International Journal of Technology
http://ijtech.eng.ui.ac.id

Research Article

Abstraction–Reconstruction as a Lens for Computational Design Thinking: A Comparative Study of the Parametric Design Environment and Building Information Modeling-Based Modeling

Aswin Indraprastha[1*], Fauzan Alfi Agirachman[2], Rakhmat Fitranto Aditra[2]

[1]Architectural Design Research Group, School of Architecture, Planning, and Policy Development, Institut Teknologi Bandung, Bandung, 40132, Indonesia

[2]Building Technology Research Group, School of Architecture, Planning, and Policy Development, Institut Teknologi Bandung, Bandung, 40132, Indonesia

[*]Corresponding author: aswinindra@itb.ac.id; Tel.: +62-222504625; Fax: +62-222500046

Abstract: The rapid adoption of building information modeling (BIM) in architecture and engineering necessitates pedagogical frameworks that integrate computational design thinking into BIM education. However, this significant paradigm shift which focuses on psychomotor enhancement is often regarded as incremental. This paper introduces Abstraction-Reconstruction, a novel framework grounded in Piaget's formal operational stage theory and dual-process models of design and computational thinking, emphasizing iterative cycles of observation, abstraction, and algorithmic thinking. An empirical study was conducted involving 84 undergraduate students across multiple disciplines, of whom 50 were from Architecture, as part of a mini capstone project. The study compared parametric skill development across two environments, a Parametric Design Environment (PDE)/Visual Algorithm Editor (VAE) and a BIM system, using six performance indicators spanning Design Skills (DS) and Parametric Skills (PS), assessed with substantial inter-rater reliability (Fleiss's K = 0.72). The BIM system outperformed PDE/VAE in parametric skills, yielding more consistent design skill scores centered around 8.0, attributed to its object-oriented structure that scaffolds abstraction through hierarchical data relationships. In PDE/VAE, Explicit Reasoning was the strongest predictor of parametric performance ($\beta = 0.67$, $p < 0.001$; $R^2 = 0.48$–0.62), while Problem Definition was the dominant predictor in the BIM environment. Problem Abstraction and Parametric Generation demonstrated a near-perfect correlation ($r = 0.96$) in PDE/VAE, underscoring abstraction as the critical bridge between design and computational thinking. A post-course evaluation confirmed persistent challenges in generalizing abstraction while affirming that BIM fosters student confidence through structured workflows. This study validates Abstraction-Reconstruction as an effective pedagogical strategy, emphasizing the need to teach it as a dual cognitive process that integrates design intuition with algorithmic thinking to prepare students for evolving practices in the architecture, engineering, and construction industry.

Keywords: Abstraction-Reconstruction; Building information modeling; Computational design thinking; Parametric modeling; Pedagogical framework

1. Introduction

The discipline of architecture is undergoing a profound epistemological shift driven by the pervasive integration of computational technology. This transition moves beyond mere digitization and into a fundamental transformation of the design process itself. Computational methodologies such as parametric modeling, algorithmic design, and building information modelling (BIM) are redefining the very nature of architectural problems and their solutions. Where traditional design thinking relies on sequential and representational tools, computational platforms

https://doi.org/10.14716/ijtech.v17i2.7885
Received June 2025; Revised July 2025; Accepted December 2025

offer a dynamic environment for exploration where designers manipulate parameters, relationships, and constraints, engaging in a dialog with an intelligent model. This shift necessitates a parallel evolution in how architects are educated. For decades, the design studio has been the core of architectural pedagogy, rooted in the principles of reflective practice and learning-by-doing. However, simply introducing software tutorials into the existing model is insufficient. The challenge is no longer just about achieving tool proficiency and teaching students how to operate a specific software, but about fostering a new form of literacy: computational design thinking. This is a cognitive skill set that enables students to conceptualize problems in terms of structured information, algorithms, and data flows, and to see the computer as a collaborative partner in the creative process rather than a drafting tool.

Therefore, the current gap in architectural education is not merely a technical lag but a conceptual one. Curricula often treat computational courses as siloed technical skills, separate from the core design studio. This reinforces a disconnect where students may learn advanced modeling techniques but lack the conceptual framework to apply them in a truly generative, critical, and reflective manner. New pedagogical frameworks that explicitly integrate the cognitive modes of design thinking with the logical rigor of computational thinking are needed. Such frameworks must guide students in mastering the essential cycles of abstraction (deconstructing a design intent into logical rules and parameters) and reconstruction (synthesizing those rules into a coherent, evaluable whole within the computational environment).

This study addresses this critical need by proposing "abstraction–reconstruction" as a central lens for computational design thinking. It argues that architectural education can better equip students to navigate and lead the technologically mediated future of the profession by making these twin processes the focus of pedagogical strategies, particularly within the context of parametric BIM, transforming them from passive software users into active, creative, and critical computational designers.

2. Literature Study

2.1 Foundations of Design Thinking

The theoretical underpinnings of how designers think have been extensively studied. Cross, 2025 established design as a distinct "third culture" of thought, separate from scientific or artistic reasoning (Cross, 2025). In this study, Cross explains that architects and designers approach problems not by solving predefined issues but by constructing and reframing problems throughout the design process. They often begin by generating early solution ideas, using them as tools to better understand the problem itself. He characterized designerly ways of knowing as tackling ill-defined problems through a solution-focused, constructive mode, utilizing codes to translate abstract requirements into concrete objects. This process is fundamentally iterative and reflective. Another distinctive attribute of designer knowing and thinking is the cyclical discovery process, which involves analysis and synthesis. The designer is aware, consciously or unconsciously, that some ingredients must be added to the existing information to discover a unique solution. The inclusion of creative attempts during idea generation in the design process typically characterizes this ingredient (Cross, 2025).

Schon, 2017 famously described it as a "reflective conversation with the situation," where designers engage in reflection-in-action and reflection-on-action, allowing problems and solutions to co-evolve. Both are fundamentally focused on internal reflection, which is achieved by experiencing and attaining a deeper state of understanding (Schon, 2017). Furthermore, Schön argued that integrating new theories and techniques within the architectural studio system is essential for developing critical reflection in design thinking. The mode of thinking relies on sketching and modeling as tools for thinking (Goldschmidt, 1991).

Further elaborating on this non-linear process, Rowe, 1991 emphasized the concepts of "problem framing and design as a process of inquiry," highlighting how a problem's perception shapes its solution (Rowe, 1991). According to his work, there are two key concepts related to how the design process deals with problems:

1. Problem framing: how the perception or framing of a problem influences the direction and outcome of the design process.

2. Design as a Process of Inquiry: Designers oscillate between problem and solution, shaping each other through the process.

Furthermore, he presented the design process not as a linear problem-solving approach but as a reflective, iterative, and context-sensitive mode of inquiry, particularly well-suited for ill-defined problems, which are typical in architecture and urban design (Rowe, 1987).

The role of creativity in this process is paramount. De Bono, 1993 on lateral thinking and Csikszentmihalyi, 1996 on flow theory posit that specific techniques and environments can cultivate creativity. De Bono, 1993 argued that one must be trained to think outside the mainstream and existing thinking patterns to improve the deliberate and systematic generation of new ideas, concepts, and values through creativity. According to Csikszentmihalyi, 1996, creativity is a dynamic interplay between individual talent, motivation, domain knowledge, and social validation, all energized by the immersive, focused experience of flow Csikszentmihalyi, 1996. Provost and Sproul, 1996 supported these notions by indicating that creativity does not rely on natural talent but can be taught Provost and Sproul, 1996. Pressman, 2019 noted that the internalization of knowledge and the infusion of imagination are crucial for discovering unique and meaningful solutions (Pressman, 2019).

2.2 The Rise of Computational and Design Thinking

Computational thinking (CT), initially coined by Papert and later by Wing, refers to a cognitive ability and skill set that utilizes abstraction and decomposition to tackle complex tasks with the mindset of a computer scientist (Wing, 2008; Wing, 2006; Papert, 2020). Anyone can use computational thinking (CT) to solve problems including design problems, although it originated as a form of thinking mostly suitable for computer scientists. Recent research on CT highlights its pivotal role in educational settings and its integration with various disciplines, particularly with advancements in technology and design methodologies. Computational thinking encompasses critical skills such as abstraction, decomposition, algorithm design, and generalization, making it a multifaceted approach to problem-solving that extends beyond computer science to engineering, architecture, and education. Bonani et al., 2022 described CT as a collection of skills that facilitate the resolution of computational problems through the use of computing resources. Furthermore, the study defines CT as applicable to recurring problems, establishing that CT-derived solutions generalize across various contexts (Bonani et al., 2022). This versatility underscores CT's relevance in contemporary educational frameworks. This view is echoed in the findings of Chakraborty, 2024, who emphasizes the relationship between CT and computer science, positing that CT is essentially the application of CT concepts to real-world problems (Chakraborty, 2024).

