factor analysis. While conducting factor analysis, variables with factor loadings less than 0.5 were suppressed to eliminate weak variables with lower factor loadings and factors having eigenvalues more than 1 were retained (see Figure 1).

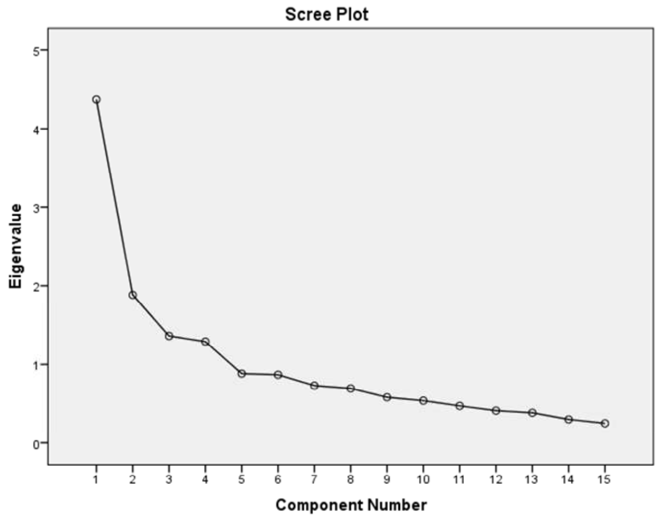


Figure 1. Scree plot.

For taking a decision on what type of rotation is suitable for factor analysis, oblimin rotation was carried out to check whether the factors are correlated or not (see Table 5).

Table 5. Oblimin rotation

Component correlation matrix				
Component	1	2	3	4
1	1.000	-.150	.251	-.215
2	-.150	1.000	-.098	.281
3	.251	-.098	1.000	-.103
4	-.215	.281	-.103	1.000
Extraction method: principal component analysis. Rotation method: Oblimin with Kaiser normalization.				

In the factor solution of oblimin rotation, the maximum value of correlation was 0.281 which is lower than the threshold value of 0.32 as suggested by [37] to determine whether the correlation exists between factors. The values suggested that there is no correlation between the factors. Therefore, orthogonal rotation, specifically varimax rotation, was carried out to achieve simple and interpretable structure of factors.

In the solution that emerged after carrying out factor analysis (see Table 6), 4 distinct factors emerged with more than 3 variables loaded on each factor. The variables to factors ratio (p:r ratio) is 15:4, in other words, 3.75:1 which is within the range of 3:1 to 7:1 as recommended by [18] and also follows thumb rule of [34] of having minimum 3 variables loaded on each factor with minimum factor loading of 0.4.

Table 6. Factor analysis and labeling of factors - factors affecting architecture

	Variables	**1**	**2**	**3**	**4**	**Labeling of the factors**	**% variance**	**Cumulative variance**
1	Area of the plot	0.779				**Site characteristics- spatial factor**	29.131	29.131
	Shape of the plot	0.762						
	Location of the plot	0.72						
	Development Control Rules	0.512						
2	Site and surrounding		0.817			**Neighbourhood characteristics- spatial factor**	12.546	41.677
	Socio-cultural background of the neighbourhood		0.732					
	Climatic parameters		0.671					
3	Family size and structure			0.821		**Households' characteristics - non-spatial factor**	9.08	50.756
	Family income and attitude to pay for extra space			0.806				
	Cultural background and lifestyle of residents		0.504	**0.612**				
	Sizes of original condominiums	0.543		**0.557**				
4	Title of the land				0.786	**Financial feasibility of redevelopment project - non-spatial factor**	8.605	59.361
	Difference in the construction rate and sale rate				0.653			
	Redevelopment type				0.632			

The factor loadings of variables ranged from 0.5 to 0.8 with average of factor loadings on each factor close to 0.7. This is in tandem with the thumb rule of sample size adequacy by [36] who suggests 100 as an adequate sample size for factor loadings more than 0.512. The factor loadings and p:r ratio established that the factors are highly overdetermined. The factor solution also suggested that sample size is adequate based on high communalities and overdetermination of factors. The variables named 'Size of the condominiums' and 'Cultural background and lifestyle of residents' are cross loaded on the two factors meaning that those are complex variables and are related to more than one factor [54]. However, they have greater loading on factor 3. Therefore, they are considered as a part of factor 3 as suggested by [54] as one of the methods to treat complex variables.

The proportion of cumulative variance of these 4 factors is more than 59%. As elicited by [30], there is no consensus found in literature about desired cumulative percentage of variance especially across different disciplines of studies. The datum for natural sciences is minimum 95% of the variance for threshold of factors to be included, whereas this threshold is attenuated to 50-60% of cumulative variance for the researches in humanities [42].

7.1. Labeling of factors, interpretation and discussion

The first and most significant factor '*Site characteristics and DCR*' with 29% of variance included following variables:

(1) Area of the plot.

(2) Shape of the plot.

(3) Location of the plot.

(4) Development control rules.

The first three variables were related to the plot characteristics and the fourth variable to the development control rules. In the exploratory research phase, it was revealed that the size, shape and location of the plot and prevalent development control rules together define the built potential of the plot which further defines the project cost and financial feasibility of the redevelopment project. The architectural aspects such as building form and height of the building are defined by these variables together. The first factor was labelled as 'Site characteristics and DCR' which was necessarily a spatial factor.

The second factor '*Neighbourhood characteristics*' included following variables such as:

(1) Site and surrounding.

(2) Socio-cultural background of the neighbourhood.

(3) Climatic parameters.

The variables included in the second factor were related to the site and its surrounding. The surrounding of the site such as neighbouring properties, natural features adjacent to the site, view from the site etc. define the location of both the units of original residents and saleable units since both the developers and original residents like to seek most beneficial location for their units. Socio-cultural background of the neighbourhood defines the size and kind of saleable units. These variables related to neighbourhood features affect architecture of redevelopment project. Therefore, this factor was labelled as 'Neighbourhood characteristics', which was a spatial factor.

Following group of variables constituted the third factor '*Households*' *characteristics*':

(1) Family size and structure.

(2) Family income and attitude to pay for the extra space.

(3) Cultural background and lifestyle of original residents.

(4) Size of the original condominium.

The studies related to housing behaviour of households and their housing decisions indicate that there is co-relation between the household characteristics like family size and structure, family income with their spatial requirements [55]. The spatial layout of house is most subjected to change due to dynamic requirements of users arising out of change in sociocultural profile [56], lifestyle [7-9], and also, family size and structure [4, 6-9]. Thus, the variables grouped in the third factor were related to attributes of original households and are justified by the literature. The factor was labeled as '*Households*' *characteristics*'.

The last factor '*Financial feasibility of the project*' consisted of following variables:

(1) Title of the land.

(2) Difference in the construction rate and sale rate.

(3) Type of redevelopment.

The variables included in the fourth factor had emerged through the in-depth interviews with professionals during exploratory stage research. The professionals had reported that each of these variables has bearing on the financial feasibility of the project. The legal title of the land has implications related to statutory fees and affects the project cost. The difference in the construction rate and sale rate determines the project cost and income on the returns. The type of redevelopment in terms of whether the development is developer-led or self-redevelopment determines the built potential of the plot since some incentives in terms of FSI are offered for self-redevelopment projects. These 3 variables together have a bearing on the financial feasibility of the redevelopment project and hence, the last factor was labelled as '*Financial feasibility of the project*'. The third and fourth factors were non-spatial factors which affect architecture of residential redevelopment.

The variable '*Needs and aspirations of original residents*' had lowest communality, and it was eliminated when factor loadings below 0.5 were suppressed in factor analysis. Thus, it indicated that needs and aspirations of original residents do not play any significant role in shaping the architecture of residential redevelopment according to professionals. However, during the in-depth interviews of professionals and members of redevelopment committee of multi-family housing, it was revealed that needs and aspirations of original residents determine the spatial requirements at unit level and building level to a certain extent. Therefore, although this variable was eliminated and found insignificant statistically; researcher investigated it through case-study method in the next phase of research. As cited in [42], retaining more factors is less harmful for interpretation than eliminating useful or meaningful factors. Researchers have to take a judicious decision while eliminating and retaining the factors. If researcher/s find/s it essential to retain a particular factor based on the literature and findings of data collected through other methods, a further investigation is recommended.

8. Conclusions

This research paper presented a step by step application of factor analysis procedures in architectural research. Based on the literature reviewed for requirements, applicability and reliability of factor analysis, factor analysis procedures for this research were followed and data were analyzed. The data fulfilled the sample adequacy requirements of the factor analysis procedures. The factors those were emerged had clusters of variables which were logical and meaningful informed by the literature and experts' opinion expressed in the qualitative phase. This strengthened the reliability of findings. This research emphasizes the significance of judicious decision of researcher/s to reach logical conclusions by triangulating the findings of factor analysis, theoretical underpinnings and data collected by other methods. A detailed account of the procedures followed and decisions taken during the factor analysis and the interpretation of factors ensure the replicability of the study.

Acknowledgement

We would like to thank all the developers and architects for participating in the in-depth interviews at the exploratory stage of the research and survey at a later stage. Also, we thank the managing committee members of co-operative housing societies for their valuable time for interviews and sharing their views. Finally, thanks are due to the anonymous referees for their valuable suggestions and comments which led to the improvement of the paper.

References

[1] R. Ozaki, Housing as a reflection of culture: privatised living and privacy in England and Japan, Housing Studies 17(2) (2002), 209-227.

[2] S. Alitajer and G. Nojoumi, Privacy at home: analysis of behavioral patterns in the spatial configuration of traditional and modern houses in the city of Hamedan based on the notion of space syntax, Frontiers of Architectural Research 5 (2016), 341-352. https://doi.org/10.1016/j.foar.2016.02.003.

[3] S. Foster, Analysis of spatial patterns in buildings (access analysis) as an insight into social structure: examples from the Scottish Atlantic Iron Age, Antiquity 63(238) (1989), 40-50.

[4] C. O. Osasona, From traditional residential architecture to the vernacular: the Nigerian experience, African Architecture Today' Conference, Department of Architecture, KNUST, Ghana, 2007.

[5] N. Dalkilic, The architectural analysis of traditional houses of Midyatmardin, Turkey, International Journal of Academic Research 4(2) (2012), 10-31.

[6] S. Dhongde, Exploring the relationship between socio cultural factors and architecture a case of domestic architecture in nineteenth century Pune, Ph. D. Thesis, Savitribai Phule Pune University, Pune, India, 2018. http://hdl.handle.net/10603/340335.

[7] K. Xie and H. Shen, How social factors affect the design of new urban residences, International Symposium on Knowledge Acquisition and Modeling, 2015.

[8] E. B. Aduwo and E. O. Ibem, Housing transformation in government constructed residential estates in Lagos Nigeria, International Journal of Humanities and Social Science Invention 6(8) (2017), 13-22. www.ijhssi.org.

[9] G. Gopinath and S. Y. Kulkarni, The impact of socio-cultural factors on the transformation of the residential architecture of Kerala, International Journal of Research (IJR) 1(5) (2014), 526-530.

[10] A. Zrobek-Rozanska, E. Zysk and S. Zrobek, Overview of socio-economic transformations based on residential architecture in a suburban area - Case Study of Villages in the Polish Region of Warmia, IOP Conf. Series: Materials Science and Engineering 245, 2017, pp. 042006. doi:10.1088/1757-899X/245/4/042006.

[11] L. Etxepare, Residential architecture and developmentalism: a place and two contexts, structural repairs and maintenance of heritage architecture, XII 247, WIT Transactions, 2011. www.witpress.com.

[12] A. S. Beavers, J. W. Lounsbury, J. K. Richards, Schuyler W. Huck, G. J. Skolits and S. L. Esquivel, Practical considerations for using exploratory factor analysis in educational research, Practical Assessment, Research, and Evaluation 18(6) (2013), 1-13. https://doi.org/10.7275/qv2q-rk76.
Available at: https://scholarworks.umass.edu/pare/vol18/iss1/6.

[13] J. T. Kellow, Exploratory factor analysis in two measurement journals: hegemony by default, Journal of Modern Applied Statistical Methods 4(1) (2005), 283-287. doi:10.22237/jmasm/1114907100.
Available at: http://digitalcommons.wayne.edu/jmasm/vol4/iss1/25.

[14] L. R. Fabrigar, D. T. Wegener, R. C. MacCallum and E. J. Strahan, Evaluating the use of exploratory factor analysis in psychological research, Psychological Methods 4(3) (1999), 272-299. https://doi.org/10.1037/1082-989X.4.3.272.

[15] R. K. Henson and J. K. Roberts, Use of exploratory factor analysis in published research: common errors and some comment on improved practice, Educational and Psychological Measurement 66(3) (2006), 393-416.

[16] L. J. Burton and S. M. Mazerolle, Survey instrument validity part i: principles of survey instrument development and validation in athletic training education research, Athletic Training Education Journal 6(1) (2011), 27-35.

[17] R. Pearson and D. Mundform, Recommended sample size for conducting exploratory factor analysis on dichotomous data, Journal of Modern Applied Statistical Methods 9(2) (2010), 359-368. doi:10.22237/jmasm/1288584240.

[18] R. C. MacCallum, K. F. Widaman, S. Zhang and S. Hong, Sample size in factor analysis, Psychological Methods 4 (1999), 84-89.

[19] Z. Nathan, The Minimum Sample Size in Factor Analysis, L. Eldon, ed., 2009. Retrieved from http://eli.johogo.com/: http://eli.johogo.com/Class/FA-Size.htm.

[20] D. N. Lawley and A. E. Maxwell, Factor Analysis as a Statistical Method, 2nd ed., Butterworths, London, 1971.

[21] A. L. Comery and H. B. Lee, A First Course in Factor Analysis, Hillsdale, NJ: Erlbaum, 1992.

[22] J. C. F. de Winter, D. Dodou and D. A. Wieringa, Exploratory factor analysis with small sample sizes, Multivariate Behavioral Research 44 (2009), 147-181. 10.1080/00273170902794206.

[23] R. P. McDonald, Factor Analysis and Related Methods, 1st ed., Psychology Press, 1985. https://doi.org/10.4324/9781315802510.

[24] P. T. Barrett and P. Kline, The observation to variable ratio in factor analysis, Personality Study in Group Behavior 1 (1981), 23-33.

[25] W. A. Arrindell and V. D. J. Ende, An empirical test of the utility of the observations-to-variables ratio in factor and components analysis, Applied Psychological Measurement 9 (1985), 165-178.

[26] A. Yong and S. Pearce, A beginner's guide to factor analysis: focusing on exploratory factor analysis, Tutorials in Quantitative Methods for Psychology 9(2) (2013), 79-94.

[27] R. Pennell, The influence of communality and won the sampling distributions of factor loadings, Psychometrika 33 (1968), 423-439.

[28] W. F. Velicer and J. L. Fava, Effects of variable and subject sampling on factor pattern recovery, Psychological Methods 3 (1998), 231-251.

[29] R. MacCallum, K. Widaman, K. Preacher and S. Hong, Sample size in factor analysis: the role of model error, Multivariate Behavioral Research 36(6) (2001), 611-637. doi:10.1207/S15327906MBR3604_06.

[30] H. Taherdoost, S. Sahibuddin and N. Jalalyoon, Exploratory factor analysis; concepts and theory, Advances in Applied and Pure Mathematics 27 (2014), 375-382. from https://hal.archives-ouvertes.fr/hal-02557344/document.

[31] P. Schonemann, Power as a function of communality in factor analysis, Bulletin of the Psychonomic Society 17(1) (1981), 57-60.

[32] D. Child, The Essentials of Factor Analysis, 3rd ed., New York, Continuum International Publishing Group, 2006.

[33] K. Y. Hogarty, C. V. Hines, J. D. Kromrey, J. M. Ferron and K. R. Mumford, The quality factor solutions in exploratory factor analysis: the influence of sample size, communality, and overdetermination, Educational and Psychological Measurement 65 (2005), 202-226.

[34] P. Samuels, Advice on exploratory factor analysis, 2016.
doi: 10.13140/RG.2.1.5013.9766.

[35] A. Field, Discovering Statistics using SPSS, 4th ed., SAGE, London, 2013.

[36] J. P. Stevens, Applied Multivariate Statistics for the Social Sciences, 5th ed., Routledge, London, 2012.

[37] B. G. Tabachnick and L. S. Fidell, Using Multivariate Statistics, 5th ed., Pearson Education Inc., Boston, MA, 2007.

[38] M. S. Bartlett, Tests of significance in factor analysis, British Journal of Psychology 3(2) (1950), 77-85.

[39] J. C. Hayton, D. G. Allen and V. Scarpello, Factor retention decisions in exploratory factor analysis: a tutorial on parallel analysis, Organizational Research Methods 7 (2004), 191-205.

[40] J. Schonrock-Adema, M. Heijne-Penninga, E. A. van Hell and J. Cohen-Schotanus, Necessary steps in factor analysis: enhancing validation studies of educational instruments, The PHEEM applied to clerks as an example, Medical Teacher 31(6) (2009), E226-E232. https://doi.org/10.1080/01421590802516756.

[41] A. B. Costello and J. W. Osborne, Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis, Practical Assessment Research and Evaluation 10(7) (2005), 1-9.

[42] M. A. Pett, N. R. Lackey and J. J. Sullivan, Making Sense of Factor Analysis: The Use of Factor Analysis for Instrument Development in Health care Research, Sage Publications Inc., California, 2003.

[43] J. D. Brown, Choosing the right type of rotation in PCA and EFA, Shiken: JALT Testing & Evaluation SIG Newsletter 13(3) (2009), 20-25.

[44] J. Paul, After Covid lull, Ahmedabad societies put redevelopment on fast track, Nov. 2021. Available at https://timesofindia.indiatimes.com/city/ahmedabad/aftercovid-lull-abad-societies-put-redevelopment-on-fasttrack/articleshow/87654576.cms#:~:text =In%20September%202018%2C%20the%20state,a%20boost%20to%20 redevelopment%20projects. Accessed on 15/04/2022 at 13.04, 2021.

[45] A. Sringeri, Redevelopment Projects in Bangalore, 2022, Available at https://www.proprepublic.com/redevelopment-projects-in-bangalore/.

[46] The State Government of Maharashtra, Revised Redevelopment Direction dated 4th July 2019 issued U/S 79A of MCS Act, 1960, Marketing and Textiles Department, The Government of Maharashtra, 2019.

[47] Y. Kim, Urban Housing Redevelopment: An analysis of the perception of vitality in apartment neighbourhood redevelopment in Korea, Ph. D. Thesis, The University of Michigan, United States of America, 2011.

[48] Plaza Homes, Reconstruction of Japanese old apartment building - reason of rebuilding, planning and resolution, 2022. Available at https://www.realestatetokyo.com/news/reconstruction-of-japanese-old-apartment-building-planningprocess/.

