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“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

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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

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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.

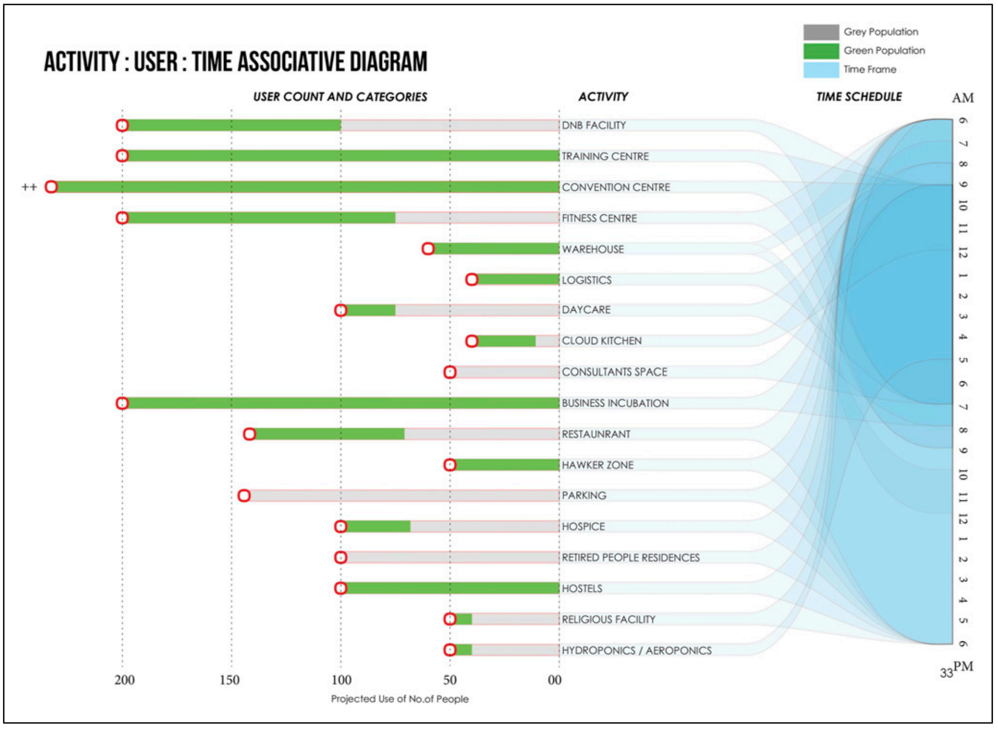

Figure 1. Data-based infographic to understand relations between the temporality of various activities and footfalls of users in a proposed hybrid program.

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.