This has led to a paradigm shift from computer-aided drafting (CAD) to computational design, where the computer is repositioned as an interactive medium for conceptualization and generation (Terzidis, 2006; Oxman, 2006). According to Terzidis and others, algorithmic methods facilitate exploration, invention, and discovery, making the algorithmic process itself an act of high-level abstraction that can yield intuitive-seeming results. Scholars like Pazini et al. (2020) directly link the advancements in parametric design to computational thinking practices. They assert that the algorithmic routines associated with parametric design illustrate how CT can facilitate sophisticated design solutions. Recent engineering implementations for performance-driven design have used computational design methods (Villaverde and Maneetham, 2024; Wijaya et al., 2024). This specific application of CT demonstrates its utility in fields that heavily depend on iterative, computational methods to develop innovative solutions Pospelov et al., 2023; Syafii et al., 2021; Kelly and Gero, 2021 proposed a dual process model emphasizing that both CT and design thinking can coexist and enhance problem-solving capabilities (Kelly and Gero, 2021).

This convergence has given rise to the concept of Computational Design Thinking (CDT), which embodies a systematic relationship between the creator, medium, and object (Oxman, 2017; Woodbury, 2010; Aish and Woodbury, 2005). In a search for a more comprehensive strategy to capture the dual-process model of thinking, which involves both acting and reflecting, some scholars have proposed the term CDT, which embodies a systematic and dynamic relationship and interaction between the creator, medium, and object (Carpo, 2017; Davis, 2013; Woodbury, 2010; Schumacher, 2009; Hensel et al., 2004). Moreover, algorithmic methods should be incorporated into the design process to be independently free from the process of computerization or digitalization involving tools and mediums of interaction to facilitate exploration and proactive engagement (Arisman et al., 2025). The algorithm process is an act of thinking in high-level abstraction. Although generally accepted as a rational and formal procedure, the algorithmic process can produce unpredictable or unobservable outputs and seem intuitive, akin to discovering a design solution.

The integration of computation into the design process is underpinned by two interrelated but distinct concepts: CT and CDT. Computational Thinking (CT) is a foundational problem-solving methodology, broadly defined by Wing, 2006 as a mental skill set that leverages concepts fundamental to computer science, such as abstraction, decomposition, pattern recognition, and algorithm design. It is a general-purpose approach applicable to any complex system, from logistics management to scientific research. In essence, CT is about creating problems and their solutions in a way that a computer or a human thinking logically can effectively execute. CDT is the specific application and adaptation of CT principles within the unique context of design domains such as architecture. While CT provides the logical framework, CDT integrates it with the core tenets of designerly ways of knowing (Cross, 2025). It is not merely about solving a predefined problem efficiently; it is about using computational processes to explore, generate, and iteratively reframe design problems and solutions.

2.3 Research Gap in Architectural Education

Despite this robust theoretical landscape, computational design thinking's pedagogical application remains underexplored. While the framework is promising for bridging intuitive and algorithmic reasoning, there is limited inquiry into how its core processes, specifically abstraction and reconstruction, can be explicitly taught and internalized by students within integrated environments, such as Parametric BIM. This study seeks to fill this void by developing a conceptual framework that makes these processes the central lens for CDE.

3. Methods

3.1 Research design

This study was conducted through a collaborative studio of five multidisciplinary departments within the university: Architecture, Interior Design, Engineering Physics, Civil Engineering, Mechanical Engineering, Environmental Engineering, and Electrical Engineering. A total of 84 fourth-year undergraduate students participated in this program, of which 50 were from the Department of Architecture. The studio functioned as both a mini-capstone and an elective course to enhance collaborative design practices through the integration of information technology. A core component of the studio was a mandatory workshop series on parametric design and building information modelling (BIM), tailored for architecture students. The objective of this study was to introduce the foundational concepts of parametric design and BIM within the context of early-stage design thinking, modeling strategies, and analytical reasoning. BIM was positioned as a modeling tool and platform for interdisciplinary information exchange and integrated design development within a digital workflow.

The parametric design workshop focused on introducing students to computational design logic, emphasizing key aspects of computational thinking, including problem decomposition, abstraction, pattern recognition, and algorithmic reasoning. Students developed simple scripts to explore the relationship between parameters and geometric outcomes. The BIM workshop extended this learning into a structured environment, where students applied parametric principles within a BIM platform to model and manipulate building elements and their associated data. Each workshop included assignments designed to assess conceptual understanding and technical proficiency.

After the studio session, a post-course review and evaluation were conducted to assess the effectiveness of the methodology and instructional approach. A structured questionnaire was distributed to collect students' reflections and responses, and quantitative data were visualized for comparative analysis and interpretation. This multi-method evaluation aimed to capture both cognitive and technical outcomes related to the integration of computational design thinking within a parametric BIM environment.

A workflow diagram highlighting the research framework is depicted in Figure 1 below:

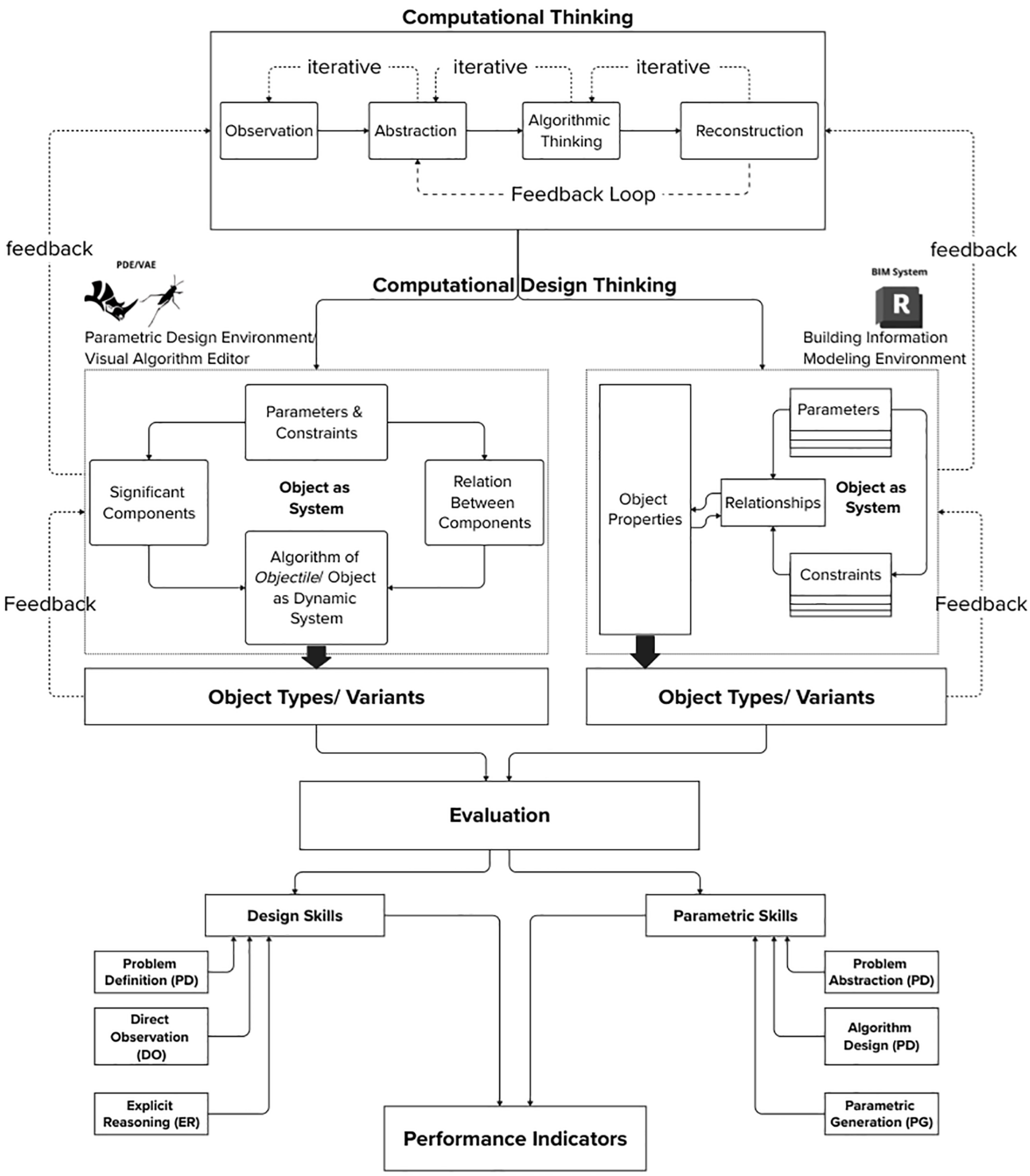

Figure 1 Research framework highlighting the workflow

We conducted a series of exploratory exercises using parametric modeling for parametric modeling in both the parametric design environment (PDE)/visual algorithm editor (VAE) and building information modeling (BIM) systems to promote understanding and reasoning. The basic premise is to enhance abstract thinking and skills through parametric thinking. This exercise reconstructs a real object and then expands the object's characteristics through parametric exploration. Students are required to explicitly explain the design process through two stages:

1. Defining the characteristics and construction of an object and finding the pattern.

2. Reconstruct the object and explore the alternatives.

The experiment was conducted using Rhinoceros and Grasshopper as PDE/VAE and Autodesk Revit as BIM authoring tool (Oxman, 2017; (Bhooshan, 2017). The students were given assignments to reconstruct real objects using parametric modeling. We required students to explicitly describe the sequence of abstracting and constructing the model to explore the understanding of abstraction–reconstruction between design skills and parametric skills. The performance indicators provide a structured evaluation framework used to assess students' capabilities in two main areas: design skills (DS) and parametric skills (PS), a method established in comparative design studies (Schnabel and Ham, 2012; Bilda and Demirkan, 2003). The indicators were categorized into Design Skills and Parametric Skills, with each category further broken down into specific criteria. Performance was rated on a three-level scale (Fair, Good, and Best), an approach aligned with competency-based frameworks used in digital design education (Zhang et al., 2017). Based on score ranges, each of these skill sets is broken down into more specific criteria, and performance is rated on a three-level scale: Fair, Good, and Best.

1. Design Skills (DS): It refers to a student's ability to engage with design problems using traditional and creative design thinking processes. These skills are rooted in architectural reasoning, spatial understanding, contextual interpretation, and problem framing. This category focuses on how well students understand and develop design problems, observe and interpret data, and reason through their design decisions (Schon, 1983) . The key features of DS include the following:

   (a) *Problem Definition (PD):* Students demonstrate the ability to clearly identify and articulate design problems, framing them in terms of user needs, environmental constraints, and functional requirements.

   (b) *Holistic/Direct Observation (DO):* Emphasizing how students interpret the context through direct site engagement or holistic synthesis. This includes sensory, spatial, and social readings of the built environment.

   (c) *Explicit Reasoning (ER):* Measures the clarity with which students articulate their design rationale. It reflects their ability to logically connect observations, analyses, and intentions into coherent concepts.

2. Parametric Skills (PS): This relates to a student's ability to operate within computational design environments. These skills reflect computational thinking, in which abstraction, logic, and algorithmic processes play central roles. In contrast to design skills, parametric skills require technical fluency, logical structuring, and the ability to shift from intuition to computation (Terzidis, 2006). The key features of PS include the following:

   (a) *Problem Abstraction (PA):* Students abstract real-world design challenges into a set of controllable parameters or variables suitable for algorithmic manipulation. This involves identifying relationships, constraints, and rules.

   (b) *Algorithmic Design (AD):* Refers to the student's ability to translate design logic into rule-based systems or scripts using PDE/VAE or BIM. It reflects a structured, often non-linear, way of thinking.

(c) *Parametric Generation (PG):* Focuses on how students use PDE/VAE and BIM to generate and manipulate geometry based on the defined parameters. This includes responsiveness to change and iterative refinement.

A grading calibration session was conducted prior to assessment to ensure consistency and objectivity in evaluating student performance across both the PDE/VAE and BIM environments. Four faculty members with expertise in computational design participated in this study. A standardized rubric based on the performance indicators described in Table 1 was reviewed and refined through a discussion of student submissions from a pilot cohort. Each evaluator independently scored the same set of 10 anonymized student works using the rubric, after which the inter-rater reliability was assessed using Fleiss's kappa coefficient, achieving a value of 0.72, indicating substantial agreement. For the primary assessment, to minimize bias, evaluators were assigned distinct sets of students, and periodic cross-checks were conducted to ensure consistency in grading. Any discrepancies or borderline cases were resolved collaboratively in review coordination meetings to ensure that a shared interpretive standard was reflected in the final grades.

The performance indicators of each skill were determined and given to the student as grading criteria as follows:

Table 1 Performance indicators of parametric modeling

Criteria	Fair	Good	Best
1. Design Skills (DS):	$n < 6.5$	$6.5 \leq n < 8.5$	$8.5 \leq n$
a. Problem Definition (PD)			
b. Holistic/Direct Observation (DO)			
c. Explicit Reasoning (ER)			
2. Parametric Skills (PS):	$n < 6.5$	$6.5 \leq n < 8.5$	$8.5 \leq n$
a. Problem Abstraction (PA)			
b. Algorithmic Design (AD)			
c. Parametric Generation (PG)			

3.2 Experiment on Abstract Thinking and Parametric Modeling in Parametric Design Environment (PDE)/Visual Algorithm Editor(VAE)

In the context of managing and controlling information flows during the design process, maintaining the designer's centrality as a visual thinker is crucial. As computational design evolves, designers' ability to engage with abstract thinking and parametric modeling within visual algorithm editors becomes increasingly essential for effective information management and control. Oxman, 2006 proposed an operational conceptual framework of information flows during the design process in the form of quadratic domains of representation, evaluation, performance, and generation, as computational design flows present multimodal and explicit interactions. (Oxman, 2006).

Understanding relationships and explicit rules between parameters and operators is an inherent aspect of parametric modeling. Woodbury, 2010 suggested that in parametric modeling, the designer establishes relationships with interconnected parts (or assemblages) and builds up, edits, observes, and selects a design using these relationships (Woodbury, 2010). In a recent development, Yu et al., 2021 summarized parametric modeling as a technique that provides a formal, descriptive, and generative design framework through parameters and their associative relations, allowing designers to change input values to generate and optimize designs and variations (Yu et al., 2021). As the most significant part of the formal notation on relationship creation in the parametric method, abstraction or abstract thinking is usually associated with a concept's vagueness or generalization. Architects and designers reach the first stage of the design process, known as synthesis, through ideation, where the creative process generates ideas (Mueller, 2018). In a more recent study, Wang and Han, 2023 noted that while the exact mechanisms of ideation processes require further exploration, the impact of creativity in these early stages is critical for achieving innovative outcomes in design (Wang and Han, 2023). This assertion confirms the findings of Hay et al., 2019, who argued that higher-order executive processes, such as evaluation and decision-making, work in tandem with idea generation, highlighting the complex cognitive processes involved in ideation (Hay et al., 2019).

In this context, abstract thinking generates the base design idea, which in turn generates design solutions. In computer science, an abstraction is the act of filtering out inessential details, identifying patterns, and generalizing concepts from a construct, system, or object. Abstract thinking has two aspects in both contexts: removing details and generalization, which are essential in computational modeling. Abstraction thinking is essential for manipulating and reasoning about abstraction, and abstraction skills are crucial for designing and constructing models that serve a specific purpose (Kramer, 2007). Abstraction and parametric modeling are closely related because designers are familiar with and practice using abstraction and parameters, such as dimensional modules, structural centerlines, and functional requirements.

To obtain and generate an abstraction of a particular concept, problem, or object, one must be able to observe it holistically and understand the built-up system, as depicted in Figure 2.