[49] E. Heurkens, Sustainable urban redevelopment in the Netherlands, Routledge Handbook of Sustainable Real Estate, eds., W. Sara, D. Tim, M. Norm and S. Sarah, Routledge - Taylor & Francis Group, Abingdon, UK, 2018.

[50] S. Pinnegar, B. Randolph and R. Freestone, Incremental urbanism: characteristics and implications of residential renewal through owner-driven demolition and rebuilding, The Town Planning Review 86(3) (2015), 279-301. doi: 10.3828/tpr.2015.18.

[51] J. W. Cresswell, Research Design-qualitative, Quantitative and Mixed Methods Approaches, Sage Publications, 2009.

[52] A. T. Abdulrahman and A. O. Abdulmohsen, Factor analysis to determine the actual causes that led to the spread of financial fraud, Advances and Applications in Statistics 79 (2022), 11-23. http://dx.doi.org/10.17654/0972361722057.

[53] L. J. Cronbach, Coefficient alpha and the interval structure of tests, Psychometrika 16 (1951), 297-334.

[54] A. T. Abdulrahman and N. S. Alshammari, Factor analysis and regression analysis to find out the influencing factors that led to the countries' debt crisis, Advances and Applications in Statistics 78 (2022), 1-16. http://dx.doi.org/10.17654/0972361722047.

[55] P. H. Rossi, Why Families Move: A Study in the Social Psychology of Urban Residential Mobility, Glencoe, IL: Free Press, 1955.

[56] P. Crowther, Designing for disassembly to extend service life and increase sustainability: architectural disassembly, 8th International Conference Durability of Building Materials and Components, NRC-CNRC, Vancouver, Canada, 1999.

ISSN INTERNATIONAL STANDARD SERIAL NUMBER INTERNATIONAL CENTRE

ISSN PORTAL The Global Index for Continuing Resources

FREE ACCESS

PUBLISHERS' AREA | DISCOVER ISSN SERVICES | SEARCH OPEN ACCESS RESOURCES | KEEPERS REGISTRY | ISSN INTERNATIONAL CENTER

Home > Record

Type an ISSN or a title | ISSN or title | Search

Advanced search ROAD search The Keepers search

Identifiers

ISSN :2583-1224

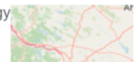
Linking ISSN (ISSN-L): 2583-1224

Key-title International Journal of Technology Engineering Arts Mathematics Science

Resource information

Title proper: International Journal of Technology Engineering Arts Mathematics Science.

Abbreviated key-title: Int. J. Technol. Eng. Arts



My Tools

Share

Print

Display linked data

Discover all the features

International Journal of Technology Engineering Arts Mathematics Science
Special Issue 1, August 2023, pp. 267-272
ISSN: 2583-1224,

. .

Understanding the Impact and Necessity of Building Information Modelling (BIM) Tools for Efficient Design and Construction

Monica Sathe[1], Vaishali Anagal[2]

[1] Fourth Year B. Arch student, Dr. B. N. College of Architecture, Pune, India
Email- sathemonica08@gmail.com
[2] Associate Professor, Dr. B. N. College of Architecture, Pune, India
Email- vaishali.anagal@bnca.ac.in

Corresponding Author: sathemonica08@gmail.com

Article Information

Article history:

Received Jun 10, 2023
Accepted Dec 10, 2023

ABSTRACT

The development of technology in recent years has been growing exponentially. Not only has it majorly revolutionized many fields like science, mathematics, and entertainment, but it has also made a huge influence on architectural trends and construction techniques. This research focuses on the necessity of digital aid, specifically Building Information Modelling (BIM) tools and how they have made an impact on the process of designing and planning structures in India. A comparative analysis is done between the syllabi of Architectural colleges across the whole nation of India, and some differences are identified regarding the teaching of BIM tools and applications during the course. The BIM syllabi is analysed further in the context of its necessity and use in professional architects' practice. BIM tools do not only help design and construction teams to work in a better and more efficient way, but the tools also allow them to utilize the data that they produce during the process, to benefit operations and various other tasks. Therefore, BIM mandates are rapidly increasing across the globe, as the years go by. The emergence of these tools has definitely made a positive influence on people's proficiency at design, planning and construction phases, but it also has a few downsides to it that are discussed further in this paper.

KEYWORDS: BIM tools, architecture, development, technology, technological convenience

1. INTRODUCTION

BIM, known as Building Information Modelling, has been an upcoming form of technology in the field of architecture, engineering, and the construction industry, over the past couple of years. It has become the very foundation of digital transformation in these areas, without which, planning seems like a very difficult and tedious task. Due to this convenience, it has started to become a necessity for people, specifically those in the previously mentioned areas of occupation, to be familiar with. Many professionals believe that BIM is the future of design and construction, which is why its training and practice are a necessity, too.

Some of the most popularly used BIM tools are as follows (in no specific order)-

1. Revit
2. AutoCAD
3. ArchiCAD
4. Navisworks
5. Aurora
6. pvDesign
7. MicroSation
8. Civil3D
9. VectorWorks Architect
10. Tekla Structures

These software tools provide an easier and more helpful approach to visualize, develop shapes and forms, and experiment with 3-D structures and objects. It aids in efficiently and precisely analyzing and checking the working of an object, with in-built simulation features with perfect accuracy, that one can keep editing and altering in minimal time, before sending it out for manufacturing, construction, or execution.

Some of the many significant benefits and advantages of using BIM tools while designing in architecture are- BIM incorporates multi-disciplinary data to create detailed and accurate digital representations and illustrations that are managed in an open cloud platform for real-time collaboration. Using BIM gives you greater visibility, more sustainable options, better decision-making, and cost savings on certain types of projects; for example, AEC (Architectural Engineering and Construction) projects.

According to the statistics provided by United Nations in 2019, it is estimated that the world population would be around 9.7 billion in the year 2050. That is only a little more than 25 years and a population of 2 billion more than the current population (as of 2022). This calls for better, organized town and city planning that is also energy and climate efficient, not just as a means to keep up with the current trends and global demand, but to also help create spaces that are resilient and smarter, as well.

This research aims at finding the gap between training offered in BIM tools and softwares and the actual implementation and execution of it in the profession of Architecture. To carry out this research, a comparative survey is done across universities in India to identify which universities offer training in BIM technology and how the training makes a difference during their practice as an architect, after graduation.

2. LITERATURE REVIEW

According to many BIM software users, the development of BIM is revolutionizing the way projects are executed across industries, adding intelligence, efficiency and little to no room for error– for making the best outcomes possible.

BIM tools help to fruitfully use the processes of analysis and evaluation programs during the progress of design. However, the current approach towards analysis and evaluation of design requires the making of a separate building model for each kind of assessment. This mainly involves using a BIM tool to create the data for a certain type of analysis to obtain design feedback. When dealing with multiple analyses, this process becomes time consuming, and largely reduces the benefits of BIM, which defies its whole purpose [Sanguinetti et al., 2012].

Several schools and institutes are using BIM for teaching architecture and civil/ structural engineering. Most of them have only introduced BIM in one subject and a few are trying interdisciplinary or collaboration between subjects [Barison, 2012]. The main approach is to introduce BIM in design studios itself. Another approach is to teach tools and BIM concepts in a particular subject, which may be further integrated with the syllabus and in the design studios. [Barison and Santos, 2010].

As BIM has become a standard in the AEC industry, it is extremely essential that these programs train the future construction professionals in the potential and benefits of BIM technology as lack of adequate training has been one of the biggest challenges of the industry to progress into the BIM era. [Yilei Huang, 2018] Although several studies have suggested that integrating BIM into existing subjects is the most feasible approach, comprehensive frameworks have not been created that are able to provide a holistic coverage of BIM in the curriculum. [Yilei Huang, 2018].

BIM, for now, seems very likely to be the trend of the future [Gokuc and Arditi, 2017]. Three models are proposed that investigate whether the fit between BIM technology and (1) design tasks, (2) the organizational competence of the design firm, and (3) designer competence affect the performance of the design firm [Gokuc and Arditi; 2017].

Despite the drawback of technology adoption facing a lot of resistance, the improvements made and benefits obtained from adopting the new technology are typically worth the efforts. According to Kaner et al. (2008), the implementation of formal BIM training for personnel on a project resulted in a productivity increase of over 600%. The study conclusively affirms that BIM undeniably enhances the quality of precast engineering designs and fabrications, while also ensuring error-free construction processes. Additionally, BIM significantly reduces the time and effort required for evaluating drawings and plans. [Sahil, 2016]. BIM implementation for renovation is relatively less developed. The recommended methods include as-built modeling and laser scanning, but these are often not detailed. Requirements for BIM in renovation projects vary. [Sacks, Gurevich, Shrestha; 2016]. Project participants' competence in BIM is vital for harnessing its benefits. Construction clients must prioritize ensuring a minimum level of ability among participants. [Barison and Santos, 2011].

According to an article by Zigurat Global Institute of Technology (2022), it is said that BIM still has a long way to go in terms of usage and application in India, but it is getting there; and in the next 10 – 20 years, when the population of India is estimated to surpass

that of China, BIM technology will be forced to expand across the country due to the inevitable need for more infrastructure, educational spaces, and social housing; which will automatically demand for qualified professionals and students for its training.
The literature emphasizes that the training of future professionals is essential for greater efficiency during design and construction processes. It also reveals that there is a gap between the training of BIM tools in the curriculum and its demand and requirement in the profession. Therefore, this study is significant to identify the gap between training and application in the Indian scenario.

3. METHDOLOGY

The initial stage of this research consisted of collecting necessary data regarding the syllabi of universities across India and comparing them with each other to obtain a pattern of training BIM tools in the degree and implementation of it during professional practice. This is further correlated with the extent to which these BIM tools are actually used by professionals in their designs and planning processes and to finally investigate the necessity of BIM training and whether it really makes a difference in the efficiency of the output as opposed to not using these tools.

A survey was conducted in the form of two questionnaires via Google Forms, one for architectural professors and tutors, the other for practicing architects, in which they were asked if any BIM-related training was provided to them when they were pursuing their B. Arch degree, if they are aware of BIM softwares, if they frequently make good use of it in their designs, if they offer BIM lessons to students and many more questions that could give a clear and realistic idea of the current trends and situation in the technology and to also be able to understand the professionals' unfiltered and unbiased opinions about it. The focus area of this research was the state of Maharashtra, India, which is where the questionnaires were administered, and the answers were obtained only from those architects who had studied in any university in the state, regardless of the state or country in which they are currently practicing.

After the necessary data was collected, it was analyzed and processed after which certain patterns and gaps were identified, that further pointed to a reasonable conclusion. For the analysis, every single response was reviewed thoroughly, and a comparative study was done to find out which institutes and universities have the most engagement with the BIM technology and to what extent they are used while making designs and executing them on-site. This survey gave a head-start and defined the next steps to take the research ahead to understand the real-life scenario of the usage and familiarity of the technology in different parts of the state.

4. DATA COLLECTION

A sufficient amount of data and information was collected that was necessary for the research to progress, like previously done research papers relevant to the topic, literature reviews, book reviews, article findings, graphical diagrams and online searches pertaining to certain aspects of the BIM technology and explaining them in concise and simple ways.
In the first stage of the research, A comparative study was done in which the architectural syllabi for years 1 to 5 of the B. Arch degree were obtained from across India and a list of similarities and differences was made to observe gaps and links between the curriculum of different universities for the course (See Table No. 1).

Stage 2 of the data collection process consisted of going deeper into understanding the technology of BIM and researching its benefits, use and application points, its scope for the future, its development and upcoming and its downsides, with the questionnaire survey.

Table 1. Differences in Curricula

Sr. No.	Region of India	University	Observations
1.	West	Mumbai University	● No computer-aided individual subject as a part of curriculum. ● Computer-based learning offered as an elective. ● Representation and Arch. Theory offered as individual mandatory subjects. ● No mandatory internship in 5th (final) year.
2.	West	Rajasthan University	● Computer-aided subject introduced in the 1st year. ● Many extra-curricular activities offered as electives. ● Internship not mandatory as a part of the course.
3.	South	Hyderabad	● Computer software training

		University	introduced in semester 4 (Year 2). ● Internship mandatory as a part of the course.
4.	West	Pune University	● Computer based software training introduced in the first half of 2nd year. ● Advanced software training offered as electives in 3rd and 4th years. ● Internship mandatory in the final year (9th semester).
5.	North	Jamia Millia, New Delhi	● Computer-based software training offered from 1st year onwards. ● Computer-aided interior design taught as an individual mandatory subject in almost all semesters. ● Internship included as a part of the course.
6.	East	Jadavpur University, Calcutta	● Computer-based training offered from the third semester (2nd year). ● Computer aid used in design studios. ● Practical Training/ Internship of 24 weeks mandatory as a part of syllabus in 7th semester (4th year).

5. DATA ANALYSIS

Through the vigorous interviews, questionnaires, and information collection, it was found that to many people (including novice trainees, young architects, and experienced professionals), BIM still, for the most part, remains to be an unfamiliar technology that many surprisingly have not even heard about or do not know the meaning and purpose of. When it comes to 2D drawing-creating softwares, like AutoCAD, or ArchiCAD, the majority of the architects are fully familiar and well-acquainted with its interfaces, and use them on a daily basis for creating plans, sections, elevations and other 2D illustrations and diagrams. The problem mostly lies when it comes to dealing with 3D models and using simulations to analyze the physical behaviour and sustainability of a certain mechanism or structure.

Through the comparative study of the architectural syllabi, it was observed that most of the universities in India have a similar curriculum and only a few universities and institutes have prominent and noticeable differences in them. (See Table No. 1). Most of the colleges and universities offer computer-aided training from the first or the second year, except Mumbai University, which doesn't have a separate mandatory subject for it and is offered as an elective. Some of the universities include a semester-long internship mandatorily as a part of their curriculum, whereas some don't.

From Table No. 1, it is observed that all of these universities offer computer-based software training some time within the 5-year course. Rajasthan University and Jamia Millia have made it mandatory to teach digital tools since the 1st year of their B. Arch course. Other universities introduce the subjects at a later stage- in the second or third year. Mumbai University does not provide mandatory lessons in digital softwares as a part of their curriculum, although they can be taught as integrated lessons with the other subjects.

Since this technology emerged quite suddenly with the revolution of other digital devices, its development wasn't observed to be an organised one and quite literally, took its own path. Despite this, it still has not fully developed and is still yet to reach and be introduced in economically weaker parts of India.

6. RESULTS AND DISCUSSIONS

After conducting the surveys and sending out the questionnaires to architects and tutors, the responses that were obtained were thoroughly observed and analysed. Around 30 responses were received for the questionnaire that was meant to be filled by professionals and practicing architects, and 15 responses from architectural professors and tutors.

In the former questionnaire, the respondents were first asked if they were aware of BIM tools, to which 83% of people answered "Yes" (See Diagram No. 1).

The universities the respondents studied their B. Arch degrees from were Pune University, Mumbai University, and Goa University. 75% of the respondents had received training of BIM softwares from the institute they studied their B. Arch degree. Majority of the people believe that BIM tools are necessary to be used during design and construction processes and believe that BIM is the future. Almost half of them had not pursued a master's degree, which means most of their training in BIM was either done during their B.Arch degree or they learned it by themselves after graduation. Contradictorily, almost half of the respondents said they do not use BIM tools in their design processes which was a surprising observation. Those who do use the tools said they mostly use it in their design process (40%), implementation (30%), execution/construction (10%), estimation (10%), and 60% said they use it for all of these processes.

For the questions about hiring employees and interns, 80% of the respondents said that they look for interns and employees that are skilled and well-equipped with the knowledge of BIM softwares, like Revit and ArchiCAD. In case an employee is not very skilled in these softwares, 60% of architectural firms provide at least basic and beginner-level lessons to them.

In the second survey for professors and tutors, all of them had pursued a master's degree from either Mumbai University or SPPU (Savitribai Phule Pune University). 80% of them teach in institutes that currently offer training in BIM, either as a part of the curriculum or as an elective. The respondents said that BIM is the need of the hour, and its training is necessary for securing a good internship and later finding better job opportunities, since that is one of the biggest requirements of architectural offices for appointing their employees. (See Diagram No. 1- for above information)

The pie charts in blue are those obtained from Form No. 1 (for practicing architects) and those in orange are obtained from Form No. 2 (for professors and tutors).

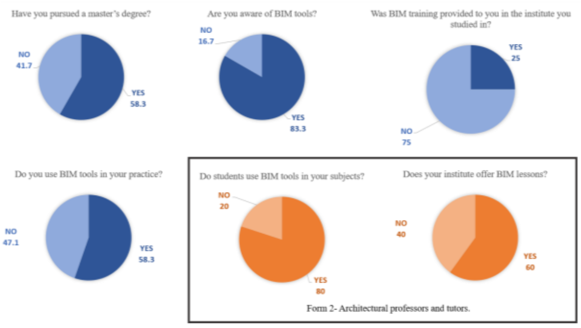


Fig. 1. Pie representations of responses obtained from surveys. (Source- Author)

7. CONCLUSIONS

From the research, the main observation made was that a good amount of institutes in Maharashtra currently offer training in BIM softwares to their students, which is a positive change, because this reveals that it only means that there is going be progress in the technology and perhaps in the next 20 years, we would be able to see BIM tools being used everywhere necessary- in architecture, construction and engineering.

Internships should be made mandatory in the curriculum to enable students to implement the skills they learned during the course and get an experience of the professional work environment.

Despite the fact that most present-day practicing architects did not receive training in BIM when they were studying in architectural institutes, they taught themselves as required to keep up with the current trends and technological innovations. This shows that BIM softwares are not extremely difficult to learn and they can be self-taught, with the right resources. But it is time-consuming. Therefore, it is best if one learns it during the time they pursue their degree and integrate it with the other subjects they study.
If these tools are taught from a very early stage of a person's professional journey (from the first year of their undergraduate program), it will be very beneficial for the students to learn and implement these tools early-on and help expand their ability to learn and grasp concepts quickly and easily.

8. REFERENCES

[1] Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. J. S. S. (2011). BIM adoption and implementation for architectural practices. Structural survey.

[2] Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252.

[3] Barison, M. B., & Santos, E. T. (2010, June). BIM teaching strategies: an overview of the current approaches. In Proc., ICCCBE 2010 international conference on computing in civil and building engineering.

[4] Barison, M. B., & Santos, E. T. (2010, November). Review and analysis of current strategies for planning a BIM curriculum. In Proceedings of the CIB W78 2010: 27th International Conference (pp. 16-18). Blacksburg Virginia: Cairo. Virginia Tech.

[5] Barison, M. B., & Santos, E. T. (2011). The competencies of BIM specialists: a comparative analysis of the literature review and job ad descriptions. Computing in Civil Engineering (2011), 594-602.