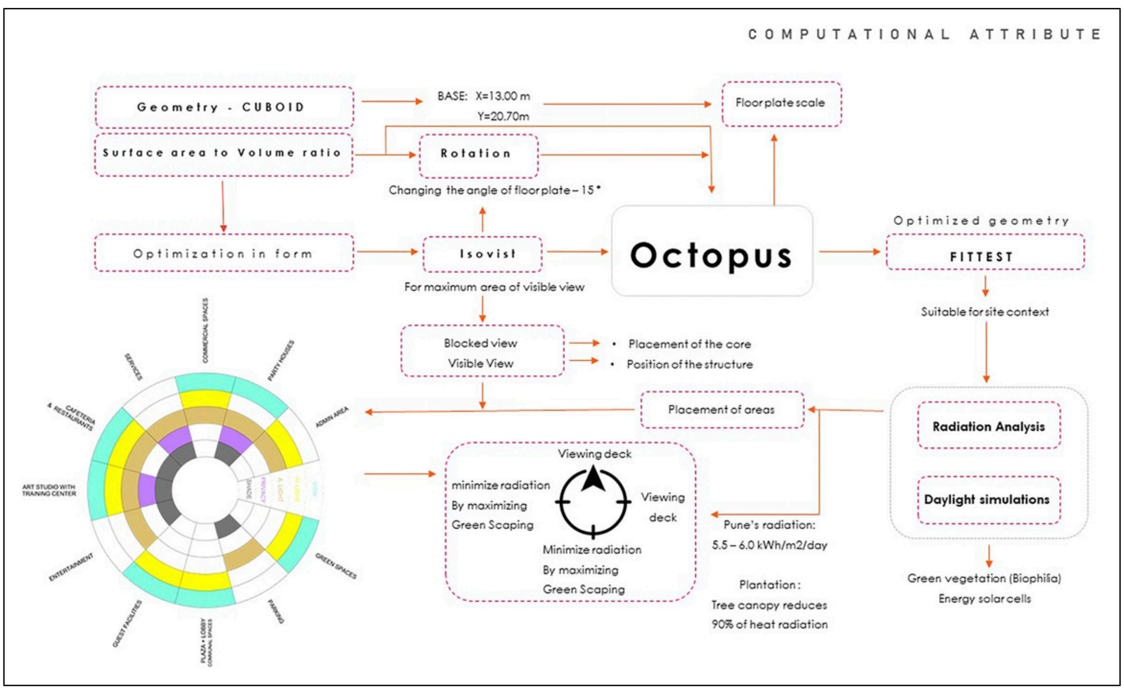

Figure 2. The diagram expressed as a flow chart/pseudocode shows an associative ecology explicitly showing external built-form geometry as a function of climatic analysis and afforded views.

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.