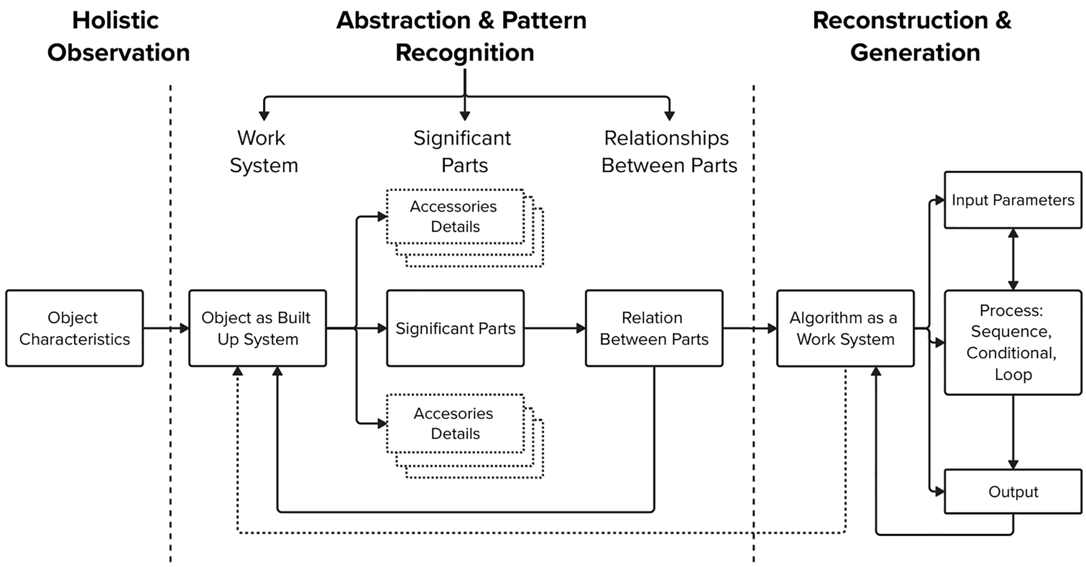

Figure 2 Diagram of observation, abstraction, and reconstruction in the parametric design environment

As proposed in the Cognitive Development theory developed by Piaget, the ability to think abstractly and hypothetically is fundamental for professionals working in fields that integrate design and computational methods, particularly the fourth formal operational stage, where individuals indicate an ability to think abstractly, systematically, and hypothetically (Piaget, 2013). Deng et al., 2022 conducted a significant study that emphasized the importance of fostering computational thinking skills within educational contexts. Integrating computational methods within design education enhances students' ability to engage in abstract reasoning and systematically tackle complex design problems (Deng et al., 2022).

Ospina and Sánchez argue for the importance of design thinking as a pedagogical framework that supports the development of effective learning strategies in students. Fostering a design-oriented mindset among learners can help overcome cognitive barriers to innovation, a common occurrence before reaching Piaget's fourth stage (Ospina and Sánchez, 2022). Additionally, Klenner et al., 2021 assert that iterative experimentation is crucial in developing design thinking competency. This practice aligns with Piagetian principles by encouraging students to hypothesize, test, and revise their approaches, ultimately improving their capacities for abstract thought and problem-solving (Klenner et al., 2021). In summary, recent literature supports the notion that Piaget's theory-informed educational practices can significantly enhance the development of abstract and systematic thinking in students, especially when integrated within computational design thinking frameworks.

3.3 Experiment on Abstract Thinking and Parametric Modeling in the Building Information Modeling (BIM) environment

The growing mandate for building information modeling (BIM) in the architecture, engineering, and construction industry underscores a broader transformation toward sustainable and data-driven methodologies. This shift compels academic institutions to develop pedagogical frameworks that integrate CDT, parametric modeling, and BIM. Specifically, BIM's object-oriented, information-based approach challenges academia to redefine fundamental design concepts, such as abstraction and data structure, within digital objects.

In the context of BIM as a platform and methodology, the workflow of abstraction to the construction of a design object requires a shift in design thinking, where the design process is regarded as a process to simulate building construction. Kolarevic, 2004 posited that digitally driven design, process, and production technologies are envisioned more comprehensively than as mere tools, to be fully embraced as ways of thinking in and of themselves.(Kolarevic, 2004) Furthermore, Ambrose suggested positioning BIM as a new way of thinking, prioritizing a combination of the traditional approach of abstraction and the opportunity of synthetic simulation, where the design process must reflect new iterative relationships between design intention, data, and communication (Ambrose, 2012).

As a relational database, BIM is built upon parametric modeling within a rigid data structure. In BIM, the relationship between a shape's dimensions and behaviors within a building component is encapsulated in a hierarchical data structure that categorizes building elements based on their function and behavior. As with the understanding of parametric modeling, abstraction plays a significant role in dissecting and reconstructing ideas during the design process to gain the full potential of BIM as a way of thinking. Holzer, 2015 showed that the design quality of BIM depends on a deeper understanding of the construction process of a building, and skills in parametric design help foster students' ability to think critically and adapt to a rapidly changing environment (Holzer, 2015).

A key challenge in examining computational thinking in the design process is to observe how problem decomposition, pattern recognition, abstraction, and ultimately, generating design solutions are based on understanding the algorithmic process. As advised by Burry, 2013, the primary process of abstraction and reconstruction allows students to think of a technique or a process rather than an object (Burry, 2013).

In this study, we experimented with parametric modeling of a building component to address these challenges and integrate parametric methodology into the BIM design system. The objective of this study is to understand a building component as a system of interrelated parts. The process of abstraction-reconstruction involves synthesizing the inherent understanding of the building system. The student developed the investigative ability to examine details, materials, the formation of built-up elements, their dependencies, and design variations through parametric modeling of a constructed building component.

Our study focused on the assignment of two building components: the wall and the window. In an Autodesk Revit BIM system, Walls and Windows are two examples of different elements. The wall is defined as a host element, and the window is defined as a hosted/component element. Both have intrinsic parameters or attributes that define particular characteristics and reflect the object's representation and behavior.

Students were required to design and generate design variations of both elements based on the parameters. Students explored and attempted to define the intrinsic flexibility associated with a particular wall and window design. They could manipulate parametric components and interactively examine design variations. The development of a mechanism for maximum customization of the elements, allowing designers to choose and modify elements with greater flexibility, is a key aspect to emphasize.

4. Results and Discussion

4.1 Abstraction-Reconstruction in a PDE/VAE Environment

In a PDE/VAE environment, the students' works were subsequently evaluated by faculty members using an established assessment rubric. The example of our experiment (Figure 3) provides an explicit development of abstract thinking through parametric modeling using simple everyday object cases. Students implement abstraction on each sample by developing rules or workflows to achieve a particular output at any stage. In the process, students are trained to create a design system using an algorithm. A system that consists of interrelated flows among input, process, and output. The goal of developing a system in parametric modeling is to create an Objectile (Deleuze, 2017; Carpo, 2017) , which refers to the entire set of typological variations of a group of generic objects or variants that share inherent qualities (Hales, 2025; Lobach, 2021; Tepehan, 2021; Haeusler et al., 2018).

A boxplot visualization is employed based on grading scores assigned by instructors to 50 participating students, using six statistical indicators: minimum, lower quartile, median, average, upper quartile, and maximum, to facilitate a comparative analysis of the overall distribution of design skills and parametric modeling competencies. Figure 4 illustrates the distribution of both the overall design skills and parametric skills indicators across the student cohort.

The figure shows that the Design Skill indicators: Problem Definition (PD), Holistic/Direct Observation (DO), and Explicit Reasoning (ER), exhibit greater central tendency and lower variability compared to the Parametric Skill indicators: Problem Abstraction (PA), Algorithmic Design (AD), and Parametric Generation (PG). Overall, design skills are more consistently understood across the student cohort, with most students demonstrating a similar level of cognitive ability in developing reasoning for sequential modeling tasks. In contrast, the Parametric Skill indicators display wider dispersion, demonstrating greater variability in student comprehension. Notably, AD shows the broadest distribution in performance (range: 9.5–6.2), which establishes significant differences in students' grasp of this concept and dictates more advanced cognitive engagement. Exploring the correlation between design skills and parametric skills reveals significant relationships between these two skills sets. The most significant correlations are as follows: 1) Explicit Reasoning with Parametric Generation (0.85), which suggests that higher reasoning ability is strongly associated with higher parametric generation performance; 2) Problem abstraction and Parametric Generation (0.96), indicating a firm relationship between these two skills. This underscores the critical importance of two core design skills: explicit reasoning and problem definition, within parametric modeling skills, with a specific emphasis on parametric generation proficiency. Furthermore, a multiple regression analysis was conducted to identify the design skills (predictors) that are the most significant factors in predicting the parametric skills (outcomes). The summary is as follows:

- Explicit Reasoning serves as the most significant predictor for all three Parametric Skills outcomes: Problem Abstraction, Algorithmic Design, and Parametric Generation. For instance, the regression coefficient for ER predicting PG ($\beta = 0.67$, $p < 0.001$) establishes a statistically significant and strong positive association. Similarly, ER exerts significant predictive power for PA ($\beta = 0.55$, $p < 0.01$) and AD ($\beta = 0.42$, $p < 0.05$). In contrast, the lower coefficients and higher p-values ($p > 0.1$) for PD and DO demonstrate their non-significant influence.