[6] Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

[7] Guise, D. (1985). Design and Technology in Architecture. https://www.osti.gov/biblio/5803827
[8] Huang, Y. (2018). Developing a Three-Level Framework for Building Information Modeling Education in Construction Management. Universal Journal of Educational Research, 6(9), 1991-2000.
[9] Sanguinetti, P., Abdelmohsen, S., Lee, J., Lee, J., Sheward, H., & Eastman, C. (2012). General system architecture for BIM: An integrated approach for design and analysis. Advanced Engineering Informatics, 26(2), 317-333.
[10] Sidani, A., Dinis, F. M., Sanhudo, L., Duarte, J., Santos Baptista, J., Pocas Martins, J., & Soeiro, A. (2021). Recent tools and techniques of BIM-based virtual reality: A systematic review. Archives of Computational Methods in Engineering, 28(2), 449-462.
[11] Solnosky, R. (2013). Current status of BIM benefits, challenges, and the future potential for the structural discipline. In Structures Congress 2013: Bridging Your Passion with Your Profession (pp. 849-859).
[12] Vilutiene, T., Hosseini, M. R., Pellicer, E., & Zavadskas, E. K. (2019). Advanced BIM applications in the construction industry. Advances in Civil Engineering, 2019.

Scopus preview - Scopus - Disaster Advances

scopus.com/sourceid/19700175287

Source details

Feedback > Compare sources >

Disaster Advances

Years currently covered by Scopus: from 2009 to 2024

Publisher: World Researchers Associations

ISSN: 0974-262X E-ISSN: 2278-4543

Subject area: Social Sciences: Geography, Planning and Development; Engineering: Safety, Risk, Reliability and Quality; Environmental Science: Environmental Science (miscellaneous); Earth and Planetary Sciences: Earth and Planetary Sciences (miscellaneous)

Source type: Journal

View all documents > | Set document alert | Save to source list

CiteScore 2023: 0.7

SJR 2023: 0.166

SNIP 2023: 0.352

CiteScore | CiteScore rank & trend | Scopus content coverage

CiteScore 2023

0.7 = 233 Citations 2020 - 2023 / 349 Documents 2020 - 2023

Calculated on 05 May, 2024

CiteScoreTracker 2024

0.9 = 284 Citations to date / 300 Documents to date

Last updated on 05 November, 2024 • Updated monthly

CiteScore rank 2023

Category Rank Percentile

Landslide Vulnerability of Urban slums: Case of Warje Slum, Pune, Maharashtra

Gokhale Vasudha[1*] and Joshi Deepa[2]
1. B.N. College of Architecture, Pune, Maharashtra, INDIA
2. MLBG College, Bhopal, M.P., INDIA
*Gokhale.va@gmail.com

Abstract
The rapid urbanization in developing countries contributed to the severity of urban environmental hazards such as slope failure and flooding. In addition, heavy rainfall or alterations to natural environmental characteristics trigger the incidence of hazards such as landslides where local topographic conditions often exacerbate the vulnerability of the built environment. Landslide causes numerous fatalities and financial damage to millions worldwide and India is no exception.

In most of the Indian cities, the physical expansion during the past few decades has resulted in increased vulnerability, with the occupation of hill slopes subject to instability. Therefore, the impact of physical characteristics of the environment and human interventions needs to be examined in assessing urban vulnerability. This study examines the vulnerability of urban settlements to landslide risk with Warje Slum, Pune, Maharashtra as a case study. It attempts to understand better the causative factors of landslides and their impact to suggest ways for better disaster management to save life and property in the future.

Keywords: Risk, vulnerable, slums, slopes, perception.

Introduction

Urbanization and consequent increase in populations contribute to the vulnerability of cities to disasters; landslide is one of them. Sky-reaching land prices in urban areas force people to construct houses on steep hill slopes. In addition, the use of substandard quality materials and technology significantly intensifies the occurrence of urban landslides. In developing countries like India, people living in disaster-prone areas have grown by seventy to eighty million per year. Landslides are the world's third most crucial natural disaster causing human casualties and damage to property and infrastructure. Various factors resulting in landslides are causative and triggering factors whereas causative factors that create a favorable condition for landslides include slope, geology, land-cover aspect and land use.

India has 12.6% of its total land as landslide prone. Research indicated that India had the highest casualities, nearly 56,000 casualties from 4,800 landslides around the world between 2004 and 2016. The country accounts for 20% of landslide deaths witnessing the fastest rise in human-triggered fatal landslides. It is found that maximum construction-triggered landslide events occurred in India, accounting for 28% followed by China, about 9%, Pakistan at 6% and the Philippines, Nepal and Malaysia, 5% each. The densely populated residential construction on hill slopes renders landslide risk management more complex. Besides lack of legislation, marginalization of low-income housing with inefficient policy measures, poor soil-use management, socio-economic crisis and lack of technical support contribute to people's susceptibility.[2]

Landslides are geomorphological processes associated with the topography's dynamic development, particularly in tropical and temperate environments. The prediction of landslides is a complex phenomenon making it difficult to protect such areas from catastrophic consequences due to landslide occurrence.[12] In urban areas, the lack of urban planning and infrastructure has led the most underprivileged population to occupy risky and unsuitable construction areas with low real estate land value.[3]

Landslides in Urban Slums: In urban areas, human activities such as housing and infrastructural construction on hill slopes and deforestation accelerate the occurrence of landslides.[1] In developing countries like India, intensive urbanization, inadequate land use and high land values compel the most impoverished population to occupy areas with vulnerable geologic and topographic characteristics. This aspect results in slum development on the hill slopes, a common phenomenon in Indian cities.[14] Recurring landslides constantly threaten the poor and socially marginalized populations living on small hillocks.

The densely populated, unplanned, haphazard, structurally deficient construction accompanied by poor infrastructure results in soil erosion, enhance the risks of landslides, particularly in the rainy season.[18] The hill slope is generally comprised of silty clay with a poor shear strength compared to sand and clay/shale. Consequently, such areas are susceptible to slope failure and mass wasting as the gravitational force acting on the slope exceeds its resisting force.

In the rainy season, soil's susceptibility to landslides increases due to excessive rainfall that saturates the soil, increasing soil mass. In such an event, material movement occurs because of slope instability depending on the slope. The slope instabilities result from geological, morphological and human-induced changes in the physical environment. In the rainy season, due to rainwater absorption, the mineral present in the water dissolves the soil and becomes heavy, losing its compaction. This process is aggravated in the case of high-intensity rains because soil minerals dissolve very quickly, turning the soil into a heavy mass of mud. Besides, deforestation increases the risk of landslides due to the absence of vegetation that holds the soil, protecting it from erosion and stabilizing the hill slopes.[13]

Risk Perception and Vulnerability: Risk represents the likelihood of an event occurring and its likely consequences governing how people live in safer and more sustainable communities. It is a belief created through the interaction between various social aspects and people about what is dangerous and what processes and factors are likely to harm them.[21] Disaster mitigation behavior of endangered people depends on risk perception that includes perception about the severity, occurrence probability, usefulness of mitigation efforts and ability to implement the suggestion.[15] Perception 'is the establishment, proof of identity and analysis of sensory information imperative to signify and recognize the environment.[19]

Risk perception refers to the qualitative evaluation of the possibility of an unwanted event, the degree of its effects and one's managing abilities.[23] Disaster risk perception and knowledge affect mitigation and adaptation behavior and disaster preparedness. People's social vulnerability depends on socioeconomic conditions and their experience of disasters that affect their response to an emergency.[8] Vulnerability depends on physical exposure to hazards and people's socioeconomic conditions generated over a long period. Vulnerability comprises resilience and strength of livelihood, baseline status, self-protection measures, social protection and governance.[6]

Risk Management and Risk Preparedness: Risk management efficiency depends on how people perceive the risks.[16] Local governments and communities prepare disaster risk management plans, having planned interventions formulated with the identification of risks, vulnerabilities and capacities against local hazards. Such plans are based on historical data of hazards at a given location addressing current hazards and vulnerabilities.

However, they often overlook future vulnerabilities and risks.[17] Risk is impending for responsiveness of uninvited, disparate effects on human life, wellbeing, assets, or the environment setting. People often prefer to live in a risky location as the availability of other facilities and benefits overshadows the risk perception.

Generally, people perceive the risk but do not accept the responsibility to mitigate others, complaining lack of resources and help offered by others and government bodies. Perception of disaster risk is more in the people belonging to lower income groups and they are generally more concerned with occurrence of natural disasters[9]. This aspect is due to fewer resources to cope with an adverse situation. Many of them cannot afford disaster preparedness measures and continue to live under disaster threats.[11]

Factors Affecting the Response of People to a Disaster: People's response to an emergency situation depends on their perception and inappropriate perception leads to failure of efforts taken for their personal, public and environmental protection[21]. Risk perception significantly influences an individual's motivation to prepare for disaster. However, research demonstrated that the interrelationship between risk perception and social response is often weak. This weak relationship is referred to as "the risk perception paradox" for three reasons. In the first case, a person understands the risk, but they prefer to accept it considering the benefits that are more than the negative impacts. In the second case, people perceive the risk but avoid taking action and pass on the responsibility to respond to others. Finally, a person understands the potential risk but refuses to respond in light of their perceived lack of resources to face the emergency.[23]

Previous experience of exposure to disaster shapes people's risk perception.[25] Besides, thrusts in experts and authorities also modify their response and preparedness for an emergency. People's perceived threat, disaster severity and fear govern their motivation to take action for self-protection.[7] On the other hand, excessive dependency and trust in government bodies result in a pessimist approach and people do not take action on disaster occurrence or any preparatory measures. Often infrequent occurrences and minor losses influence the perceived risk of an adverse event.[24] In dealing with uncertain risks, people's acceptability of a hazard and decision making process is based on directives and information provided by government bodies, experts. In such a case, less trust on authorities results in lower level of risk perception.[4]

Protection motivation theory postulates that people's decision to respond protectively or non-protectively depends on two cognitive processes: threat appraisal and coping appraisal.[5] Risk appraisal, also called risk perception, comprises a disaster's perceived probability and perceived consequences.[22] A coping appraisal is an act to reduce or avert the possible threat that depends on response efficacy (perceived effectiveness of an action), self-efficacy (the perceived ability to implement the action) and response cost (perceived cost likely to be incurred in implementation).[10]

Landslides in Indian Urban Areas: Landslides have been observed frequently in Indian cities in the last two decades. In Mumbai, in the financial capital of India, 1.5 lakh families live on the hill slopes and 300 lives have been lost to landslides in the last 20 years. The third major disaster in the city was the landslide at Lal Bahadur Shastri Nagar slums in Saki Naka andheri East, in 2005, killing 11 people including four children. In July 2021, 10 people were killed in an illegal slum at the height of 500 feet on a hill at LBS Marg, Vikhroli (West), due to a landslide following heavy rainfall. The constant heavy rain recently triggered a landslide in the

Tony Peddar Road area of Mumbai, resulting in a wide crack in the footpath.

The Malin village in Ambegaon, Pune, Maharashtra, in 2014, experienced a massive landslide, burying about 40 houses, reportedly killing 151 people. The heavy rainfall receiving 108 mm of rain in a day that continued throughout the following day caused the landslide. Large-scale deforestation was the primary undelaying anthropogenic reason that resulted in landslides exhibiting the sheer negligence of geological aspects in the developmental process. The village people opted for a shift of agricultural practices from rice and finger millet, for which the steep hill slopes were leveled, rendering the hills unstable. One of the possible reasons was the large-scale construction of the Dimbhe Dam in the vicinity.

The Study Context- Pune, Maharashtra: Pune is one of the large cities in Western Maharashtra where the metropolitan area has a population of 5 million, which makes it the seventh largest metro area by population in India. The total number of slums in Pune city is 151,278, with a population of 690,545 residents, making around 22.10% of the total population of Pune city (Census, 2011). The city is experiencing the indiscriminate cutting of hills and deforestation for building construction, developing residential/housing areas, clay and sand mining and developing a road network. Industrial development and mass migration resulted in an unprecedented increase in land and property prices. The unaffordability to purchase a residential facility in prime areas forces people from the low and low-medium economic class to occupy the hill slopes, top or foot of hills. Such residential structures are built without following the prescribed development control rules and regulations.

In many places, the hills are cut with steep slopes ranging from 45-80 degrees that cannot bear the heavyweight imposed by the construction activities making the area susceptible to a landslide. The landslide-prone slum community in Warje slum consists of several small clusters of settlements or slums on a hillock in Warje, Pune. Oral history has revealed that this settlement was uninhabited, the hillock on which several communities from Pune, gradually built a settlement. Later, other groups that migrated to the city from different states joined and drew in relatives and caste groups from their rural locality, consolidating their position within the community.

Material and Methods

A detailed exploratory field investigation was conducted at Warje slum Pune and data were collected through two methods: naturalistic observation and semi-structured interviews. A total of 158 residents participated in the survey. It is followed by assessing the physical vulnerability of building stock where a section of the slum was selected comprising of 526 houses in the area under study. The data were analyzed by SPSS 21 (Statistical Package for Social Sciences) and construct validity was checked by the factor analysis method. In addition, the suitability of data for factor analysis was tested through the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett's test of sphericity (Bartlett's test) by using SPSS.

The vulnerability of the built stock was evaluated to predict likely damages caused by landslides. The elements of buildings such as construction material, age, structure type, number of floors and number of occupants, were used to assess the vulnerability. About 526 residential units were surveyed for six factors.

Results and Discussion

A total of 158 residents participated in the study and the socio-demographic characteristics of them are presented in table 1.

Table 1
Sample Composition

Gender	Male	92	58.2
	Female	66	41.8
Economic status	20000-30000	38	24.7
	30000-50000	83	53.9
	more than 50000	33	21.4

Table 2
House Type and Disaster Experience.

Variable	Groups	Frequency	Percent
House Type	Mud	4	2.6
	Patra	30	19.5
	Brick and Patra	77	50.0
	Pacca single story	40	26.0
	Pacca double story	3	1.9
Disaster experience	No	84	54.5
	Some	68	44.2
	Very much	2	1.3

Fifty-eight percent (92) were male and 42.6 percent (66) were female. The family income of 25 percent (38) was 20000-30000, 54 percent (83) respondents earned Rs, 20,000 – 50000, while it is more than 50,000 per month for 21 percent (33) families. The house typology and the resident's experience of a disaster were explored and the analysis is presented in table 2.

The house type of 50 percent of people (77) was a brick structure with a lightweight tin sheet roofing (Patra); 19.5 percent lived in a house made of lightweight sheets (Patra). Twenty-six percent (40) had a single-storied brick house with an RCC roof; 2% lived in a double-storied pacca structure. However, 2.6 percent (4) had a mud house. 54.5 percent of respondents 84 did not experience any disaster, 44 percent (68) had encountered a disaster to a certain extent and 1.3 percent just two had experienced a significant disaster in the past.

Scale items, M and SDs of items were presented in table 3. When a disaster occurs, family earnings stop for a long time (M=3.2792, SD =.57731). People want to leave the house because of possible disasters (M= 1.6818. SD= .87600.)

Data were subjected to factor analysis using principle axis factoring and orthogonal varimix rotation. The output of KMO and Bartlett's Test is shown in table 4.

KMO measure 0.556 indicating the data were sufficient for factor analysis. The Barlett's test chi square value 254.85 p< .05 showed that there was patterned relationship between items. Using Eugin value cut off value > than 1.0 there were 3 factors that explain a cumulative covariance of 29.231 %. The scree plot confirms the finding of retaining 3 factors. The table 5 shows factor loadings after rotation using significant factor criteria of 0.5.

The first factor (item 1,2, 7), named as exposure, took factor loading ranging from 0.569 to 0.541. The second factor (item 6,10,11) was named as impact with factor loading ranging from 0.536 to 0.719 and the third factor (item 8,12) named as the anxiety, took factor loading ranging from 0.536 to 0.327. The factor analysis indicated the people's concerns about the exposure of their community to flood and fire where the possibility of landslides is not thought of. The second concern is the impact of a landslide compared to others regarding physical damages, disturbance to family's day-to-day living and financial losses. Finally, the third factor was the fear and anxiety that they possessed about the occurrence of a disaster like a landslide.

Perceived Likelihood of Disasters: The perceived likelihood of disasters and the subsequent threat is shown in fig. 1.

Table 3
Items, Mean and Standard Deviation of Measurement Instrument

Items	Mean	Std. Deviation
likely to have flood	2.3442	.47664
likely to have fire disaster	2.8831	1.01587
likely to have land slide	1.0000	.00000
likely to have earthquake	1.0000	.00000
threat in rainy season	3.1234	.70783
It is likely that I could be harmed in disasters at home	2.7013	.58444
It is likely that my family could be harmed in disasters at home	2.9740	.51065
It is likely that my house could be harmed in disasters more easily than other houses	3.0195	.63112
It is likely that I will have more problems than other households	3.0390	.73993
I feel depressed when my area is affected from rains	2.7013	.45918
likely disasters occurrence make me worry when I come to my place	3.0130	.62609
I think that disasters pose great financial damage	3.0390	.41037
When a disaster occurs my family earning stops for a long time.	3.2792	.57731
I want to leave this house because of the possibility of disasters	1.6818	.87600

Items removed from scale

Table 4
KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.556
Bartlett's Test of Sphericity	Approx. Chi-Square	254.838
	df	66
	Sig.	.000

Table 5
Factor Loading

Factor Name	Item No		Factor Load
Exposure	1	likely to have flood	0.569
	2	likely to have fire disaster	0.810
	7	I will have more damages than other households	0.541
Impact	6	My house could be harmed in disasters more easily than other houses	0.536
	10	When a disaster occurs my family will be in trouble for a long time.	0.607
	11	I think that disasters pose great financial damage	0.719
Anxiety	8	I feel depressed when my area is affected from rains	0.536
	12	likely disasters occurrence make me worry when I come to my place	0.327

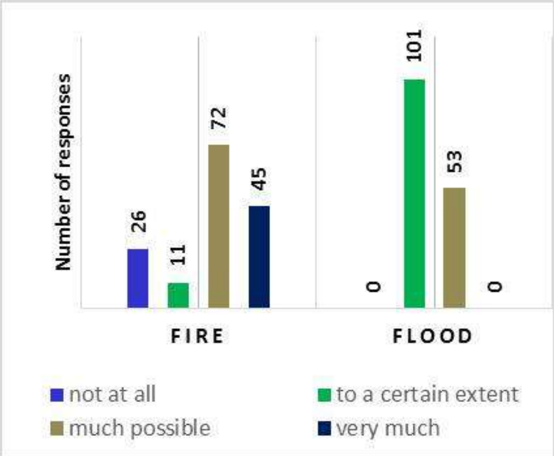


Fig. 1: Likelihood of Disasters

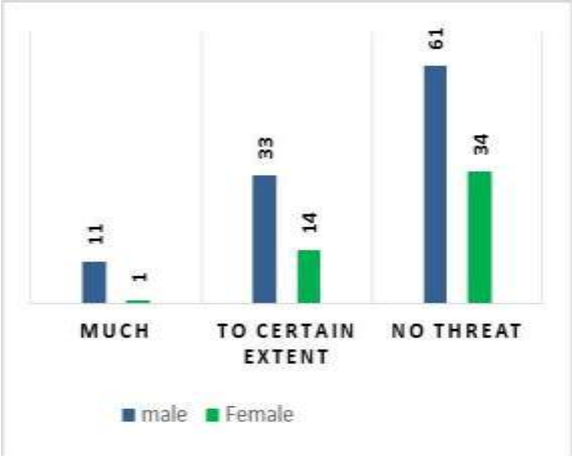


Fig. 2: Threat to the house.