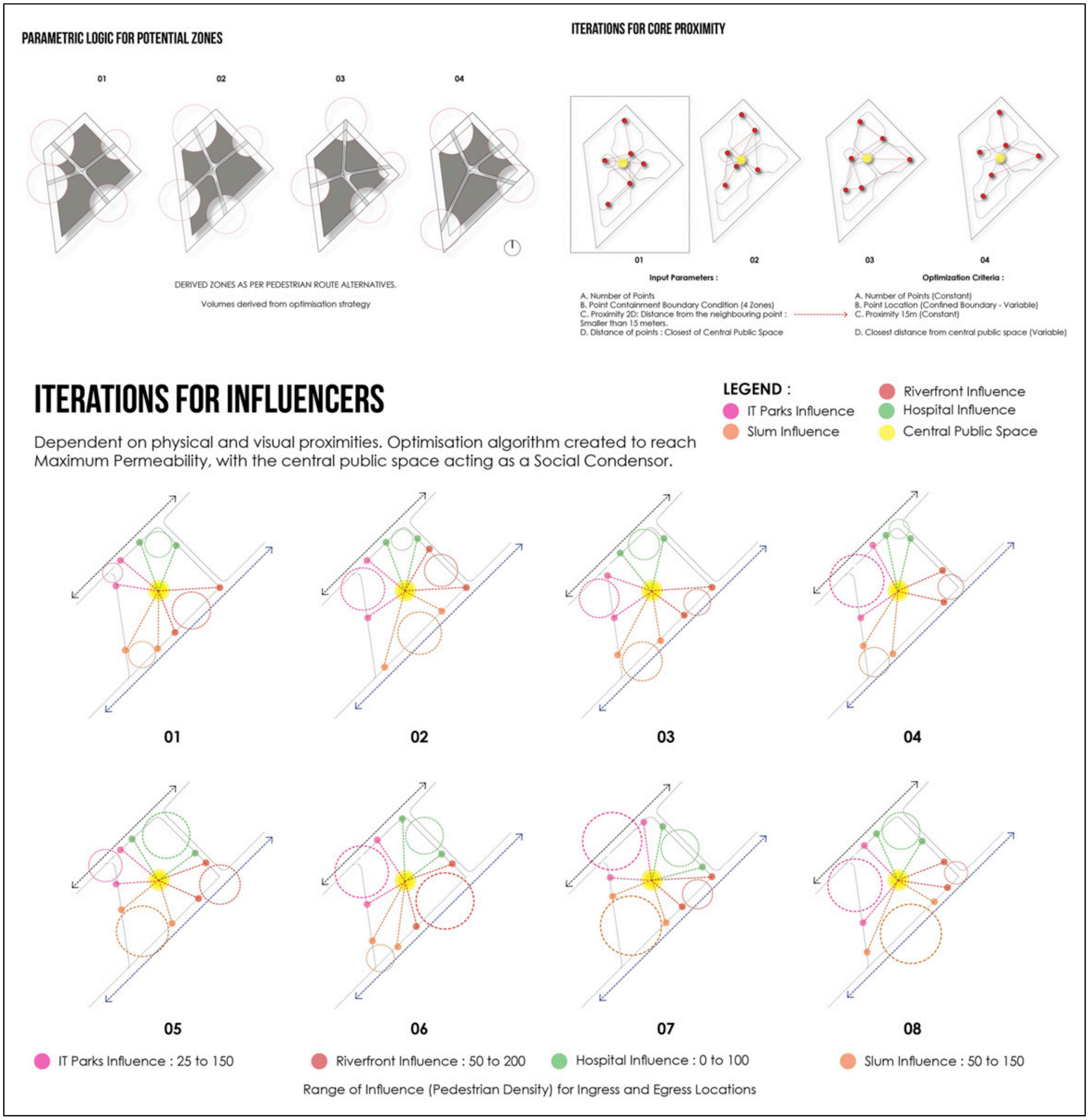

Figure 3. Understanding the influence of urban adjacency, varying radii are set to define the range of users, demarcating potential public zones, the shape of the podium, and the placement of cores based on distances and visibility logic.

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

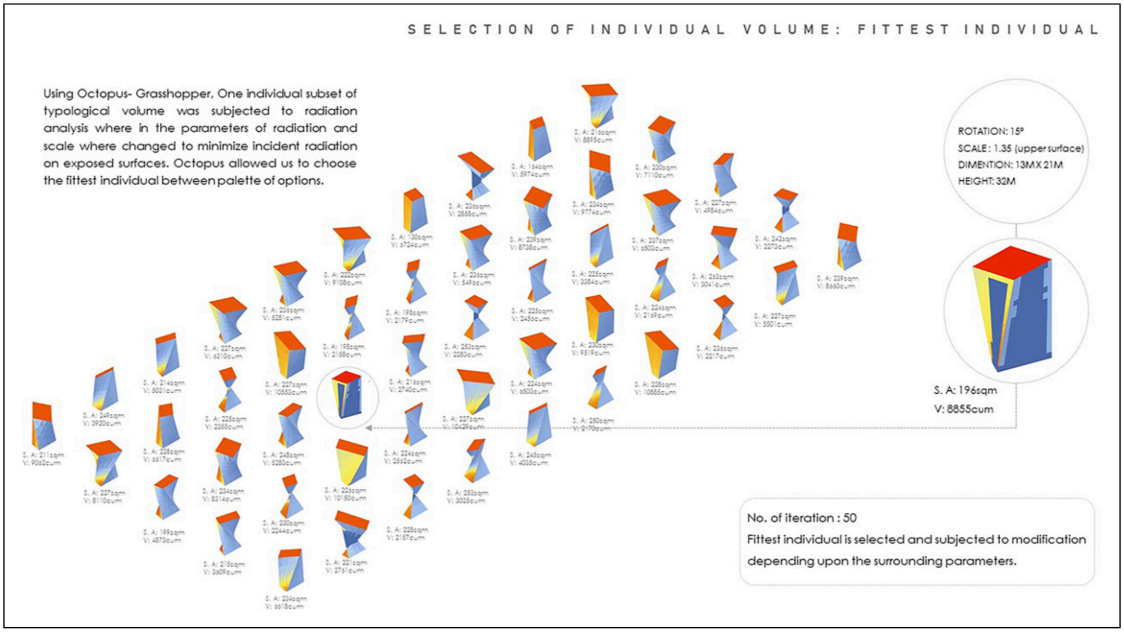

Figure 4. Optioneering through Octopus for optimum geometry that satisfies least heat gain, maximum view, and a usable functional floor-to-volume ratio.

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.