- The R^2 values for the models ranged from 0.48 to 0.62, indicating moderate-to-strong explanatory power.

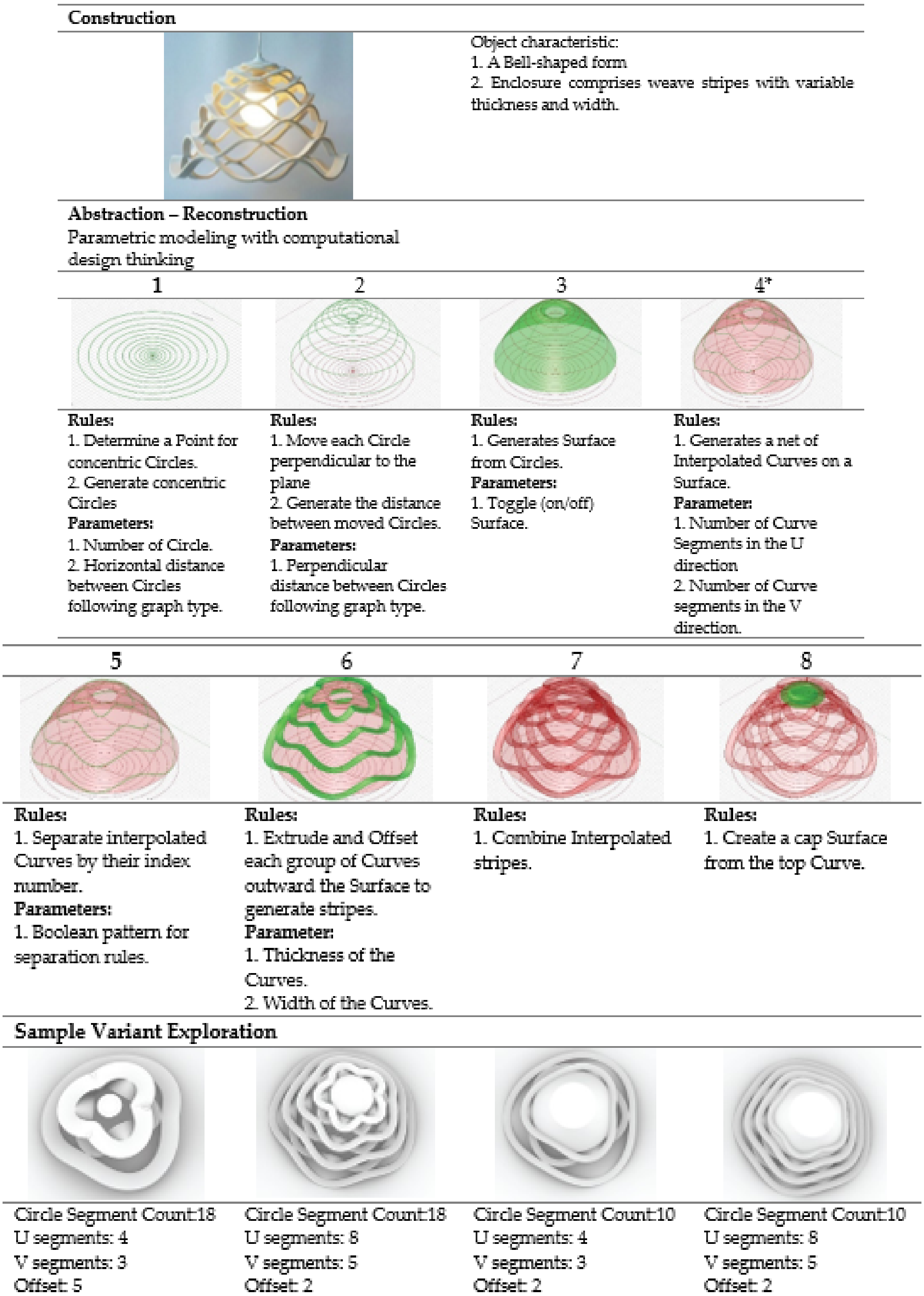

Figure 3 Case 1: Parametric exploration through Abstraction-Reconstruction of an object

- Based on the p-values, problem definition and holistic and direct observation have less significant impacts in predicting parametric skills.
- These findings support the hypothesis that explicit reasoning is a key cognitive skill underpinning students' capacity for computational modeling, especially in algorithmic tasks.

The line diagram in Figure 5 provides a clear visual representation of the regression coefficients for three parametric skills (Problem Abstraction, Algorithmic Design, and Parametric Generation) with respect to the design skills (Problem Definition, Holistic and Direct Observation, and Explicit Reasoning). Explicit reasoning should be prioritized when aiming to improve parametric skills, as it has the most substantial and positive influence. While Holistic and Direct Observation and Problem Definition contribute to parametric skill outcomes, their influence is weaker. Focus could be given to improving explicit reasoning to enhance problem abstraction, algorithmic design, and parametric generation. This analysis provides valuable insights into the relative contributions of design skills toward the development of parametric skills and can inform strategies for targeted skill improvement.

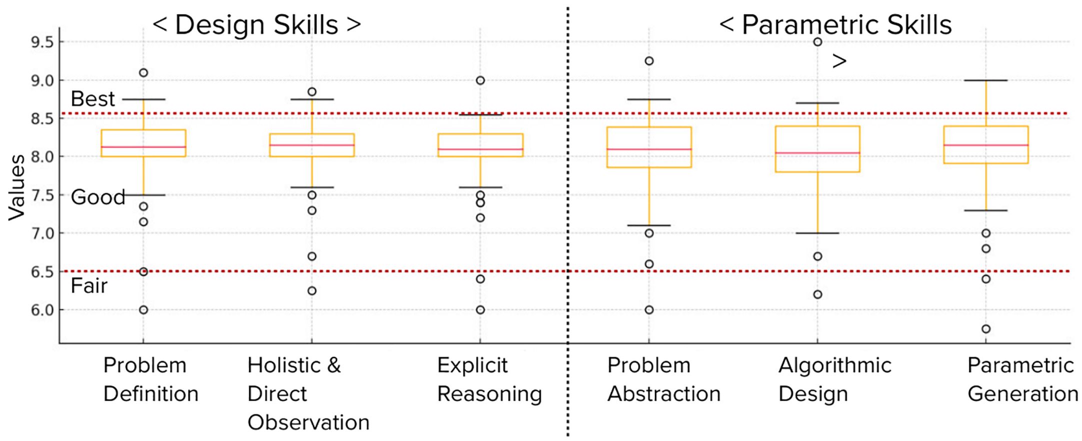

Figure 4 Distribution of Abstraction-Reconstruction Design and Parametric Skills in PDE-VAE

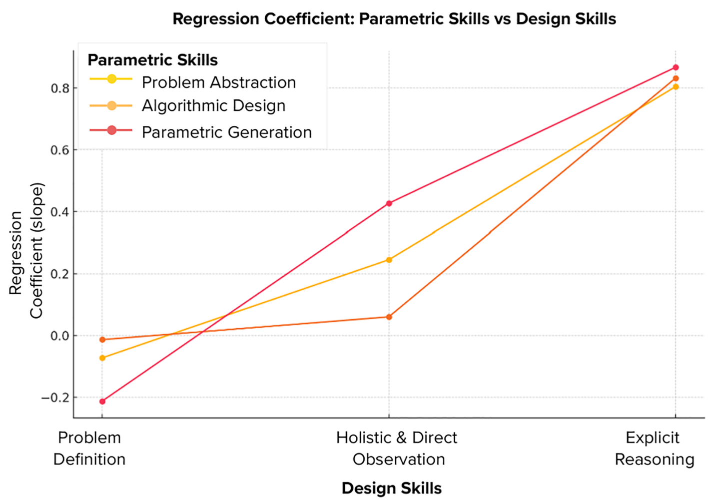

Figure 5 Regression coefficient for Parametric Skills in PDE/VAE indicating that explicit reasoning is a significant factor in improving parametric modeling skills

4.2 Abstraction reconstruction in a BIM system

The BIM system supports parametric modeling through a system that significantly differs in workflow from that of a PDE/VAE. The sample result (Figure 6) provides examples of the abstraction and reconstruction of the parametric modeling BIM system. Parametric modeling is encapsulated within layers of the object's attributes and behaviors within hierarchical BIM objects and data structures. In this example, the Host Component (e.g., Wall) and the Hosted Component (e.g., Window) were first designed and developed based on their parametric dimensions according to the overall design and their elements, followed by other parametric attributes such as behavior and materials.