According to the respondents, the disaster types that may occur mostly were a flood followed by fire. However, as per respondents, there was no possibility of landslides and earthquakes. The threat to their house due to the disaster was severe for 30% of respondents. For 45% of people, it was a moderate level and for 25%, it was not significant; however, not a single person rated their house as safer from disasters.

The respondent's concern about how a likely landslide affects them and their community is examined. Analysis indicated that 74% were worried about their family wellbeing that was the highest followed by concerns about impact on the house that was for 60% respondents. About 57% respondents were concerned with their personal safety, however, 49% perceived impact on the whole neighborhood (fig. 3).

Physical Vulnerability Assessment: Physical vulnerability of sampled houses was examined with six constructs: roofing type, structural typology, vertical configuration, position from steep slope, quality of construction and the state of maintenance. The section of Warje slum was selected having steep to moderate slope. The details of level of vulnerability (LV) are presented in table 6 where LV1to LV4 denotes low to high vulnerability.

It is observed that more than 50% of houses have roofs with low resistance being made of lightweight material secured by placing heavy material on the top. Many houses had a flat roofs. RCC roofs in GI or Asbestos sheets were not adequately tied to the parent structure, making them vulnerable to separating in case of a structure's movement. About 26% of such houses were rated as LV2. About 23% of the houses having RCC roofs just placed on the load-bearing structure are rated as VL1, considering the lack of structural strength in the absence of beams and columns (Fig. 4).

Fig. 3: Perceived impact of a landslide

Table 6
Level of Vulnerability

Roof	**LV**	**Position from Steep slope**	**Score**
Flat roof in Reinforced Concrete	LV1	Less than 5 m	LV 1
Flat roof in GI or Asbestos sheet	LV 2	Greater than 5 m	LV 2
Pitched or flat roof with stone/heavy material placed on the top	LV 3	On the Steep Slope	LV 3
Structural Typology		**Quality of Construction**	
Stone Masonry	LV 4	Good	LV 1
Brick Masonry	LV 3	OK	LV 2
RC frames with infill walls	LV 2	Bad	LV 3
Patra	LV 1	**State of Maintenance**	
Vertical Configuration		Good	LV 1
Regular	LV 1	OK	LV 2
Irregular	LV 2	Bad	LV 3

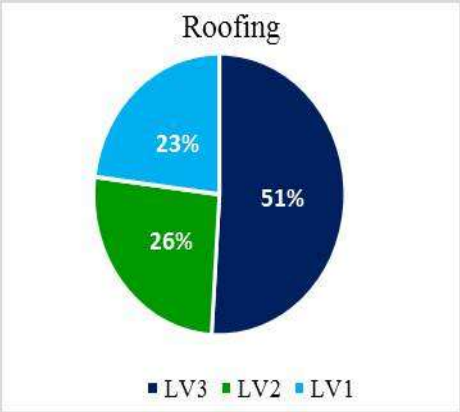


Fig. 4: Roofing typology

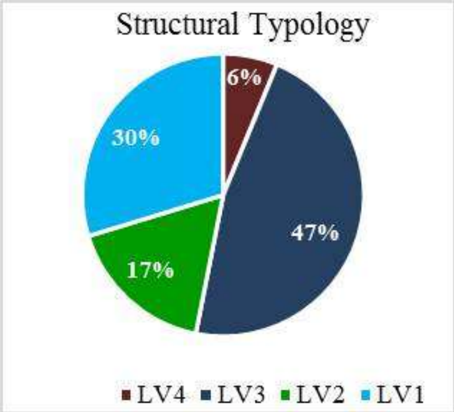


Fig. 5: Structural typology

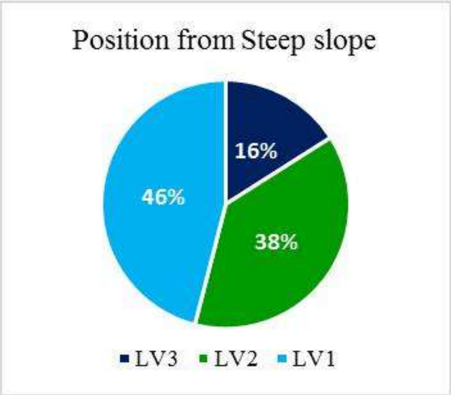


Fig. 6: Location

Fig 7: Quality of Construction

The observation indicated that 6% of the houses used stone masonry without following standards and were found highly vulnerable (V4). Brick masonry construction typology is used for 47% of houses with substandard mortar, with or without plaster and rated significantly vulnerable (VL3). The houses using RCC were not adequately designed as many had missing beams, columns and heavy infills are rated as vulnerable to a certain extent (VL2). However, houses made out of lightweight sheets referred to in the local dialect Marathi "Patra" were used for constructing the house and were rated marginally vulnerable (VL1) (Fig. 5). About 16% of the houses either located on the edge of the slope or at the foot of the slope are rated highly vulnerable (V3), 38% of houses located near the unstable slope are rated vulnerable to a certain extent (VL2) on exposure to a landslide. 46% of houses are not located very close to the slope, but the likelihood of soil settlement considering the soil characteristics is rated as vulnerable (VL1) as shown in fig. 6. The highly substandard quality of construction observed for 46% of houses renders them highly vulnerable (VL3). About 33% of houses used substandard quality material and were poorly executed and rated marginally vulnerable (VL2). 21% of houses followed the standard practices to a certain extent.

However, they compromised in providing strengthening measures considering likely damages due to landslide and were rated as vulnerable (VL1) as in fig. 7. About 58% of houses were in bad shape due to ill maintenance, 25% were maintained to a certain extent while 17% were in a comparatively better state but still not adequately maintained to have enough strength and capacity to resist a landslide (fig.8). The vertical configuration of 65% of houses was exemplary.

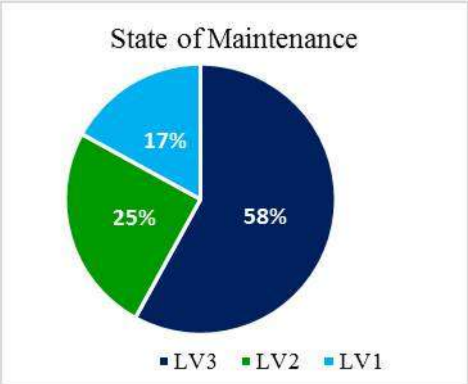


Fig. 8: Maintenance Level

However, 35% of houses with irregular vertical configuration projections without proper support, attics and lofts used as functional space or for storing heavy material made them significantly vulnerable.

The research examined slum dwellers' capacities, solidarity and perception of disaster occurrence, focusing on landslides. It is uncovered that various spatial, social and environmental characteristics are responsible for rendering the living areas located on hill slopes vulnerable to disasters. The analysis uncovered the people's perception of a landslide, where their multiple capacities and solidarity surfaced to respond to such an event. It is established that slum dwellers will continue living, recreating spatial, social and environmental characteristics ignoring the likelihood of a disaster such as a landslide unless Government bodies take proactive measures.

It is established that these areas constitute disastrous urbanscapes occupied with socially and spatially vulnerable communities. The densely populated area with poorly constructed houses located abutting each other increases vulnerability whereas illegality and lack of essential services increase disaster proneness. The political, economic and organizational capacities are compromised to a more significant extent forcing the community for a continual living in disastrous conditions.

The analysis indicated that slum dwellers living in hazardous locations face disasters frequently, particularly heavy rains. Their socio-spatial vulnerability depends on the physical environmental condition that is highly deficient. Besides, the socio-economic conditions generated in their lifetime add to their vulnerability. The absence of financial resources and lack of knowledge result in least protection motivation that does not directly arouse and sustain against a potentially disastrous situation. It is noticed that their response is non-protective due to denial, fatalism, or wishful thinking. People living in slums in the area under study tend to underestimate the danger due to a lack of experience with landslides.

This aspect hinders preparedness intentions during a possible event. In dealing with uncertain risks, people's acceptability of a hazard and decision-making process is based on directives and information provided by Government bodies and experts. In such cases, less trust in authorities results in lower risk perception.

People found denial mode and did not accept the likelihood of a landslide and its adverse impact. They refused to take any measure to strengthen. Most of the respondents do not have adequate information; the lack of trust in regulatory bodies and experts affects their coping mechanisms. Extreme events such as landslides and floods create hazardous conditions and impact human systems, depending on the existing vulnerabilities in the living environment.

Conclusion

The probability of a disaster unfolds the vulnerability of populations impacting communities functioning and social welfare. The difficulty in improving the capacity of a community to resist landslides is attributed to the inability of people to conceptualize landslides that have never occurred in the area under investigation. People's acceptance of the likelihood of landslides is conditioned by their immediate past, limiting their thought processes. They visualize the future as a mirror of that past. The knowledge and information about such low-probability hazards are to be enhanced to increase the memorability and imaginability to realize their perceived riskiness, irrespective of the evidence.

The frequent occurrences of landslide-induced accidents in urban slums have caused significant damage to life and property in the recent past. This phenomenon warrants architects, planners and local governments to identify and analyze risk areas to manage and prevent such hazards with required emergency planning measures. The resistance of a building against a landslide depends on the physical and geographical aspects of a building. Therefore, to avoid damage and minimize the intensity of a landslide, it is necessary to increase the resistance of buildings.

The physical vulnerability of such a location is to be reduced, considering the magnitude, the impact of a likely disaster on structural elements and exposure values. A building's physical vulnerability is the expected degree of loss due to the impact of an event that depends on factors such as the type of element at risk, its resistance and the presence of protective measures. Such features need to be enhanced to save the disadvantaged population living in slums located on hill slopes.

References

1. Abedin J., Rabby Y.W., Hasan I. and Akter H., An investigation of the characteristics, causes and consequences of June 13, 2017, landslides in Rangamati District Bangladesh, *Geo-environmental Disasters*, **7(1),** 1-19 **(2020)**

2. Alcántara-Ayala I., On the historical account of disastrous landslides in Mexico: the challenge of risk management and disaster prevention, *Advances in Geosciences*, **14,** 159-164 **(2008)**

3. Bezerra L., Neto O.D.F., Santos O. and Mickovski S., Landslide Risk Mapping in an Urban Area of the City of Natal, Brazil, *Sustainability*, **12(22),** 9601 **(2020)**

4. Bronfman N.C., Cisternas P.C., López-Vázquez E. and Cifuentes L.A., Trust and risk perception of natural hazards: implications for risk preparedness in Chile, *Natural Hazards*, **81(1),** 307-327 **(2016)**

5. Bubeck P., Wouter Botzen W.J., Laudan J., Aerts J.C. and Thieken A.H., Insights into flood-coping appraisals of protection motivation theory: Empirical evidence from Germany and France, *Risk Analysis*, **38(6),** 1239-1257 **(2018)**

6. Cannon T., Vulnerability, ‘‘innocent’’ disasters and the imperative of cultural understanding, *Disaster Prevent Management*, **17(3),** 350–357 **(2008)**

7. Eiser J.R., Bostrom A., Burton I., Johnston D.M., McClure J., Paton D. and White M.P., Risk interpretation and action: A conceptual framework for responses to natural hazards, *International Journal of Disaster Risk Reduction*, **1**, 5-16 **(2012)**

8. Fatemi F., Ardalan A., Aguirre B., Mansouri N. and Mohammadfam I., Social vulnerability indicators in disasters: Findings from a systematic review, *International Journal of Disaster Risk Reduction*, **22**, 219-227 **(2017)**

9. Gallo L.C., Bogart L.M., Vranceanu A.M. and Matthews K.A., Socioeconomic status, resources, psychological experiences and emotional responses: a test of the reserve capacity model, *Journal of Personality and Social Psychology*, **88(2),** 386 **(2005)**

10. Grothmann T. and Reusswig F., People at risk of flooding: Why some residents take precautionary action while others do not, *Natural Hazards*, **38(1),** 101-120 **(2006)**

11. Hallegatte S., Vogt-Schilb A., Rozenberg J., Bangalore M. and Beaudet C., From poverty to disaster and back: A review of the literature, *Economics of Disasters and Climate Change*, **4(1),** 223-247 **(2020)**

12. Listo F.D.L.R. and Vieira B.C., Mapping of risk and susceptibility of shallow-landslide in the city of São Paulo, Brazil, *Geomorphology*, **169**, 30-44 **(2012)**

13. Mahmood A.B. and Khan M.H., Landslide vulnerability of Bangladesh hills and sustainable management options: a case study of 2007 landslide in Chittagong City, In SAARC workshop on Landslide risk management in South Asia, 61-71 **(2010)**

14. Martire D., De Rosa M., Pesce V., Santangelo M.A. and Calcaterra D., Landslide hazard and land management in high-density urban areas of Campania region, Italy, *Natural Hazards and Earth System Sciences*, **12(4),** 905-926 **(2012)**

15. Michalsen A., Risk assessment and perception, *Injury Control and Safety Promotion*, **10(4),** 201-204 **(2003)**

16. Mızrak S. and Aslan R., Disaster risk perception of university students, *Risk, Hazards & Crisis in Public Policy*, **11(4),** 411-433 **(2020)**

17. Prabhakar S.V.R.K., Srinivasan A. and Shaw R., Climate change and local level disaster risk reduction planning: need, opportunities and challenges, *Mitigation and Adaptation Strategies for Global Change*, **14(1)**, 7-33 **(2009)**

18. Disaster Risk Reduction Planning: Need, Opportunities and Challenges, *Mitigation and Adaptation Strategies for Global Change*, **14(1),** 7–33 **(2009)**

19. Samaddar S. and Tanano H., Where do Individuals Seek Opinions for Evacuation? A Case Study from Landslide-prone Slum Communities in Mumbai, *Journal of Natural Disaster Science*, **36(1),** 13-24 **(2015)**

20. Stehr S.D., Dealing with Disaster: Public Management in Crisis Situations, *Perspectives on Politics*, **10(3),** 843-844 **(2012)**

21. Slovic P., Fischhoff B. and Lichtenstein S., Facts and fears: Understanding perceived risk, Societal risk assessment, Springer, Boston, MA, 181-216 **(1980)**

22. Sun L. and Faas A.J., Social production of disasters and disaster social constructs: An exercise in disambiguation and reframing, *Disaster Prevention and Management*, **27(5),** 623–35 **(2018)**

23. Tang J.S. and Feng J.Y., Residents' disaster preparedness after the Meinong Taiwan earthquake: A test of protection motivation theory, *International Journal of Environmental Research and Public Health*, **15(7),** 1434 **(2018)**

24. Wachinger G., Renn O., Begg C. and Kuhlicke C., The risk perception paradox—implications for governance and communication of natural hazards, *Risk Analysis*, **33(6),** 1049-1065 **(2012)**

25. Zaalberg R., Midden C., Meijnders A. and McCalley T., Prevention, adaptation and threat denial: Flooding experiences in the Netherlands, *Risk Analysis: An International Journal*, **29(12)**, 1759-1778 **(2009)**

26. Zinda J.A., Williams L.B., Kay D.L. and Alexander S.M., Flood risk perception and responses among urban residents in the northeastern United States, *International Journal of Disaster Risk Reduction*, **64,** 102528 **(2021)**.

(Received 06th November 2022, accepted 10th January 2023)

scopus.com/sourceid/21101055039

Scopus | Empowering discovery since 2004

Author Search Sources Create account Sign in

Source details

Feedback > Compare sources >

Cities and Health

Years currently covered by Scopus: from 2017 to 2024

Publisher: Taylor & Francis

ISSN: 2374-8834

Subject area: Social Sciences: Urban Studies; Medicine: Public Health, Environmental and Occupational Health

Source type: Journal

View all documents > Set document alert Save to source list

CiteScore 2023
5.7

SJR 2023
0.738

SNIP 2023
0.820

CiteScore | CiteScore rank & trend | Scopus content coverage

CiteScore 2023

5.7 = 1,749 Citations 2020 - 2023 / 306 Documents 2020 - 2023

Calculated on 05 May, 2024

CiteScoreTracker 2024

6.5 = 2,137 Citations to date / 329 Documents to date

Last updated on 05 November, 2024 • Updated monthly

CiteScore rank 2023

Category Rank Percentile

Taylor & Francis
Taylor & Francis Group

Cities & Health

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rcah20

Women's contested mobility and equity in Indian urban environment: case of public toilets in Pune, Maharashtra

Vasudha A. Gokhale, Deepa Joshi & Anjali Acharya

To cite this article: Vasudha A. Gokhale, Deepa Joshi & Anjali Acharya (2023) Women's contested mobility and equity in Indian urban environment: case of public toilets in Pune, Maharashtra, Cities & Health, 7:6, 1072-1087, DOI: 10.1080/23748834.2023.2242091

To link to this article: https://doi.org/10.1080/23748834.2023.2242091

Published online: 18 Aug 2023.

Submit your article to this journal

Article views: 28

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=rcah20

CITIES & HEALTH
2023, VOL. 7, NO. 6, 1072–1087
https://doi.org/10.1080/23748834.2023.2242091

Routledge
Taylor & Francis Group

ORIGINAL SCHOLARSHIP

Check for updates

Women's contested mobility and equity in Indian urban environment: case of public toilets in Pune, Maharashtra

Vasudha A. Gokhale [a], Deepa Joshi [b] and Anjali Acharya [c]

[a]Department of Architecture, Dr. B.N. College of Architecture for Women, S.P. Pune University, Pune, India; [b]Department of Economics, Government M L B Girls PG College, Bhopal, India; [c]Department of Forensic Science, Institute for Excellence in Higher Education (IEHE), Bhopal, India

ABSTRACT
Public toilet facilities in an urban setting are an essential infrastructure that guarantees every citizen's right to sanitation in the public realm. This paper contends on the fragility of urban infrastructure in addressing women's needs focusing on public toilet facilities in Indian cities. We argue that the deficit and inequitable provision of urban public toilets in Indian cities restricts women's participation in the public realm and perpetuates social inequality, with Pune, India, as the case. The spatial features of 124 public toilet facilities in 15 wards were examined in light of gender-responsive guidelines under the Swachha Bharat Mission. Various contextual, psychosocial, and technological factors influencing toilet use behavior were identified with semi-structured in-depth interviews with 45 women in three different life stages using the Integrated Behavioural Model for Water, Sanitation, and Hygiene. The analysis provided a nuanced understanding of various spatial and psychosocial aspects governing women's public toilet use in Pune. Analysis showed that various initiatives for improving sanitation adopted an androcentric vision in designing public toilets discounting women's equitable participation in the public realm. The finding delineates a spatial paradigm on providing inclusive public toilets contributing to women's mobility and equity in the Indian urban environment.