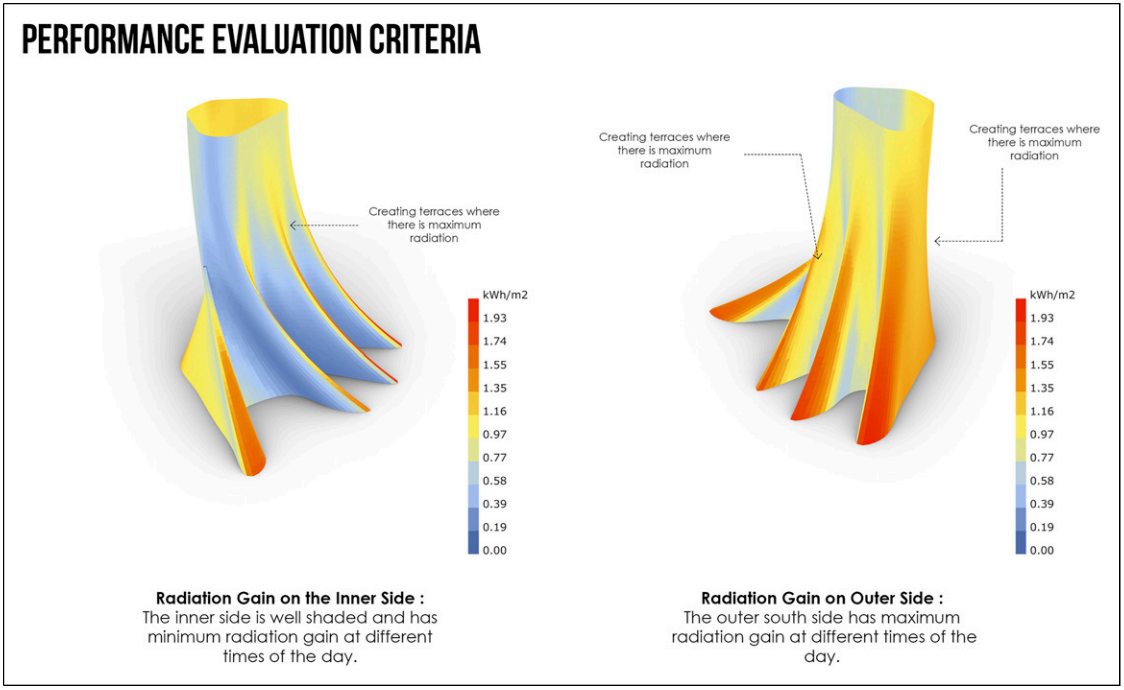

Figure 5. The graphic shows the use of daylight simulation using Ladybug to evaluate the heat gain response wrt the incident radiation on the built form.