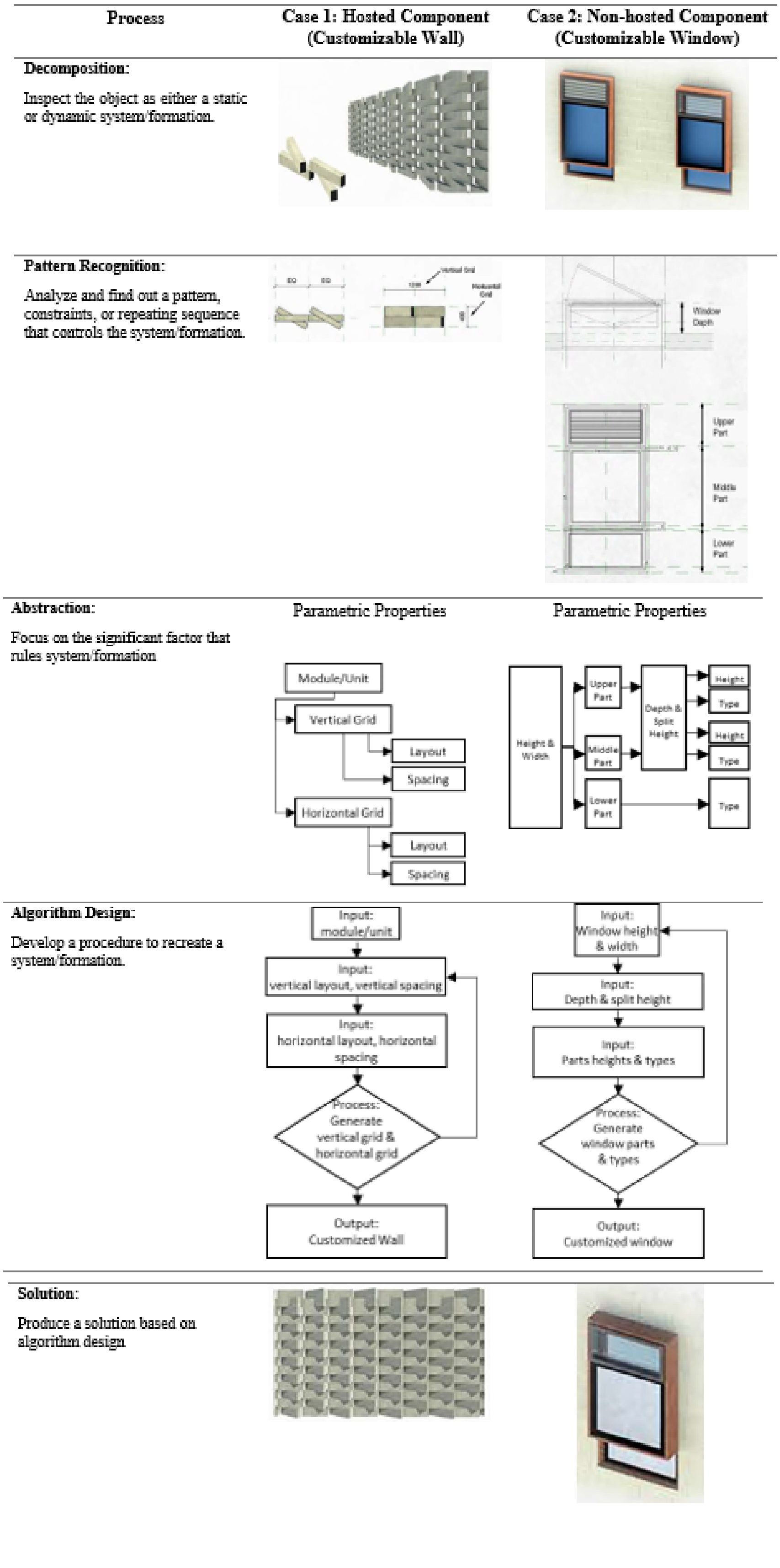

Figure 6 Case study: Parametric modeling process of wall and window in BIM system

Although both approaches are grounded in the same underlying principle of parametric design, the cognitive processes involved in abstraction and reconstruction vary between the two approaches. The BIM system integrates parametric capabilities within a more structured, object-oriented modeling framework, where abstraction often occurs through the manipulation of predefined object parameters and relationships. The act of reconstructing a design solution involves different modes of reasoning and problem-solving. Figure 4 illustrates examples of this process, showing how parametric objects are generated and manipulated within the BIM system, highlighting the contrast in cognitive and procedural engagement compared to PDE/VAE workflows.

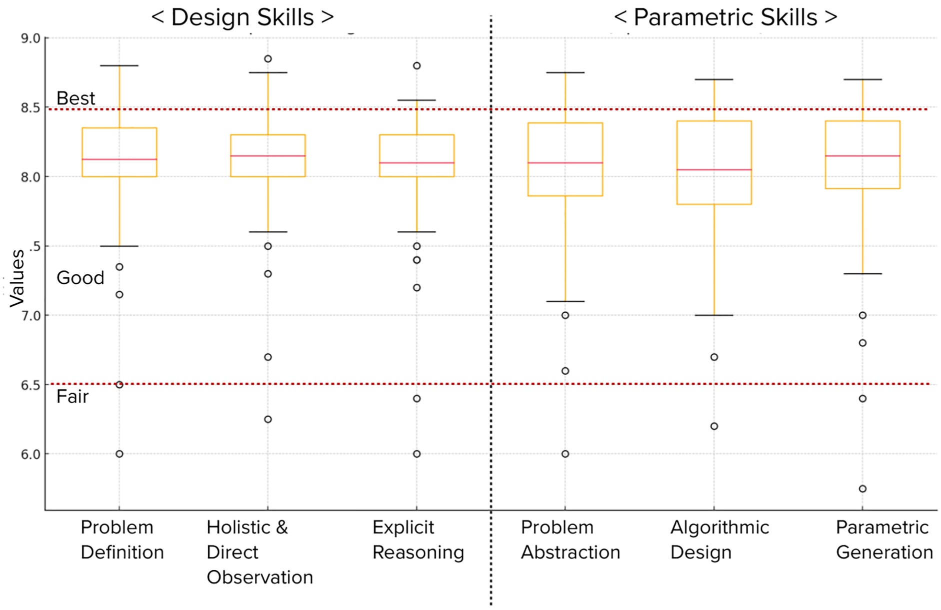

Figure 7 Distribution of Abstraction-Reconstruction Design and Parametric Skills in the BIM system

The evaluation of parametric modeling in the BIM system, as depicted in Figure 7, illustrates that the Design Skills attributes are more consistent, with most participants scoring in a relatively narrow range, centered around 8.0, which is higher than that in PDE/VAE. Across the student cohort, the empirical data establishes a proficiency in design-related tasks within the BIM system. In comparison, parametric skills show a wider range of performances, with more outliers and a larger spread. While the median score remains approximately 8.0, the empirical data confirms significant variability in individual performance across parametric tasks. These skills may be more complex or have higher performance thresholds, resulting in a broader range of outcomes.

Moreover, the correlation analysis between design skills and parametric skills revealed the following significant relationships:

- Problem Abstraction and Algorithmic Design (0.93) have the highest correlation (0.93), indicating that Problem Abstraction is one of the strongest predictors of success in Algorithmic Design.
- The significant correlation between Explicit Reasoning and Parametric Generation (0.84) establishes a direct relationship: proficiency in Explicit Reasoning dictates superior performance in Parametric Generation.
- Holistic and Direct Observation and Parametric Generation (0.79) is another important correlation, indicating that strong holistic observation skills contribute to Parametric Generation success.

From these correlations, we can infer that problem abstraction and algorithmic design are closely linked, and improving one is likely to improve the others. Similarly, explicit reasoning and parametric generation are strongly related, making them key areas of focus for improvement if we want to boost performance in parametric tasks.