ARTICLE HISTORY
Received 5 March 2023
Accepted 25 July 2023

KEYWORDS
Sanitation; menstrual; adolescents; safety; incontinence

Introduction

Urban growth is invariably associated with sanitation and waste management (Bichard and Knight 2011), where lack of basic sanitation creates unhygienic conditions leading to unhealthy living environments and increased illnesses (United Nations 2007). More than 2.4 billion people lack access to health infrastructure and basic sanitation globally. The role of well-designed and maintained sanitation facilities in improving social, economic, and environmental conditions in a place and enhancing public health is well recognized (Roma and Pugh 2012). Public health infrastructure includes adequate public toilet facilities contributing to the inhabitants' social life, helping them maintain health, well-being, and dignified life. Public toilet facilities reflect a city's sociocultural and economic character and are often referred to as the essential barometer of civilization where people live or gather (Evans 2019). Besides, satisfactory operation and maintenance of public toilets improve sanitation and hygiene, providing an inclusive, safe urban environment and contributing to sustainable development (Ssekamatte *et al.* 2019). The provision of public toilets is a public health, humanitarian, educational, architecture, urban planning, and business concern where the toilet facility's serviceability and adequate spatial distribution suitable for the intended population is a prerequisite (Thieme and Koszmovszky 2020, Fu *et al.* 2022). However, the toilet facility is often designed to ignore the socioeconomic and cultural factors that affect the usage patterns of women, hampering their equitable mobility in the urban sphere (Heijnen *et al.* 2015). Previous studies established that women avoid places of business, entertainment, and leisure devoid of adequately designed and located toilets to address their peculiar needs (Greed 2004, Hanson 2010, Bichard and Knight 2012). This aspect is significant for women living in Indian cities where inadequate sanitation facilities are a persistent problem (Banana *etal.* 2015, Wankhade 2015, Vedachalam and Riha 2015). In addition, public toilet facilities need to cater to adolescent girls and women who face additional challenges with menstrual hygiene and need access to menstrual products, facilities for disposing of used materials, and a supportive environment to manage menstruation without embarrassment or stigma (Sommer *et al.* 2016, Maroko *et al.* 2021). Although it is a normal and healthy part of life for most women, it has always been linked with taboos

CONTACT Vasudha A. Gokhale Gokhale.va@gmail.com Department of Architecture, Dr. B.N. College of Architecture for Women, S.P. Pune University, BNCA Campus, Karve Nagar, Pune 411052, India
© 2023 Informa UK Limited, trading as Taylor & Francis Group

and myths in India excluding women from many aspects of socio-cultural life (Garg 2015).

Research scholarship addressed the issue of women's access to sanitation from different perspectives focusing on rural areas of India. However, research on public toilet facilities in Indian cities for women is scarcely explored. The problem addressed in this research is women's equitable access and use of public toilet facilities, with Pune, India, as a case. It argues that Indian cities lack gender-sensitive public toilet facilities that are a significant aspect of guaranteeing women's equitable mobility in the urban realm. The insights obtained from a survey of existing public toilets and interviews with women living in Pune, India, can serve as a guideline for proposing future equity-based policies.

Public toilets as a gendered space

Past research illustrates historical and cultural meanings and perceptions of public toilets as a gendered space, where the conventional approaches and assumptions concerning the human body, sexuality, privacy, social practices, and technological advances manifested in their design and construction across cultures (Walker *et al*. 2013, Njeru 2014). The public toilets for women are often called the 'World of Unmentionable Suffering' (Penner 2005). Such toilet facilities were developed considering class, race, and gender, representing the middle-class moralism of the nineteenth century that stressed various forms of bodily restraints to attain respectability representing pure womanhood, catering to their unique needs. In the early twentieth century, consideration for women's bodily and spatial characteristics was stressed for providing users privacy (Cooper *et al*. 2000, Isunju *et al*. 2011). Many initiatives have been taken in advanced countries to address women's equitable access to the public toilet, such as the restroom equity act enforced in 1989 in California to address less number of public toilets for women resulting in delays in using such facilities (Banks 2013). 'Potty Parity' was the phrase coined to represent equitable provision and access of all users to public restrooms, including advocacy efforts and legislation to address the issue of long queues in women's restrooms. The first Restroom Equity Bill passed by the Virginia Legislature, in which the equal size and number of restrooms for men and women were considered unfair due to more space and time requirements for women users (Banzhaf 2002, Anthony and Dufresne 2007, Levy 2010, Banks 2013). The absence of women's toilets in the chambers of the supreme court, USA until 1981 and in the USA senate until 1992 are glaring examples of gender inequality in political and legal spheres (Plaskow 2008, Rushin and Carroll 2017, Shannon and Hunter 2020). The International Plumbing Code (IPC) assigned a quota for the minimum number of gender-segregated toilet facilities in public spaces with required space in 2004 (Huh *et al*. 2019, Hochbaum 2019, Farajollahzadeh and Hu 2021).

Many Asian countries also took proactive steps to improve sanitation to provide citizens with a better quality of life. Since 2015 under China's toilet revolution, 68000 public toilets have been builtin urban areas in Mainland China to promote sanitation coverage and people's well-being (Cheng *et al*. 2018, Yan *et al*. 2021). Bangladesh witnessed large-scale rural and urban sanitation promotion programs to spread public toilet use and related hygiene practices in 1991 and 2014 (Hasan and Rahman 2021). The Total Sanitation and Sanitation Marketing (TSSM) program launched in East Java, Indonesia, and the Philippine Approach to Total Sanitation (PhATS), are some of the government-level initiatives to promote hygienic sanitary practices (Borja-Vega 2014, Nelson *et al*. 2014, Robinson and Gnilo 2016). Historically in the wake of India's non-violent independence movement, a well-equipped and maintained toilet symbolized dignity under the great visionary leader Mahatma Gandhi (Reddy *et al*. 2009). The Indian government made efforts to achieve equitable sanitation, including the 'National Urban Sanitation Policy' in 2008 and a people-centered sanitation program, the 'Total Sanitation Campaign', initiated in 1999. A Social Service Organization, 'The Sulabh International', provides toilet facilities all over India as one of the initiatives promoting sanitation and public health. Starting in Bihar, the organization has constructed about 3154 public toilets serving 10 million people nationwide (Pathak *et al*. 2022).

Swachha Bharat Mission (SBM), or Clean India Mission in 2014, aimed to eliminate open defecation and improve solid waste management. It is an attempt to generate awareness to bring about a behavioral change in the Indian population regarding healthy sanitation practices (Chaudhary 2017). This mission is one of the largest step towards achieving universal sanitation coverage and improving cleanliness operating in two domains, the Swachh Bharat Mission – Gramin and the Swachh Bharat Mission -Urban (Bharat and Sarkar 2016). Research indicated that more than 95 million toilets have been built across rural and urban India since the launch of this mission (Dandabathula *et al*. 2019).

The 'Swachh Bharat Mission-Urban (SBM-U)' aims to develop inclusive sanitation facilities to achieve desired cleanliness and services standards for public and community toilets in urban areas to cater to the need of women, physically challenged people, children, and transgender population and strengthening of urban local bodies to design, execute and operate systems (Suthar *et al.* 2019).

Accessibility and safety

Public toilets are an example of a public space not accessible on equal terms and a testimony to the inability to achieve equal cities (Banks 2013). In the lack of accessible toilets in the urban spheres, women often experience bladder leashes, where less toilet provision demonstrates the male domination seeking to preserve the patriarchal tradition of segregated private and public spheres limiting women's access to public spaces (Flanagan 2014, Ellisa and Luana 2022). Women's toilet inequality includes less than men, inadequate design and facilities, absence of separate toilets, and no such facility (Moore 2001). Moreover, women standing with their legs crossed in long queues in female toilets are egregious and apparent results of the discrepancy between female and male toilet provisions (Plaskow 2016). Accessibility aspects of public toilets are associated with individual behavior, choice, status, and community behavior. Accessible toilets are recognized as a crucial public amenity, the lack of which represents embodied and gendered insecurity leaving women and the elderly vulnerable (Thieme and Koszmovszky 2020). Generally, such spaces need gender-wise separation to prevent either sex from viewing the exposed private body parts of the other (Greed 2004, Gershenson 2010). Sex-segregated toilets are preferred as they address women's inherent biological differences and different functional needs. However, they intensify the segregation of men and women in the public realm (Greed 2004, Kogan 2007, Doan 2010, Jones and Slater 2020, Machunda *et al.* 2020).

People civilize following social constructs and societal obligations in the public sphere, where an individual's cultural perception governs safety, shame, and discomfort. Public toilet provision and design shape how people perceive bodily image and privacy within the enclosed toilet space (Duong 2021). Safety is a subjective psychological aspect that differs for each person, depending on their past experiences and social expectations (Molotch 2010). The toilet as a space is referred to as an uncomfortable liminal zone to test and prove gender differences. They provide a space for trading cultural capital and reflect womanhood. However, the lack of safety from a male-bodied person is a significant concern who may intrude in sex-segregated toilets rendering the space dangerous (Skeggs 2001, Jeffreys 2014, Skoglund and Holt 2021). To address women's safety and privacy concerns in avoiding sexual violence, the 'Bathroom Bill' passed in 2016 in North Carolina, USA, mandated using sex-segregated toilets in public places and schools, considering that the absence of such provisions would render the female population more vulnerable to sexual assault (Davis 2018). Feelings of safety and worry are associated with the urban environment characteristics of public toilets, and they are often considered potential spots of vandalism, anti-social behavior, and crime (Eck and Weisburd 2015, Hartigan *et al.* 2020). As per Routine Activities Theory, crime occurs without physical surveillance and the provision of security guards that reduce the opportunity for criminal activity (Hollis *et al.* 2013, Belur *et al.* 2017). The public toilet design relates to land-use patterns, architectural design, and urban planning, where many urban planning features as a designed road- network, often facilitating gender-related crimes. The research established that poorly lit areas create an uncertain environment, while the lack of surveillance, guards, broken doors, and missing locks render toilets unsafe (Afacan and Gurel 2015, Belur *et al.* 2017).

Health concerns

Toilet use has numerous health implications as research established that about 20% of women suffer from urinary infections, inflammation of the bladder wall referred to as interstitial cystitis resulting in increased urinary frequency and feeling of urgency. Pregnant women need to use toilets frequently, as in early pregnancy, urination increases due to hormonal changes. Furthermore, in late pregnancy, the bladder's capacity is reduced due to the pressure the uterus applies (Sahoo *et al.* 2015, Plaskow 2016). Poor menstrual hygiene management often affects women's risk of reproductive tract infections and urinary tract infections (Sommer *et al.* 2016). Women often hold onto urine as toilets are not readily available, where the urine retention and distension of the bladder increase the susceptibility to continence issues and may lead to renal damage (Banzhaf 2002, Teunissen *et al.* 2006). To avoid toilet use, women tend to limit water or fluid consumption, which causes dehydration, constipation, headache, and increased risk of kidney stone creation (Popkin *et al.* 2010). They have more significant contact with toilet fixtures such as toilet seats and cabinets, increasing vulnerability to health hazards than men. Moreover, unhygienic toilet facilities cause the spread of many skin infections, such as Methicillin-Resistant Staphylococcus Aureus (MRSA).

The public life of people with health issues often becomes challenging due to the limited availability of accessible public toilets (White 2021). Inaccessibility and ill maintenance of public toilets deter people from using them, and they often modify their routines and habits outside the home environment. Due lack of adequate toilet facilities within walking distance, older adults often face embarrassment as they may have incontinence problems commonly known as the loss of bladder control which keeps them home-bound, increasing isolation and causing poor mental health (Kitchin and Law 2001, Bichard *et al.* 2006, Hanson *et al.* 2007, Satterthwaite *et al.* 2015, Lowe 2018).

Architectural design and planning concerns

Public toilets are part of an individual's social life and are designed to satisfy architectural norms, rituals, and identity, symbolizing the culture and social milieu of the host community. Dara Blumenthal (2014) examined identity and embodiment using post-humanism and feminist theory, referring to the emotional response experienced in using a toilet. It included fear, anxiety, shame, and embarrassment (FASE) that maintains a homo clausus order, representing emotional, rational, and physical self-control (Blumenthal 2014). The design of public toilets needs to cater to women who use toilets more frequently than men due to many physical and health-related issues; besides, many women are likely to assist children or use them for breastfeeding; hence, they need more time to perform the required activity (Roma and Pugh 2012, Singh *et al.* 2018, Fileborn and Marshall 2020). A women-friendly toilet facility needs a separate entrance, good lighting, adequate doors, windows, and locks to assure privacy, culturally appropriate menstrual material availability, and a waste disposal option for equitable use. Besides, they should be affordable with a safe and convenient location (Corradi *etal.* 2020, Machunda *et al.* 2020). A public toilet has a direct user interface; hence it must be designed to satisfy users' needs and aspirations (Moreira *et al.* 2022).

Public toilets: the Indian scenario

India suffers from an alarming shortage of toilets as only 11.9% of the population has adequate sanitation, and 3.2% use public toilets (Wankhade 2015, Frøystad 2020). Insanitary conditions due to inadequate public toilet facilities are a significant concern in Indian cities suffering from poor maintenance, vandalism, and ignorance from the service providers and local government (Khosla and Dhar 2013, Kulkarni *et al.* 2017, Koonan 2019). Significant evidence showcases the vulnerability of Indian women to sexual violence where poor design and inadequate location of public toilets supported eave teasing, assault, and even rape as extreme events in both rural and urban settings (Viswanath and Mehrotra 2007, Molotch 2010, Gershenson 2010, Tacoli and Satterthwaite 2013, Srinivasan 2015, Sahoo *et al.* 2015, Shiras *et al.* 2018, Nunbogu and Elliott 2022). Providing adequate sanitation facilities for women considering their peculiar needs, is a neglected issue in the Indian context despite recognizing the adverse impact on their health and well-being (Reddy *et al.* 2009). The research established that various cultural, behavioral, and religious reasons govern sanitation and toilet use practices, as many women face the problem of using conventional Western-style public toilets, and the low partition walls between two stalls create privacy issues (Warner 1998, Jain and Subramanian 2018). A Plethora of research discussed flaws in public toilet provisions affecting women's safety, health, and well-being, focusing on rural women (Patel 2003, Datta and Ahmed 2020). However, women's concerns regarding access to healthy sanitation are still a neglected area of concern.

Study setting and context

The study was conducted in Pune, a major metropolis in the western province of Maharashtra with an urban/metropolitan population of 5,057,709, of which 2,656,240 are males and 2,401,469 are females. The city earned the nickname a pensioner's paradise and Oxford of the East; however, the information technology industry has witnessed unprecedented growth in the last few decades. Besides, the city is a popular choice for women to study and work to nurture a conducive ecosystem for women's education and employment (Nalavade 2000, Srinivasan and Kulkarni 2019). In Pune, many initiatives were taken with joint efforts by the municipal government, social organizations, and NGOs providing good sanitation facilities to more than half a million people (Burra *et al.* 2003). Pune Municipal Corporation (PMC) has constructed 797 community and 395 public toilet blocks, each with separate units for men and women. Community toilets are located near slums to cater to the slum population; however, public toilets are placed on streets, transport hubs, parks, and marketplaces (PMC, Hobson 2000). Pune Municipal Corporation presented a policy document with a vision of improving public health and safety, particularly of the marginalized population, including women, the elderly, and the physically challenged cohort. The intent is to provide a cohesive, well-maintained, universally accessible network of public toilets in all the city neighborhoods. The design principles include equitable use, allowing flexibility to accommodate individual preferences and abilities. Despite various initiatives the local government takes, public toilet facilities in the city remain gender-blind and do not satisfy the Gender Responsive Guideline under the Swachh Bharat Mission – Urban (SBM-U) (niua.org). This research examined the current status of public toilets in Pune and aimed to identify various social and spatial aspects that have a bearing on their equitable use.

Methodology

The primary database was collected through semi-structured interviews and observations at the 15 wards in Pune between August 2021 and February 2022. The

Table 1. Pune City Zones

S.N.	ZONE	WARD
1	**ZONE I**	Dhole Patil Yerwada Nagar Road
2	**ZONE II**	Aundh Ghole Road Kothrud
3	**ZONE III**	Dhakawadi Sahkar Nagar Warje Karve Nagar
4	**ZONE IV**	Kondhwa Tilak Road Hadapsar
5	**ZONE V**	Kasba Bhawani Peth Bibvewadi

Source: Pune Municipal Corporation (PMC 2023).

city is divided into five zones and 15 ward offices (each consisting of three), as shown in Table 1 and Figure 1.

A windshield survey was performed to identify the toilets located in each ward for detailed survey and analysis. Driving through the locality, researchers identified male and female toilets, noted the relevant characteristics, and marked their location on the area map. The toilet location and the number of male and female toilets are shown in Figure 2.

The windshield survey provided helpful information about toilet facilities distribution and location, based on which 124 toilets catering to women users were selected for analysis; the breakup is shown in Figure 3.

The method adopted was the naturalistic observation of sampled cases performed by trained women research assistants. They are supposed to enter the facility and observe the physical condition three times daily to ensure the broadest range of observational consistency. Five study parameters, each represented with specific attributes, adopted from "Gender Responsive Guidelines under Swachha Bharat Mission-Urban (niua.org) as presented in Table 2.

The adequacy of the parameters was rated as good, satisfactory, and unsatisfactory; in addition, notes were taken to serve as descriptive observational variables for each attribute to elaborate and justify the rating assigned to each toilet. The findings from the survey are presented in Figure 4 and elaborated in the next section.