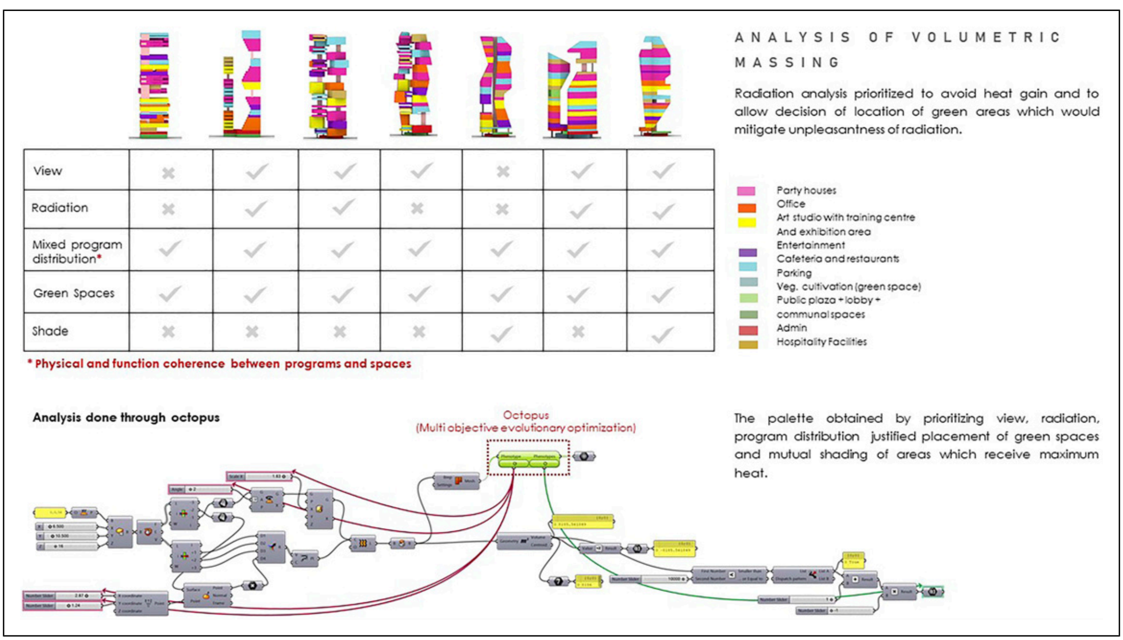

Figure 6. Optioneering as a product of multi-optimization criteria for exploratory massing options. Octopus as an evolutionary solver helps impartial scoring of parameters.

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

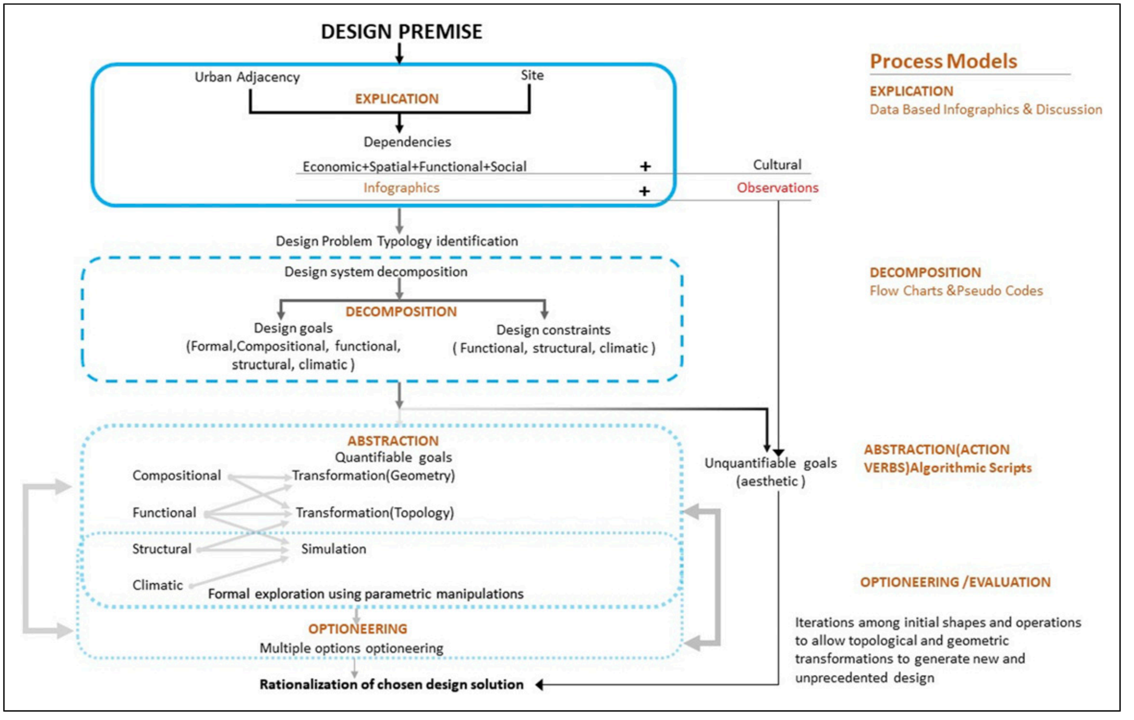

Figure 7. Diagram showing the author's perception of process interpretation and specific attributes of the parametric process. The incremental transparency indicates legibility and arrow thickness corresponds to the magnitude of iteration cycles. The subjective decisions are outliers but also contribute 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.

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