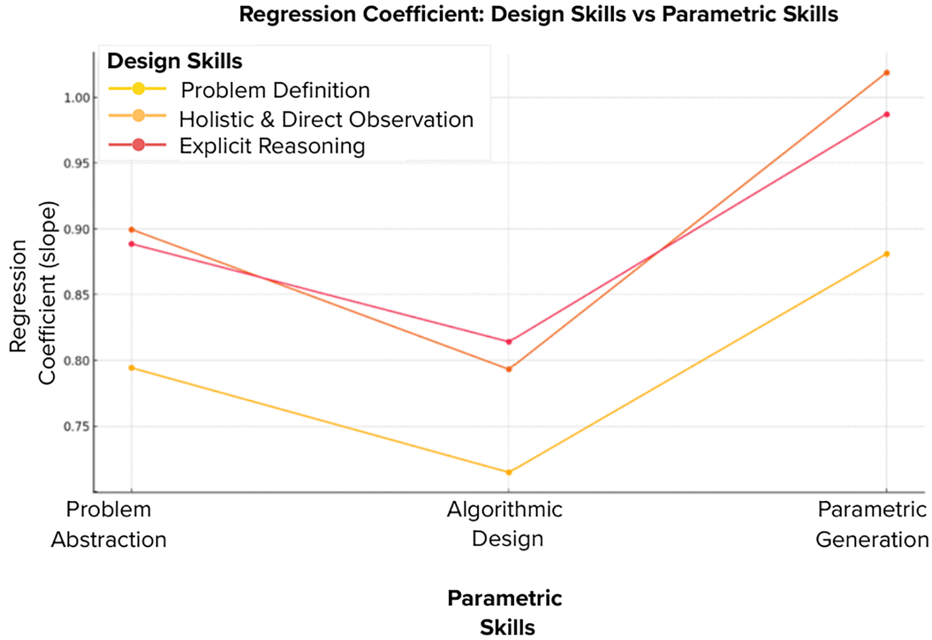

Figure 8 Regression coefficient for parametric skills in the BIM system, indicating that problem definition is the most influential factor for parametric modeling skills

The regression analysis depicted in Figure 8 confirms that Problem Definition possesses a higher slope than other Design Skills, establishing its stronger and more pronounced influence on Parametric Skills compared to Holistic Observation or Explicit Reasoning. Problem Definition plays the central role in determining parametric outcomes, while other design skills function as moderate, complementary factors. This empirical reality dictates that within a Building Information Modeling (BIM) system, the initial identification and articulation of user needs, environmental constraints, and functional requirements serve as the primary cognitive engine for computational success.

The distinct pattern observed for Algorithmic Design (AD), which fails to align closely with Parametric Generation (PG), establishes AD as a specialized skill necessitating specific and rigorous cognitive demands.

Algorithmic Design (AD) requires specialized technical and domain-specific knowledge, rendering it significantly less influenced by general problem-solving abilities than Problem Abstraction (PA) or Parametric Generation (PG). This empirical divergence dictates a pedagogical shift toward targeted development and specialized training for AD, as it lacks the close alignment with general design skills observed in other parametric competencies.

Algorithmic design in the BIM system involves a higher level of abstraction and logical thinking, which may not be directly dependent on DS. For example:

- Problem abstraction may rely more on understanding the problem in a general sense, whereas algorithmic design focuses on structuring and breaking down problems in a systematic manner.

- Parametric generation might require more spatial or design thinking, whereas AD is more computationally focused, explaining the less pronounced connection to the other skills.

4.3 Review and evaluation of the study

Interviews were conducted and a questionnaire was distributed to 50 students to obtain direct feedback. For the discussion and questionnaire, the participants responded to two types of course reviews: 1) course evaluation and 2) course expectations. The course evaluation consists of four questions related to the perception and level of understanding of parametric design and BIM modeling. In comparison, the Course Expectation has four questions related to the course's substantive expectations and its future extension. For each type of questionnaire in the Course Evaluation, students scored one to 4 (1 = Worst/Unlikely; 4 = Best/Likely). The results of the course evaluation are depicted in Figure 9 (in the supplementary file).

In the course evaluation, most respondents revealed that they understood the concept and principles of parametric methodology and the BIM system. Simultaneously, the most challenging issue is abstraction and generalization in the BIM system. Overall, BIM Modeling scores higher than parametric design. The author perceives this result as reflecting the expectations of students to engage with BIM and computational processes after graduation. However, despite how significantly the students perceive it, they still struggle to grasp the abstraction step in a computational approach.

During the interview, most students thought that abstraction-reconstruction is crucial to the parametric design methodology. Therefore, they expect more time to internalize the process and develop the algorithm. Abstraction reconstruction also plays a crucial role in understanding parametric modeling in BIM. As the BIM system has encapsulated parametric modeling in a more form-driven and object-oriented workflow, students perceived more confidence after understanding the BIM data structure and abstraction principles.

Course Expectation results reflect desirable aspects of the parametric methodology they expect to have, and they believe that expanding their competency is essential. the ability to develop parametric modeling skills is the most critical factor they expect, considering that this skill is the foundation of BIM modeling. Parametric modeling in a BIM system involves more complex information than geometric-centric parametric modeling. Each BIM component has parameters or attributes that regulate the object's shape, behavior, and performance.

5. Discussion

The rise of BIM as a technology, methodology, and platform will transform the design approach and methodology. This will disrupt the pedagogical system of design thinking and making in academia. In recent years, Computational Design Thinking has been referred to as a dual-mode approach that combines design and computational thinking. Through this study, the Abstraction-Reconstruction methodology is proposed as a new approach to contribute to the pedagogical strategy of parametric design. As parametric design has been regarded as a new paradigm of design thinking that moves from typological thinking to topological design thinking, from object-oriented design to relation (assemblage)-oriented design (Jacobus et al., 2023; Jabi and Woodbury, 2013Meredith, 2008, it is imperative to investigate the new way of thinking that has the potential to integrate generative, performative, representative, and evaluative process models based on digital data and information technology.

The observed variability in student performance, particularly in the Algorithmic Design (AD) indicator within the PDE/VAE environment, can be further understood through the lens of Cognitive Load Theory (CLT) (Sweller et al., 2011; Sweller, 1988). CLT posits that learners have a limited working memory capacity, which can be overwhelmed when engaging with tasks that impose high intrinsic or extraneous cognitive load. In the PDE/VAE context, students were required to simultaneously manage visual scripting logic, parameter mapping, and design outcomes activities that demand concurrent spatial, procedural, and symbolic reasoning. This likely imposed a high intrinsic cognitive load, especially for novices unfamiliar with ART or VP environments.

In contrast, the BIM system provides structured, object-oriented workflows featuring predefined relationships and parametric elements, which reduces cognitive demands by offering scaffolded abstraction pathways. Consequently, the consistent performance in BIM tasks confirms that the cognitive scaffolding inherent in BIM tools enables students to internalize abstraction and reconstruction more efficiently.

Incorporating cognitive load considerations, such as sequencing tasks by complexity, integrating visual cues, and reducing split attention effects, into curriculum design could enhance student learning and engagement, especially in early-stage computational design education.

Integrating parametric design methodology and the BIM system represents a new approach to introducing a fresh perspective into an applicative and industrial ecosystem that challenges traditional design culture, particularly in the new dialog and iterative relationships between design, data, and the design object as a system. Parametric design is one of the core skills necessary to fully leverage the benefits of BIM, particularly in the areas of authoring, simulation, and coordination.

The results of this study reveal that when addressing design problems, parametric thinking, as a method of thinking through the abstraction-reconstruction methodology, presents a challenge in its dual mode of thinking, design thinking, and computational thinking. The study also confirms the issue of moving fluently between the two, which, in the study context, lies in the ability to generate an abstraction of the defined problem. A pragmatic approach to understanding computational thinking in the creative process of architectural design exploration, incorporating the BIM system enhances learning ability, particularly in problem abstraction, removing unnecessary details, and focusing on the significant aspects that comprise an object.

6. Conclusions

Critical thinking embedded within the abstraction-reconstruction process of parametric BIM modeling is essential for cultivating a comprehensive understanding of parametric systems and for meaningfully integrating computational design thinking into architectural practice. Parametric modeling functions as a conduit for dual cognitive modes, facilitating interaction with design objects within the PDE/VAE environment, and thereby enables a holistic engagement with architectural exploration, construction, and environmental integration. Within this framework, the abstraction stage proves particularly pivotal, while problem definition exerts a significant influence on parametric modeling outcomes within the BIM system. From a pedagogical standpoint, this study identifies four key dimensions of computational design thinking that demonstrably enhance learning capacity: the explicitation and decomposition of design problems; the differentiation and classification of parameters, rules, and constraints; the development of abstraction and algorithmic logic; and the reconstruction, rationalization, and exploration of design solutions. Taken together, these findings underscore the urgency for architectural education to embrace a new paradigm, one that fosters analytic and synthetic dialogues throughout the design process. As information-led technologies continue to reshape the AEC industry, the cultivation of computational design thinking is not merely advantageous but increasingly indispensable.