Availability

Availability is represented by 800 m distance between two toilets along a road or 400 meters (5-minute walk) distance from a significant node distance from a significant node which is considered a comfortable

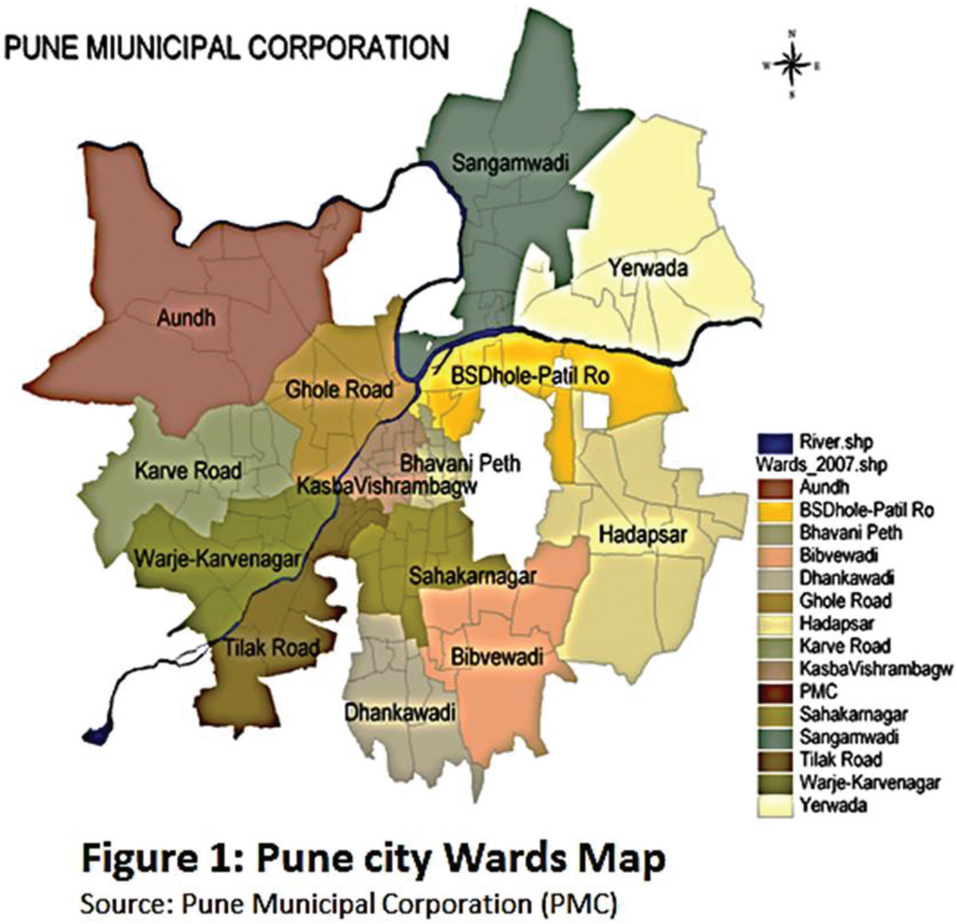


Figure 1. Pune city ward map. Source: Pune Municipal Corporation (PMC 2023)

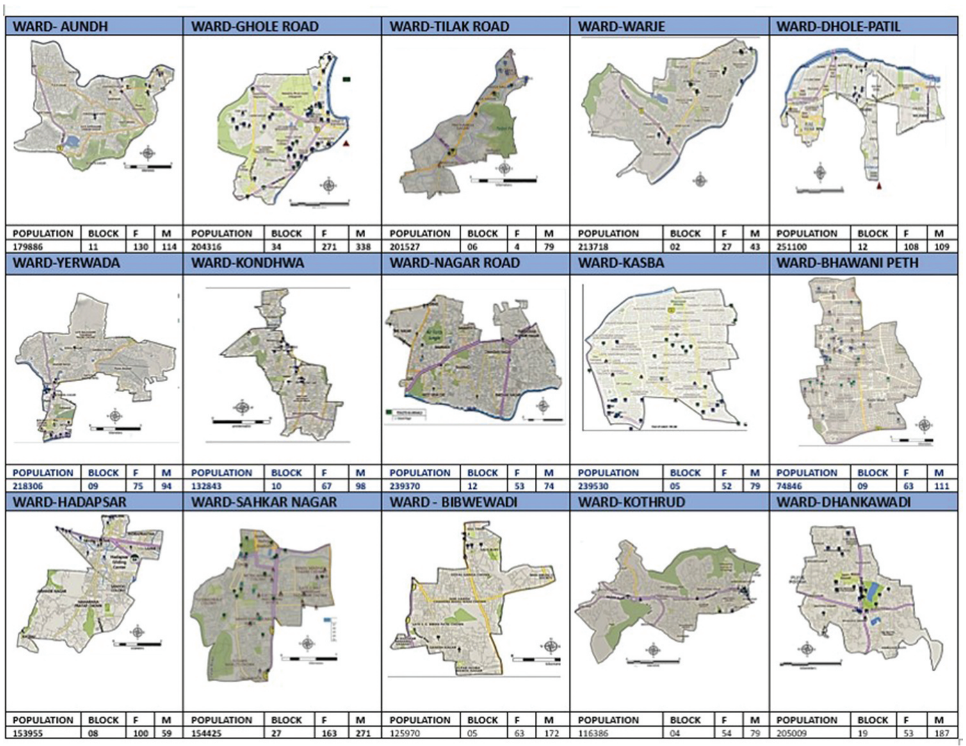


Figure 2. Location of public toilets.

walking distance to access a toilet facility and safety. Disproportionally located toilets where the concentration of toilets was observed at particular places in Aundh, Kothrud, Dhole-Patil, Yerwada, Kondhwa, Bibvewadi, and Hadapsar wards. At the same time, the rest part was devoid of toilet facilities. Just 22% of toilets satisfied the requirement, 30% were at a fair distance, and the location of 46% of toilets was rated 'unsatisfactory'. More than 50% of the toilet locations were rated unsafe due to various reasons, such as; being located in remote or rundown locations, concealed by dense trees, walls, and buildings resulting in the lack of passive surveillance, and being located close to places deemed unsafe for women, such as liquor shops.

Toilet design

Gender-friendly toilet design criteria included the availability of a separate unit for women, the entry reasonably away or facing a different direction from the male toilet unit, and visual intrusion. Another aspect is the provision of adequate signage for male and female toilets graphically and in the local language Marathi, and Hindi or English, to make them accessible for local people and the migrant population. The presence of adequately designed units for males and females providing privacy to use toilets in a dignified way was found in 10% of toilets; 41% were designed satisfactorily, and 49% of toilets' design was not rated as gender friendly. Adequacy of signage was noticed to a certain extent where signage in 28% and 38% of toilets were rated 'good' and satisfactory respectively while the rest, 33%, were not up to the mark.

Cubicle design

Cubicle design adequacy was examined considering the size of the cubicle and accessibility of toilets for the physically challenged population. The provision of a minimum of one cubicle accessible for physically challenged people meeting national accessibility guidelines, is a mandatory requirement under Gender Responsive Guidelines under Swachha Bharat Mission-Urban. However, no sampled cases satisfied this requirement. Most cubicles satisfy the size (1.1 square meters) requirement prescribed by Pune Municipal Corporation (PMC).

Safety

Good lighting conditions represented safety for women's toilets during day and night and surveillance. Adequacy of light during the day is based on adequate illumination for required visibility through fenestration design facilitating daylight penetration inside and artificial lighting. Inadequacy of lighting in toilets during day and night is found in 52% and 76% of toilets, respectively, appearing as a significant technological dimension that is likely to affect toilet use during day and night. The reason was the limited

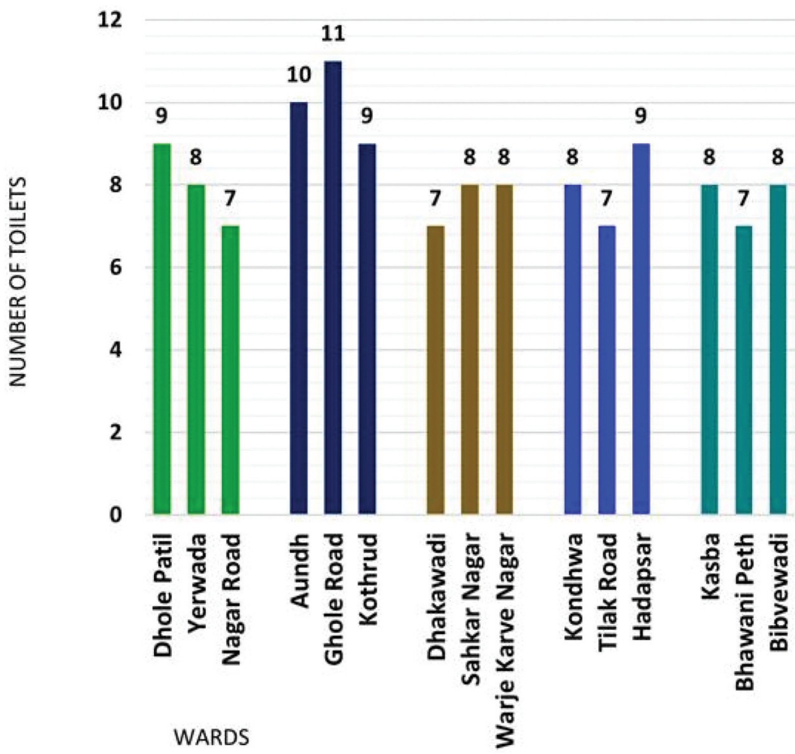


Figure 3. Sampled toilets.

Table 2. Parameters for gender responsive toilet.

	Parameters	Attributes	Criteria
1	Availability	Reasonable distance:	800 m Interval along a major road.
			Distance from a major node (400 m)
		Safe Location:	Reasonably visible from approach road
			Remote/Run-down locations
2	Toilet Design	Privacy	Separate toilet/part in same toilet for male and female units
			Toilet entrance at a sufficient distance from each other
			Face different directions or have separating walls.
		Signage	Adequate Graphical Signage
			Signage in local language/English/Hindi.
3	Cubicle design	Size of Cubicle	Minimum 1.1 Sq.m. area
		Accessibility:	Toilet cubicle accessible for people with disabilities
4	Safety	Lighting	Outside Lighting for Entrances, exits, walkways, paths-
			Inside Lighting in cubicles, wash areas
		Surveillance	Presence of a security guard/caretaker
5	Quality	facilities	Wash Basin, Water, Soap. Hooks and ledges for hanging clothes for keeping belongings off the floor.
		Menstruation management	Access to products for menstruation
		Waste disposal	Availability of regularly cleaned and covered litter bins,
		Hygiene	Cleanliness, Use of disinfection liquid
		Physical condition	Floor, walls, doors windows, hardware, sanitary fittings

Source: Adopted from niua.org, 2018.

entry of daylight attributed to the use of concrete grills with fewer perforations and small ventilators. Besides, ill maintenance of fenestration and consequent accumulated dust on glazed surfaces added to the gloomy and dingy interiors. Another reason was the Inefficiency of artificial lighting due to the use of luminaries with less wattage and non-working light fittings that did not add to the illumination level during the day and made toilets inaccessible after dark. The absence of female caretakers or guards in 70% of toilets is alarming as most toilet facilities were unpaid and operated with minimal cost.

Quality

Quality is represented by the attributes, including available facilities, menstruation management, waste disposal, hygiene, and the physical condition of the toilets. Availability of various facilities such as basins, water, soap, hooks, and ledges for hanging clothes for keeping belongings off the floor was rated good and satisfactory for 24% and 59% of toilets, respectively. The rest, 21%, were rated as 'unsatisfactory' in providing facilities to satisfy users' needs. Highly deficient menstruation management due to a total lack of access to products

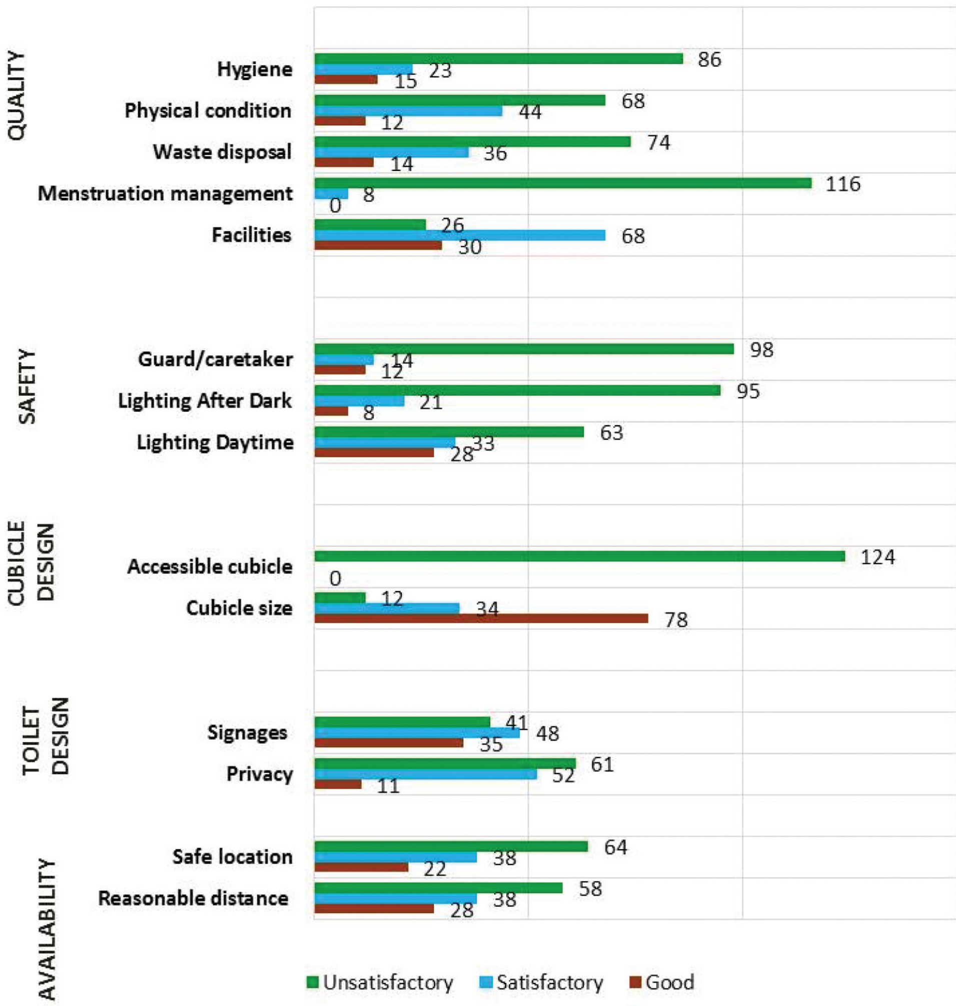


Figure 4. Survey responses.

for menstruation and unique arrangement for their disposal was found in 94% of toilets, indicating ignorance of this aspect in the provision of public toilets. Unsatisfactory hygienic conditions in 69% of toilets attributed to dirty surfaces, foul odors, less or no use of toilet cleaners, and disinfection liquid resulted from less frequent cleaning operations, in addition to the unsanitary behavior of users. Lack of adequate number, size, and type of litter bins, and irregular cleaning operations showcased inefficient waste management in 59% of toilets is likely to affect the quality of the facility, demotivating women to use them frequently. Broken tiles, water-flooded floors, damaged and low-performing hardware, and dull and worn-out interiors indicated the physical condition of 55% of toilets needed to be improved, out of which 35% were in bad shape and 7% were unusable.

The next step included structured interviews conducted by trained research assistants to capture women's experiences and perceptions regarding public toilet facilities. The respondents ($n = 45$) were recruited across the 15 wards of Pune, including three life stages young, middle aged and elderly Three women from the middle age group were pregnant and 4 from elderly group were using a walker. The composition of the sample is presented in the Table 3.

Respondents were randomly selected who travel for 30 minutes to 2 hours every day using public transport, walking, two-wheeler for work, errands, and leisure activities identified from bus stops, offices, temples, and public toilets. The identified women were contacted to know their willingness to participate in the study, explaining its purpose. Verbal consent was obtained, and the interview time and venue were selected at the respondent's convenience. Interviews were conducted in English and the local language, Marathi, lasting 15-30 minutes. Data gathered from the individual interviews were collated and constructed into narratives based on the users' experiences and perceptions concerning public toilets. Data were audio recorded and

Table 3. Composition of the sample.

	STATUS	AGE	NUMBER
1	Young : Adolescent and Early working age	15-24 years	16
2	Middle Aged : Prime working age	25-54 years	21
3	Elderly : Mature working age and elderly	55 onwards	8

transcribed verbatim; however, the interview data in Marathi was translated into English for analysis. A grounded theory approach using NVIVO Software was adopted. The emerged themes included Availability, Safety & Privacy, Health & Hygiene, Cleanliness, Accessibility, and Design concerns. The verbatim quotes under each theme are presented in Tables 4–6, which are further analyzed in light of dimensions of the Integrated Behavioural Model for Water, Sanitation, and Hygiene (IBM-WASH) framework comprised of three intersecting dimensions that influence behaviors (Contextual, Psychosocial, and Technology dimensions) (Dreibelbis *et al.* 2013).

Table 4. Availability, safety & privacy.

Availability	*The toilet is located in remote area with dense vegetation around its scary and un-safe". "There is no toilet along the route when I go for walk"*
	"It is too far from the road. Many times it is hard to control the pressure".
	"I avoid to go out for long period as there is no women toilet available in the temple"
	"I haven't seen any women's toilet along the road I daily use.
	"I prefer to go to toilet in a coffee shop or mall as no clean public toilets nearby".
	"I use two-wheeler for commuting to workplace. In peak hour it take longer to reach due to heavy traffic. I use toilets located in coffee shop often and never even thought of going to a public toilet".
Safety and Privacy	*"There always the threat of gender-based violence to send my young daughter in public places".*
	"I feel scared in accessing public toilet when there is no one present".
	"Many men are sitting in front of toilet it is embarrassing to enter public toilet".
	"There is less light inside I cannot see properly and feel risk of falling down"
	"We avoid using public toilets due to safety and privacy concerns".
	"In night it is scary as most of the area is dark. I had an injury because I hit my head".
	I do not feel un-safe as I can handle the situation, however I do not use due to un-hygienic condition.
	It is visible from the road no privacy at all.
	"The window was broken anyone can see me using".
	I prefer toilets in restaurants, malls as there is much privacy.
	There is no facility to make-up my appearance, I do not go only to urinate.
	It won't give me a feeling of relaxation at all.

Table 5. Health, hygiene and cleanliness.

Health and Hygiene	*"There is foul smell always, I have to hold my breath".*
	"The toilet floor was flooded with water and there were many flies".
	"I feel it risky to sit on the seat as I may be infected".
	"I have to touch many dirty surfaces"
	"Many users are coughing, I may catch it"
	"I always try to delay urination and limit liquid intake".
	"I am always worried about getting infection".
	"I never used a public toilet I feel they are not safe"
	I use public toilet only in extreme emergencies.
	"I need to hold wall and door, there is no soap available to wash my hands making my health at risk
Cleanliness	*The toilet was so dirty"*
	"Early morning toilets are comparatively clean however, later they became highly dirty".
	"The foul smell and dirty surroundings made me to decide not to use it as far as possible".
	"Toilet was clean but foul smell made it uncomfortable and leave the space early".
	"The garbage piled up make me irritated"
	"Never thought of getting some mensural supplies in public toilets".
	"Why they do not use phenyl, I have to hold breath due to foul smell".
	The male members sitting at male toilet can see who using toilet. I am not comfortable
	We have to stand outside in an exposed place in case toilets are occupied.
	"People watching you entering the toilet, opening the door its ridiculous"
	I need to access toilet but it is very stressful as there are no ramps to access the toilet as I used to walk with walker".
	"Public toilets look so shabby I cannot stand".
	"The toilet walls are not well painted every thing is ugly and dull".

Table 6. Accessibility and design aspects.

Accessibility	*"There are just two cubicles which are often occupied".*
	I take longer time to un-dress and use toilets because of Indian outfit I used to wear.
	After dark it is impossible to access as the light is not working".
	There is always dark, I cannot see the things properly.
	"I try to avoid using toilet as I cannot use Indian type seat as it is difficult to sit down and get up due to knee pain".
	I need to use toilet but it take long time as there are no handrails for support".
	The entrance steps are difficult to climb with walker, even the small cubicle make me uncomfortable.
Design Aspects	*"The Indian type toilet seat is just few inches from the door It is difficult to enter and shut the door".*
	"Toilet was so tiny I could not move".
	"The steps are broken and floor is slippery".
	"Why they do not use some superior quality material in construction like it is used in malls and other places".
	"There is no openable window, its suffocating".
	"They could have provided exhaust fan".
	"No hanger to keep my belongings and dupatta".
	The floor is always wet, I need to take care of my saree.

Based on the concerns noted, safety concerns included multiple dimensions ranging from possible sexual assault to physical harm. Responses regarding immediate surroundings that affect privacy were visibility and lack of acoustical privacy mentioned by five adolescents, and eight young respondents indicated their heightened sensitivity to the micro design features of the physical environment in addition to social and environmental cues, including perceptions about the disreputable and presence of men that affected their visit to public toilets. The responses of three adult working women indicate that they expect not only physical privacy in toilets but also mental privacy or solitude as they perceive toilets as more than just a facility with functions far beyond elimination, a place where they can mend their appearance, and get a retreat from the public sphere. The respondents had concerns regarding the threat of physical harm due to unfavorable environmental characteristics such as inadequate lighting and slippery floors. Five women (three elderly and two pregnant) had issues related to their physical issues or abilities, such as walking to distant locations of toilets, causing exhaustion from substantial physical exertion, and apprehension about falling, particularly in navigating through spaces devoid of supporting mechanism such as a railing or grab bars. The noteworthy observation was that safety from likely sexual assault was not a significant concern as 28 respondents (5 adolescents, 17 middle-aged, and six elderly) avoided the use of public toilets due to fear of getting an infection, less privacy, fear of falling, and having an unpleasant experience.

Twelve middle-aged women had issues with bad-smelling toilets. The extreme response of the two was that they were driven out of the space because of nasty odor, and they rejected staying there a moment longer than needed. Three professionals reject using public toilets due to cognition, which is the appraisal process that considers the current situation and the possibility that the toilets could be dirty and unhygienic. The avoidance behavior was noticed in more than fifty percent of respondents due to germ-specific phobia. Seven adolescents and five women respond that they are often acutely self-conscious when other people are near or in the toilets when it is being used. Besides, they have feelings of shame and embarrassment while entering or leaving a public toilet.

Limited availability of toilets reduced the frequency of outdoor visits of 8 elderly and three middle-aged respondents suffering incontinence. Lack of maintenance and ill-designed drainage resulted in dirty floors. It even flooded toilet floors, making their use difficult as they are primarily in traditional outfits like saree or salwar suites, as reported by six middle-aged respondents. Twelve women have problems with large amounts of water that gets splashed around in squat-style restrooms, keeping the floors always wet. This aspect cause more discomfort in toilets with squatting seats, a much-needed facility in the Indian context. The lack of a ramp and small cubicle size was mentioned as highly stressful for elderly women ($N = 3$) who use a walker.

Discussion

The physical survey revealed that availability needs to be met in the public toilets by the number of toilets provided or by the distance from each other. The two major problems identified include toilets in secluded, unsafe spots and unhygienic conditions due to ill maintenance and management and a lack of regulatory mechanisms (Greed 2004, Vyas *et al.* 2015). Unattended toilets, full of garbage and dirt, were reported as frequent. The range of factors identified that are likely to affect the acceptability of public toilets for sustained use are further discussed in light of contextual, technological, and psychosocial dimensions.

Contextual dimensions

Several Contextual dimensions emerged, resulting in an unfavorable environment and barriers to public toilet access. Respondent's previous experience of public toilet use stigmatized public toilets as unclean, unhygienic places, which was perceived as a threat to their health and well-being (Geisler 2000, O'Reilly and Louis 2014, Sahoo *et al.* 2015, Bisung and Elliott 2016, Caruso *et al.* 2018, Sclar *et al.* 2018). The interview precepts showed that the emergence of 'germaphobia' from an unclean and cluttered environment amongst health-conscious respondents fueled the avoidance behavior. A problem confirmed by the respondents was the perceived likelihood of unwanted and anti-social behaviors in and around public toilets. Various contextual dimensions, such as lack of sound and visual privacy and absence of a female caretaker or guard one of the reasons that discouraged the respondents from accessing public toilets supporting the concept of informal social control, 'eyes on the street', and policing as an essential attribute to avoid the feeling of insecurity (Platt and Milam 2018, Hallberg 2021). Besides, the respondents were skeptical about accessing toilets located in remote or rundown locations or locations concealed by dense trees, walls, and buildings resulting in the lack of passive surveillance as such locations do not ensure the protection of them from sexual violence (Bell 1998, Pearce *et al.* 2020). Users opt to use public toilets in extreme emergencies and prefer toilets housed in commercial establishments like malls and restaurants because such facilities address their functional, aesthetics, health, and safety needs influencing value fulfillment (Griffin 2008, Musa *et al.* 2022). Responses indicated how the physical environment could trigger intense fear and anxiety, particularly the adolescent's response expressed fear and perceived inability to use the facility when other persons are present or may enter the room. The hostile and scary indoor environment due to ill maintenance, the uncertainty of locks functions, etc., add to the insecurity in using the toilet.

Psychological dimensions

The psychosocial Dimension comprised the behavioral, social, or psychological determinants that governed respondents' toilet use. Due to poor sanitation, several stressors concerning the physical and social environment surfaced, rendering respondents physically vulnerable and psychologically distressed (Schouten and Mathenge 2010, O'Reilly and Louis 2014, Nelson *et al*. 2014, Biswas and Joshi 2021). In agreement with previous studies, the respondents had a mental map of public toilets; this perceived image governed their usage pattern in public toilets (Lowe 2018, Yan *et al*. 2021). Interview data unfolded many psychological aspects, such as anxiety, embracement that stimulated avoidance behaviors, and unwillingness to use public toilets. Quality of physical and social environments influencing personal safety contributed to the stress of using public toilet facilities, as per the responses of 12 out of 16 adolescents. Adolescents' heightened privacy issues due to inadequate physical separation between male and female toilets demonstrated the architectural implications of toilet design, indicating the need for a more inclusive environment in the public domain (Barcan 2005, Sanders and Stryker 2016). Besides, they associated public toilets with illicit activity. They felt shame and embracement due to the stigma they endured and felt ashamed even to be seen walking into a public toilet. The toilet use was contingent on the severity of urgency, particularly for the elderly and adolescents who need access to menstrual needs. However, adolescent respondents expressed using various behavioral strategies to manage or limit urgency in avoiding public toilet use. Participants, particularly women who used to be in Saree, expressed that they often use toilets to check their outfits and make-up; many used them to take a break, socialize, or find solitude. The pressing need for privacy to handle various practices, particularly for changing the menstrual material, was expressed when the PT environment was found un-supportive of upholding cultural practices and values (Nallari 2015, Sommer *et al*. 2015, Ramster *et al*. 2018, Maroko *et al*. 2021). The respondents, mainly working women, labeled public toilets unacceptable and tended to set up strategies to resist using them, such as ensure using the toilet before leaving home, taking less water intake, or seeking alternative locations like shopping malls or restaurants. Such compelling compromises lead to melancholy (Plaskow 2008).

Technological dimensions

Technological Dimension emerged, including the specific attributes that influence the adoption and sustained use of public toilets, including cubicle design in terms of available space, light, and ventilation, number of cubicles, maintenance, and cost. Young women from socially liberal, middle-class families in Pune enjoy the right to participate in the public sphere for work, education, or leisure. They access urban public spaces associated with bodily exposure functions of varied degrees, such as gyms; clothing shops; swimming pools; however, they are supposed to follow specific parameters of time, space, and dress and follow culturally coded social norms where bodily exposure is often unacceptable(Mathur 2008, Ellis *et al*. 2014). Many respondents who used to wear 'Saree' or 'Salwar kameez' experienced toilet use stressful due to the space crunch, flooded floors, and lack of facilities to hang accessories. Besides, the need for more time, the strange gaze of others waiting made them uncomfortable (Greed 2004, Barcan 2005, Ellis *et al*. 2014, Ramster *et al*. 2018). Women from middle and upper-income families usually move in private vehicles, particularly two-wheelers. Use may afford to access toilets located in public consumption locations, such as coffee shops and malls. However, others who rely on public transportation do not have other options to use and use public toilets when required. Although public toilets are provided in Pune to promote social life and facilitate public festivals and events, the women population's lack of maintenance and appropriateness remains persistent (Joshi 2018).

Conclusions

The finding of this research revealed the strong relationship between architectural designs in performing intimate activities to the effect that ignorance towards female friendly features in public toilets is no longer acceptable. The public toilet is associated with multiple dimensions of safety, ranging from possible sexual assault to physical harm, where the perception of safety varies across various life stages. It is revealed how the physical environment can trigger intense fear and anxiety, particularly adolescents who expressed fear and perceived inability to use public toilets when other persons are in the vicinity or may enter the room. Altruistic fear as a maternal caretaker appeared in middle-aged women for the safety of their teenage daughters concerning a potential danger of imminent and distal threat while accessing a public toilet. It is established that avoiding public toilets has very l little to do with the actual risk of assault or getting an infection and more with how users' brains are conditioned. This aspect calls for social engineering to destigmatize public toilet facilities eliminating the associated negativity with gender-sensitive architectural and planning intervention. The strategy to take leave on certain days to avoid accessing public toilets for menstruation needs revealed that this aspect is ignored in public toilet provisions causing social isolation and inactivity, preventing women from participating fully in social life and consequently losing millions of work hours. Although the provision of private and hygienic management of menstruation is a part of the Swachh Bharat Mission – Urban, access to products for menstruation is still not in place. This is revealed that the decisions to use public toilets manifest in various contextual influences of physical environmental, socioeconomic, and cultural factors. To address this issue the design of toilets should consider the peculiar needs of Indian women who are often in traditional outfits (draping Saree or Salwar kameez) with adequate size of cubicles and required facilities. Providing accessible toilets near nodes like temples and parks will support the social life of the elderly. Locating toilets not more than 400 m from a vital node is desirable to save elderly and pregnant women from exhaustion due to substantial physical exertion. Adequate supporting mechanisms such as railing or grab bars can eliminate apprehension about falling, facilitating elderly and physically challenged women to come out of the home environment and participate in socio-cultural and religious events. It has been found that women are psychologically more affected by disorderly behavior and messy environments. They reacted strongly to seeing deserted, dirty, and dingy places and expressed unwillingness to use such spaces. It is established that urban women's aspirations about public toilet facilities have gone beyond functionality, and they need a cheerful, refreshing, and hygienic environment that could be achieved with good architectural design. This research established that planning and designing public toilets with a gender-sensitive approach could facilitate the mobility of the women population in Indian cities, achieving equity in the urban environment.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Vasudha A. Gokhale is a Professor of Architecture from Dr. B.N. College of Architecture for Women, S.P. Pune University, India. Her research areas include Disaster Management, Gender studies, and architectural research.

Deepa Joshi is an associate professor at MLB College, Bhopal. She is an economist with interest in sociological research.

Anjali Acharya is a professor and Head of the Department of Forensic Science, Institute for Excellence in Higher Education(IEHE), Bhopal, India, currently researching crime against women.

ORCID

Vasudha A. Gokhale http://orcid.org/0000-0003-4819-7570
Deepa Joshi http://orcid.org/0009-0004-5800-0561
Anjali Acharya http://orcid.org/0009-0000-0074-5414

References

Afacan, Y. and Gurel, M.O., 2015. Public toilets: an exploratory study on the demands, needs, and expectations in Turkey. *Environment and planning B: planning and design*, 42 (2), 242–262. doi:10.1068/b130020p.

Anthony, K.H. and Dufresne, M., 2007. Potty parity in perspective: gender and family issues in planning and designing public restrooms. *Journal of planning literature*, 21 (3), 267–294. doi:10.1177/0885412206295846.

Banana, E., *et al.*, 2015. Sharing reflections on inclusive sanitation. *Environment and Urbanization*, 27 (1), 19–34. doi:10.1177/0956247815569702.

Banks, T.L., 2013. Toilets as a Feminist Issue: a True Story. In: *Feminist Legal Theories*. Routledge, 131–157. Available from: https://digitalcommons.law.umaryland.edu/fac_pubs/334?utm_source=digitalcommons.law.umaryland.edu%2Ffac_pubs%2F334&utm_medium=PDF&utm_campaign=PDFCoverPages.

Banzhaf, J.F., 2002. *Copy of recent "potty parity" complaint against the*. University of Michigan. Available from: http://banzhaf.net/pottyparity.html.

Barcan, R., 2005. Dirty spaces: communication and contamination in men's public toilets. *Journal of international women's studies*, 6 (2), 7–23. Available from: https://vc.bridgew.edu/jiws/vol6/iss2/2.

Bell, W., 1998. Women and community safety. *Bell planning associates South Australia*, 32, 11–73.

Belur, J., *et al.*, 2017. Perceptions of gender-based violence around public toilets in Mumbai slums. *International journal of comparative and applied criminal justice*, 41 (1–2), 63–78. doi:10.1080/01924036.2016.1240094.

Bharat, G.K. and Sarkar, S., 2016. *Swachh bharat mission (urban) towards cleaning India: a policy perspective*. New Delhi, India: TERI India.

Bichard, J., Hanson, J., and Greed, C., 2006. Away from home (public) toilet design: identifying user wants, needs and aspirations. In: *Designing accessible technology*. Springer London, 227–236. doi:10.1007/1-84628-365-5_23.

Bichard, J.A. and Knight, G., 2011. *Publicly accessible toilets: an inclusive design guide*. UK: Helen Hamlyn Centre for Design, Royal College of Art. https://researchonline.rca.ac.uk/id/eprint/440.

Bichard, J.A. and Knight, G., 2012. Improving public services through open data: public toilets. In: *Proceedings of the institution of civil engineers-municipal engineer*. (vol. 165, No. 3). Thomas Telford Ltd, 157–165. doi:10.1680/muen.12.00017.

Bisung, E. and Elliott, S.J., 2016. 'Everyone is exhausted and frustrated': exploring psychosocial impacts of the lack of access to safe water and adequate sanitation in Usoma, Kenya. *Journal of water, sanitation and hygiene for development*, 6 (2), 205–214. doi:10.2166/washdev.2016.122.

Biswas, D. and Joshi, S., 2021. Sanitation and gendered psychosocial stress in peri-urban Bangalore. *Development in practice*, 31 (4), 548–557. doi:10.1080/09614524.2020.1862762.

Blumenthal, D., 2014. *Little vast rooms of undoing: exploring identity and embodiment through public toilet spaces*. Rowman & Littlefield. Available from: https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.591922.

Borja-Vega, C., 2014. The effects of the total sanitation and sanitation marketing programme on gender and ethnic groups in indonesia. *Waterlines*, 33 (1), 55–70. doi:10.3362/1756-3488.2014.007.

Burra, S., Patel, S., and Kerr, T., 2003. Community-designed, built and managed toilet blocks in Indian cities. *Environment and urbanization*, 15 (2), 11–32. doi:10.1177/095624780301500202.

Caruso, B.A., *et al.*, 2018. The association between women's sanitation experiences and mental health: A cross-sectional study in Rural, Odisha India. *SSM-Population health*, 5, 257–266. doi:10.1016/j.ssmph.2018.06.005.

Chaudhary, A.L.K.A., 2017. Swachh Bharat mission-need, objective and impact. *International journal for research in management and pharmacy*, 6 (2), 24–28.

Cheng, S., *et al.*, 2018. Toilet revolution in China. *Journal of environmental management*, 216, 347–356. doi:10.1016/j.jenvman.2017.09.043.

Cooper, A., *et al.*, 2000. Rooms of their own: public toilets and gendered citizens in a New Zealand city, 1860-1940. *Gender, place and culture: a journal of feminist geography*, 7 (4), 417–433. doi:10.1080/713668884.

Corradi, G., Garcia-Garzon, E., and Barrada, J.R., 2020. The development of a public bathroom perception scale. *International journal of environmental research and public health*, 17 (21), 7817. doi:10.3390/ijerph17217817.

Dandabathula, G., *et al.*, 2019. Impact assessment of India's swachh bharat mission–clean India campaign on acute diarrheal disease outbreaks: yes, there is a positive change. *Journal of family medicine and primary care*, 8 (3), 1202. doi:10.4103/jfmpc.jfmpc_144_19.

Datta, A. and Ahmed, N., 2020. Intimate infrastructures: the rubrics of gendered safety and urban violence in Kerala, India. *Geoforum*, 110, 67–76. doi:10.1016/j.geoforum.2020.01.016.

Davis, H.F., 2018. Why the "transgender" bathroom controversy should make us rethink sex-segregated public bathrooms. *Politics, Groups & Identities*, 6 (2), 199–216. doi:10.1080/21565503.2017.1338971.

Doan, P.L., 2010. The tyranny of gendered spaces–reflections from beyond the gender dichotomy. *Gender, place & culture*, 17 (5), 635–654. doi:10.1080/0966369X.2010.503121.

Dreibelbis, R., *et al.*, 2013. The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. *BMC public health*, 13 (1), 1–13. doi:10.1186/1471-2458-13-1015.

Duong, S.A., 2021. Fostering Through Flushing: Reimagining the Public Toilet Typology. Available from: http://hdl.handle.net/2429/78133 .

Eck, J. and Weisburd, D.L., 2015. Crime places in crime theory. *Crime and place: Crime prevention studies*, 4. Available from: https://ssrn.com/abstract=2629856.

Ellis, S.J., McNeil, J., and Bailey, L., 2014. Gender, stage of transition and situational avoidance: a UK study of trans people's experiences. *Sexual and relationship therapy*, 29 (3), 351–364. doi:10.1080/14681994.2014.902925.

Ellisa, E. and Luana, L., 2022. Female restrooms in the tourist destination: how the socio-spatial conditions of public toilets influence women's perception of safety. *Journal of asian architecture and building engineering*, 21 (4), 1624–1639. doi:10.1080/13467581.2021.1941995.

Evans, A., 2019. How cities erode gender inequality: a new theory and evidence from cambodia. *Gender andsociety*, 33 (6), 961–984. doi:10.1177/0891243219865510.

Farajollahzadeh, S. and Hu, M., 2021. Potty Parity: Process Flexibility via Unisex Restroom. *Rotman School of Management Working Paper*, 3914880. doi:10.2139/ssrn.3914880.

Fileborn, B. and Marshall, L., 2020. Increasing public toilet safety for gender-diverse populations. *Architecture Australia*, 109 (5), 30.

Flanagan, M., 2014. Private needs, public space: public toilets provision in the anglo-Atlantic patriarchal city: London, Dublin, Toronto and Chicago. *Urban history*, 41 (2), 265–290. doi:10.1017/S0963926813000266.

Frøystad, K., 2020. Failing the third toilet test: Reflections on fieldwork, gender and Indian loos. *Ethnography*, 21 (2), 261–279. doi:10.1177/1466138118804262.

Fu, B., Xiao, X., and Li, J., 2022. Big data-driven measurement of the service capacity of public toilet facilities in China. *Applied sciences*, 12 (9), 4659. doi:10.3390/app12094659.

Garg, S. and Anand, T., 2015. Menstruation related myths in India: strategies for combating it. *Journal of Family Medicine and Primary Care*, 4 (2), 184.

Geisler, T.C., 2000. On public toilets in Beijing. *Journal of architectural education*, 53 (4), 216–219. doi:10.1162/104648800564626.

Gershenson, O., 2010. 9. The restroom revolution: unisex toilets and campus politics. *In*: H. Molotch and L. Noren, eds. *Toilet: public restrooms and the politics of sharing*. New York, USA: New York University Press, 191–207. doi:10.18574/nyu/9780814759646.003.0020.

Greed, C., June 2004. Public toilets: the need for compulsory provision. *Proceedings of the institution of civil engineers-municipal engineer*, 157 (2), 77–85. doi:10.1680/muen.2004.157.2.77.

Griffin, C.J., 2008. Workplace restroom policies in light of New Jersey's gender identity protection. *Rutgers law review*, 61, 409.m.

Hallberg, O., 2021. Public toilets in an intersectional perspective: –The call for change.

Hanson, J., Bichard, J., and Greed, C., 2007. *The Accessible Toilet Resource Manual*. London, University College London. Available from: https://discovery.ucl.ac.uk/4847/.

Hanson, S., 2010. Gender and mobility: new approaches for informing sustainability. *Gender, place & culture*, 17 (1), 5–23. doi:10.1080/09663690903498225.

Hartigan, S.M., *et al.*, 2020. Why do women not use the bathroom? Women's attitudes and beliefs on using public restrooms. *International journal of environmental research and public health*, 17 (6), 2053. doi:10.3390/ijerph17062053.

Hasan, S.F. and Rahman, F., 2021. Re thinking the public toilet of Dhaka city: an adaptable prototype design solution to improve the existing situation. *Creative space*, 9 (1), 1–14. doi:10.15415/cs.2021.91001.

Heijnen, M., *et al.*, 2015. Neighbour-shared versus communal latrines in urban slums: a cross-sectional study in Orissa, India exploring household demographics, accessibility, privacy, use and cleanliness. *Transactions of the royal society of tropical medicine and hygiene*, 109 (11), 690–699. doi:10.1093/trstmh/trv082.

Hobson, J., 2000. Sustainable sanitation: experiences in Pune with a municipal-NGO-community partnership. *Environment and urbanization*, 12 (2), 53–62. doi:10.1177/095624780001200205.

Hochbaum, R.S., 2019. Bathrooms as a homeless rights issue. *NCL review*, 98, 205. Available from: https://scholarship.law.unc.edu/nclr/vol98/iss2/2?utm_source=scholarship.law.unc.edu%2Fnclr%2Fvol98%2Fiss2%2F2&utm_medium=PDF&utm_campaign=PDFCoverPages.

Hollis, M.E., Felson, M., and Welsh, B.C., 2013. The capable guardian in routine activities theory: A theoretical and conceptual reappraisal. *Crime prevention and community safety*, 15 (1), 65–79. doi:10.1057/cpcs.2012.14.

Huh, W.T., *et al.*, 2019. The potty parity problem: Towards gender equality at restrooms in business facilities. *Socio-Economic planning sciences*, 68, 100666. doi:10.1016/j.seps.2018.11.003.

Isunju, J.B., *et al.*, 2011. Socio-economic aspects of improved sanitation in slums: a review. *Public health*, 125 (6), 368–376. doi:10.1016/j.puhe.2011.03.008.

Jain, A. and Subramanian, S.V., 2018. Intrinsic and instrumental perspectives to sanitation. *SSM-Population health*, 5, 267–269. doi:10.1016/j.ssmph.2018.07.005.

Jeffreys, S., July 2014. The politics of the toilet: a feminist response to the campaign to 'degender'a women's space. In: *Women's studies international forum*. (vol. 45). Pergamon, 42–51. doi:10.1016/j.wsif.2014.05.003.

Jones, C. and Slater, J., 2020. The toilet debate: stalling trans possibilities and defending 'women's protected spaces'. *The sociological review*, 68 (4), 834–851. doi:10.1177/0038026120934697.

Joshi, N., 2018. Low-income women's right to sanitation services in city public spaces: A study of waste picker women in Pune. *Environment and urbanization*, 30 (1), 249–264. doi:10.1177/0956247817744932.

Khosla, P. and Dhar, S., 2013. Safe access to basic infrastructure—More than pipes and taps. *In*: C. Whitzman, C. Legacy, F. Andrew, M.S. Klodawsky, and K. Viswanath, eds. *Building inclusive cities: women's safety and the right to the cities*. Florence: Routledge, 117–139.

Kitchin, R. and Law, R., 2001. The socio-spatial construction of (in) accessible public toilets. *Urban Studies*, 38 (2), 287–298. doi:10.1080/00420980124395.

Kogan, T.S., 2007. Sex-separation in public restrooms: law, architecture, and gender. *Michigan journal of gender & law*, 14, 1. Available from: https://repository.law.umich.edu/mjgl/vol14/iss1/1.

Koonan, S., 2019. Sanitation interventions in India: gender myopia and implications for gender equality. *Indian journal of gender studies*, 26 (1–2), 40–58. doi:10.1177/0971521518812114.

Kulkarni, S., O'Reilly, K., and Bhat, S., 2017. No relief: lived experiences of inadequate sanitation access of poor urban women in India. *Gender & development*, 25 (2), 167–183. doi:10.1080/13552074.2017.1331531.

Levy, K., 2010. Equal, but still separate: the constitutional debate of sex-segregated public restrooms in the twenty-first century. *Women's rights law reporter*, 32, 248.

Lowe, L., 2018. No place to go*: how public toilets fail our private needs*. UK: Melville House, Ltd.

Machunda, R., Moyo, F., and Mshida, H., 2020. Status Report on Gender and Inclusion Assessment for female friendly Public and Community Toilets in Babati Town Council-Manyara region.

Maroko, A.R., *et al.*, 2021. Public restrooms, periods, and people experiencing homelessness: an assessment of public toilets in high needs areas of Manhattan, New York. *PloS one*, 16 (6), e0252946. doi:10.1371/journal.pone.0252946.

Mathur, K., 2008. Body as space, body as site: bodily integrity and women's empowerment in India. *Economic and political weekly*, 43 (17), 54–63.

Molotch, H., 2010. Learning from the Loo. *Toilet: public restrooms and the politics of sharing*, 1–20. doi:10.18574/nyu/9780814759646.003.0004.

Moore, S.A., 2001. Facility hostility–sex discrimination and women's restrooms in the workplace. *Georgia law review*, 36, 599.

Moreira, F.D., Rezende, S., and Passos, F., 2022. Public toilets from the perspective of users: a case study in a public place, Brazil. *Journal of water and health*, 20 (1), 41–53. doi:10.2166/wh.2021.127.

Musa, H., Bashir, U.M., and Kyari, M.H., 2022. Evaluation of Health, Religious Factors, and Modern Technologies in Public Toilets During Hajj. *African Journal of Environment and Natural Science Research*, 5 (2), 66–85. doi:10.52589/AJENSRKRRNOFJM.

Nalavade, S.B., 2000. Changing geography of Pune urban area. *Journal of ecological society*, 13 (1), 5–7. doi:10.54081/JES.013/01.

Nallari, A., 2015. "All we want are toilets inside our homes!" the critical role of sanitation in the lives of urban poor adolescent girls in Bengaluru, India. *Environment and urbanization*, 27 (1), 73–88. doi:10.1177/0956247814563514.

Nelson, K.B., *et al.*, 2014. User perceptions of shared sanitation among rural households in Indonesia and Bangladesh. *PloS one*, 9 (8), e103886. doi:10.1371/journal.pone.0103886.

niua.org. 2018. Gender Responsive Guideline under the Swachh Bharat Mission – Urban (SBM-U). https://scbp.niua.org/sites/default/files/SBM-U%20Gender%20Responsive%20Guidelines.pdf.

Njeru, J.N., 2014. Rethinking public toilet technologies in Nairobi: the case of Ikotoilet facilities. *Journal of water, sanitation and hygiene for development*, 4 (2), 324–328. doi:10.2166/washdev.2014.109.

Nunbogu, A.M. and Elliott, S.J., 2022. Characterizing gender-based violence in the context of water, sanitation, and hygiene: A scoping review of evidence in low-and middle-income countries. *Water security*, 15, 100113. doi:10.1016/j.wasec.2022.100113.

O'Reilly, K. and Louis, E., 2014. The toilet tripod: understanding successful sanitation in rural India. *Health & place*, 29, 43–51. doi:10.1016/j.healthplace.2014.05.007.

Patel, V., 2003. Gender budget-A case study of India. Centre for advanced study in economics, University of Mumbai, *Working Paper UDE (CAS)*, 7 (7), 3–30.

Pathak, P., *et al.*, 2022. Key Drivers Influencing Tribal Communities to become Open Defecation Free: Case of Dantewada District, Chhattisgarh in India. Available from: https://repository.lboro.ac.uk/account/articles/9593033.

Pearce, R., Erikainen, S., and Vincent, B., 2020. TERF wars: an introduction. *The sociological review*, 68 (4), 677–698. doi:10.1177/0038026120934713.

Penner, B., 2005. Researching female public toilets: gendered spaces, disciplinary limits. *Journal of international women's studies*, 6 (2), 81–98. Available from: https://vc.bridgew.edu/jiws/vol6/iss2/6.

Plaskow, J., 2008. Embodiment, elimination, and the role of toilets in struggles for social justice. *CrossCurrents*, 58 (1), 51–64. Available from: http://www.jstor.org/stable/24461652.

Plaskow, J., 2016. Taking a break: toilets, gender, and disgust. *South Atlantic quarterly*, 115 (4), 748–754. doi:10.1215/00382876-3656147.

Platt, L.F. and Milam, S.R., 2018. Public discomfort with gender appearance-inconsistent bathroom use: the oppressive bind of bathroom laws for transgender individuals. *Gender Iisues*, 35 (3), 181–201. doi:10.1007/s12147-017-9197-6.

PMC, 2023. Pune Municipal Corporation. pmc.gov.in

Popkin, B.M., D'Anci, K.E., and Rosenberg, I.H., 2010. Water, hydration, and health. *Nutrition reviews*, 68 (8), 439–458. doi:10.1111/j.1753-4887.2010.00304.x.

Ramster, G., Greed, C., and Bichard, J.A., 2018. How inclusion can exclude: the case of public toilet provision for women. *Built environment*, 44 (1), 52–76. doi:10.2148/benv.44.1.52.

Reddy, Y.M., Raghavan, S., and Vedala, S.C., 2009. A narrative exposition on public toilet usage by women: A study from Warangal. *Indian journal of gender studies*, 26 (1–2), 108–137. doi:10.1177/0971521518808100.

Robinson, A. and Gnilo, M., 2016. Beyond ODF: a phased approach to rural sanitation development. *Sustainable sanitation for all: experiences, challenges, and innovations*, 9 (1), 155.

Roma, E. and Pugh, I., 2012. Toilets for health. Available from: http://researchonline.lshtm.ac.uk/790341/.

Rushin, S. and Carroll, J.E., 2017. Bathroom laws as status crimes. *Fordham law review*, 86, 1. Available from https://ssrn.com/abstract=3007770.

Sahoo, K.C., *et al.*, 2015. Sanitation-related psychosocial stress: A grounded theory study of women across the life-course in Odisha, India. *Social science & medicine*, 139, 80–89. doi:10.1016/j.socscimed.2015.06.031.

Sanders, J. and Stryker, S., 2016. Stalled: gender-neutral public bathrooms. *South Atlantic quarterly*, 115 (4), 779–788. doi:10.1215/00382876-3656191.

Satterthwaite, D., Mitlin, D., and Bartlett, S., 2015. Key sanitation issues: commitments, coverage, choice, context, co-production, costs, capital, citywide coverage. *Environment & urbanization, brief*, 27 (1), 1–6.

Schouten, M.A.C. and Mathenge, R.W., 2010. Communal sanitation alternatives for slums: A case study of Kibera, Kenya. *Physics and chemistry of the earth, parts A/B/C*, 35 (13–14), 815–822. doi:10.1016/j.pce.2010.07.002.

Sclar, G.D., *et al.*, 2018. Exploring the relationship between sanitation and mental and social well-being: a systematic review and qualitative synthesis. *Social science & medicine*, 217, 121–134. doi:10.1016/j.socscimed.2018.09.016.

Shannon, J.H. and Hunter, R.J., Jr, 2020. The Civil Rights Act of 1964: Beyond Race to Employment Discrimination Based on Sex: The'Three Letter Word'That Has Continued to Vex Society and the United States Supreme Court. *Journal of Social and Political Sciences*, 3 (3). doi:10.31014/aior.1991.03.03.196.

Shiras, T., *et al.*, 2018. Shared latrines in Maputo, Mozambique: exploring emotional well-being and psychosocial stress. *BMC international health and human rights*, 18 (1), 1–12. doi:10.1186/s12914-018-0169-z.

Singh, P.K., Jasilionis, D., and Oksuzyan, A., 2018. Gender difference in cognitive health among older Indian adults: A cross-sectional multilevel analysis. *SSM-Population health*, 5, 180–187. doi:10.1016/j.ssmph.2018.06.008.

Skeggs, B., May 2001. The toilet paper: femininity, class and mis-recognition. In:*Women's studies international forum*. (vol. 24, No. 3–4). Pergamon, 295–307. doi:10.1016/S0277-5395(01)00186-8.

Skoglund, A. and Holt, R., 2021. Spatially organizing future genders: an artistic intervention in the creation of a hir-toilet. *Human relations*, 74 (7), 1007–1032. doi:10.1177/0018726719899728.

Sommer, M., *et al.*, 2016. Managing menstruation in the workplace: an overlooked issue in low-and middle-income countries. *International journal for equity in health*, 15 (1), 1–5. doi:10.1186/s12939-016-0379-8.

Sommer, M., *et al.*, 2015. Violence, gender and WASH: spurring action on a complex, under-documented and sensitive topic. *Environment and urbanization*, 27 (1), 105–116. doi:10.1177/0956247814564528.

Srinivasan, R., 2015. Lack of toilets and violence against Indian women: empirical evidence and policy implications. *Available at SSRN 2612052*. doi:10.2139/ssrn.2612052.

Srinivasan, S. and Kulkarni, V.D., 2019. A study on preference of convenience foods by working segments of the information technology companies, Pune City. *Atithya: a journal of hospitality*, 5 (1), 62–70.

Ssekamatte, T., *et al.*, 2019. Opportunities and barriers to effective operation and maintenance of public toilets in informal settlements: perspectives from toilet operators in Kampala. *International journal of environmental health research*, 29 (4), 359–370. doi:10.1080/09603123.2018.1544610.

Suthar, P., Joshi, N.K., and Joshi, V., 2019. Study on the perception of Swachh Bharat Abhiyan and attitude towards cleanliness among the residents of urban Jodhpur. *Journal of family medicine and primary care*, 8 (10), 3136. doi:10.4103/jfmpc.jfmpc_502_19.

Tacoli, C. and Satterthwaite, D., 2013. Gender and urban change. *Environment and urbanization*, 25 (1), 3–8. doi:10.1177/0956247813479086.

Teunissen, D., *et al.*, 2006. "It can always happen": the impact of urinary incontinence on elderly men and women. *Scandinavian journal of primary health care*, 24 (3), 166–173. doi:10.1080/02813430600739371.

Thieme, T. and Koszmovszky, J.D., 2020. The toilet: unmentionable humanitarian object or luxury good? *Field actions science reports The journal of field actions*, (Special Issue 22), 30–33. Available from: http://journals.openedition.org/factsreports/6251.

UN, 2007. The need for latrines and toilets. Available from: http://googleweblight.com.

Vedachalam, S. and Riha, S.J., 2015. Who's the cleanest of them all? Sanitation scores in Indian cities. *Environment and urbanization*, 27 (1), 117–136. doi:10.1177/0956247814560978.

Viswanath, K. and Mehrotra, S.T., 2007. 'Shall we go out?'Women's safety in public spaces in delhi. *Economic and political weekly*, 1542–1548. Available from: https://www.jstor.org/stable/4419521.

Vyas, S., *et al.*, 2015. An overview of the predictors of symptomatic urinary tract infection among nursing students. *Annals of medical and health sciences research*, 5 (1), 54–58. doi:10.4103/2141-9248.149790.

Walker, J., Frediani, A.A., and Trani, J.F., 2013. Gender, difference and urban change: implications for the promotion of well-being? *Environment and urbanization*, 25 (1), 111–124. doi:10.1177/0956247812468996.

Wankhade, K., 2015. Urban sanitation in India: key shifts in the national policy frame. *Environment and urbanization*, 27 (2), 555–572. doi:10.1177/0956247814567058.

Warner, W.S., 2 September 1998). Cultural Influences that affect the acceptance of compost toilets: Psychology, religion and gender. International composting toilet news [online]. Available from: http://www.compostingtoilet.org/articles/wwarner.html.

White, L., 2021. 'I have to know where I can go': mundane mobilities and everyday public toilet access for people living with irritable bowel syndrome (IBS). *Social & cultural geography*, 24 (5), 1–19. doi:10.1080/14649365.2021.1975165.

Yan, R., *et al.*, 2021. Operating status of public toilets in the Hutong neighborhoods of Beijing: an empirical study. *Journal of environmental management*, 287, 112252. doi:10.1016/j.jenvman.2021.112252.