References

Aish, R., & Woodbury, R. (2005). Multi-level interaction in parametric design. *Smart Graphics*, 151–162. https://doi.org/10.1007/11536482_13

Ambrose, M. A. (2012). Agent provocateur - bim in the academic design studio. *International Journal of Architectural Computing*, *10*(1). https://doi.org/10.1260/1478-0771.10.1.53

Arisman, A., Widiastuti, I., Indraprastha, A., & Sudradjat, I. (2025). Creativity in generative design: The impact of architects' control over geometric parameters in early-stage form-finding using genetic algorithms. *International Journal of Architectural Computing.* https://doi.org/10.1177/14780771251340203

Bhooshan, S. (2017). Parametric design thinking: A case-study of practice-embedded architectural research. *Design Studies*, *52*, 115–143. https://doi.org/10.1016/j.destud.2017.05.003

Bilda, Z., & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies*, *24*. https://doi.org/10.1016/S0142-694X(02)00032-7

Bonani, A., Gennari, R., Melonio, A., & Rizvi, M. (2022). Design and computational thinking with iotgo: What teachers think. *Methodologies and Intelligent Systems for Technology Enhanced Learning, 12th International Conference*, 165–174. https://doi.org/10.1007/978-3-031-20617-7_21

Burry, M. (2013). *Scripting cultures: Architectural design and programming*. Wiley.

Carpo, M. (2017). *The second digital turn: Design beyond intelligence*. MIT Press.

Chakraborty, P. (2024). Computer, computer science, and computational thinking: Relationship between the three concepts. *Human Behavior and Emerging Technologies*. https://doi.org/10.1155/2024/5044787

Cross, N. (2025). *Designerly ways of knowing and thinking*. Springer London. https://doi.org/10.1007/978-1-4471-7541-4

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. Harper Collins Publishers.

Davis, D. (2013). *Modelled on software engineering: Flexible parametric models in the practice of architecture* [Doctoral dissertation, RMIT University].

De Bono, E. (1993). *Serious creativity: Using the power of lateral thinking to create new ideas*. Harper Business.

Deleuze, G. (2017). Postscript on the societies of control. In *Surveillance, crime and social control*. Routledge. https://doi.org/10.4324/9781315242002-3

Deng, W., Guo, X., Cheng, W., & Zhang, W. (2022). Embodied design: A framework for teaching practices focused on the early development of computational thinking. *Computer Applications in Engineering Education*, *31*(2), 365–375. https://doi.org/10.1002/cae.22588

Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal*, *4*(2), 123–143. https://doi.org/10.1080/10400419109534381

Haeusler, H., Hespanhol, L., & Hoggenmueller, M. (2018). Participationplus. *Smart and Sustainable Built Environment*, *7*(1), 133–149. https://doi.org/10.1108/sasbe-10-2017-0049

Hales, D. (2025). The cacheian objectile: Design fictions of the furnishing of territories. *Digital Creativity*, *36*(2), 153–165. https://doi.org/10.1080/14626268.2025.2494818

Hay, L., Duffy, A. H. B., Gilbert, S. J., Lyall, L. M., Campbell, G., Coyle, D., & Grealy, M. A. (2019). The neural correlates of ideation in product design engineering practitioners. *Design Science*, *5*. https://doi.org/10.1017/dsj.2019.27

Hensel, M., Menges, A., & Weinstock, M. (2004). Emergence in architecture. *Architectural Design*, *74*(3).

Holzer, D. (2015). Bim and parametric design in academia and practice: The changing context of knowledge acquisition and application in the digital age. *International Journal of Architectural Computing*, *13*(1), 65–82. https://doi.org/10.1260/1478-0771.13.1.65

Jabi, B., W.and Jhonson, & Woodbury, R. (2013). *Parametric design for architecture*. Laurence King Publishing.

Jacobus, F., Carpenter, A., Nunzio, A., & Badeschi, F. (2023). *Architectonics and parametric thinking: Computational modeling for beginning design*. Routledge. https://doi.org/10.4324/9781003252634

Kelly, N., & Gero, J. S. (2021). Design thinking and computational thinking: A dual process model for addressing design problems. *Design Science*, *7*. https://doi.org/10.1017/dsj.2021.7

Klenner, N., Gemser, G., & Karpen, I. O. (2021). Entrepreneurial ways of designing and designerly ways of entrepreneuring: Exploring the relationship between design thinking and effectuation theory. *Journal of Product Innovation Management*, *39*, 66–94. https://doi.org/10.1111/jpim.12587

Kolarevic, B. (2004). *Architecture in the digital age: Design and manufacturing*. Taylor & Francis. https://doi.org/10.4324/9780203634561

Kramer, J. (2007). Is abstraction the key to computing? *Communications of the ACM*, *50*(4), 36–42. https://doi.org/10.1145/1232743.1232745

Lobach, K. (2021). Architectural object-states: The crisis of the architectural object. https://doi.org/10.32920/ryerson.14662707.v1

Meredith, M. (2008). *From control to design: Parametric, algorithmic architecture*. Verb.

Mueller, C. (2018). Handbook of design thinking [ResearchGate].

Ospina, J. M. G., & Sánchez, D. E. G. (2022). Design thinking traits and cognitive passive resistance: Mediating effect of linear thinking. *Management Research Review*. https://doi.org/10.1108/mrr-11-2021-0803

Oxman, R. (2006). Theory and design in the first digital age. *Design Studies*, *27*(3), 229–265. https://doi.org/10.1016/j.destud.2005.11.002

Oxman, R. (2017). Thinking difference: Theories and models of parametric design thinking. *Design Studies*, *52*, 4–39. https://doi.org/10.1016/j.destud.2017.06.001

Papert, S. (2020). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Piaget, J. (2013). *Child's construction of quantities: Selected works vol 8*. Routledge. https://doi.org/10.4324/9781315006253

Pospelov, K. N., Burlutskaya, Z. V., Gintciak, A. M., & Troshchenko, K. D. (2023). Multi-parametric optimization of complex system management scenarios based on simulation models. *International Journal of Technology*, *14*(8), 1748–1758. https://doi.org/10.14716/ijtech.v14i8.6832

Pressman, A. (2019). *Design thinking: A guide to creative problem solving for everyone*. Routledge. https://doi.org/10.4324/9781315561936

Provost, L. P., & Sproul, R. M. (1996). Creativity and improvement: A vital link. *Quality Progress*, 101–107.

Rowe, P. G. (1987). *Design thinking* (1st ed.). MIT Press.

Rowe, P. G. (1991). *Design thinking* [New Edition]. MIT Press.

Schnabel, M. A., & Ham, J. J. (2012). Virtual design studio within a social network. *Electronic Journal of Information Technology in Construction*, *17*, 397–415.

Schon, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books. https://doi.org/10.4324/9781315237473

Schon, D. (2017). *The reflective practitioner: How professionals think in action*. Routledge. https://doi.org/10.4324/9781315237473

Schumacher, P. (2009). Parametricism: A new global style for architecture and urban design. *Architectural Design*. https://doi.org/10.1002/ad.912

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1016/0364-0213(88)90023-7

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer.

Syafii, N. I. M., Ichinose, M., Kumakura, E., Jusuf, S., Hien, W., Chigusa, K., & Ashie, Y. (2021). Assessment of the water pond cooling effect on urban microclimate: A parametric study with numerical modeling. *International Journal of Technology*, *12*(3), 461–471. https://doi.org/10.14716/ijtech.v12i3.4126

Tepehan, N. (2021). Designing objectiles as diagrams for movement. https://doi.org/10.7488/era/1555

Terzidis, K. (2006). *Algorithmic architecture*. Architectural Press. https://doi.org/10.4324/9780080461298

Villaverde, L., & Maneetham, D. (2024). Kinematic and parametric modeling of 6dof industrial welding robot design and implementation. *International Journal of Technology*, *15*(4), 1056–1070. https://doi.org/10.14716/ijtech.v15i4.6559

Wang, D., & Han, J. (2023). Exploring the impact of generative stimuli on the creativity of designers in combinational design. *Proceedings of the Design Society*. https://doi.org/10.1017/pds.2023.181

Wijaya, S., Utami, S., & Mangkuto, R. (2024). Multi-objective optimisation of skylight design parameters for a low-rise building in the tropics. *International Journal of Technology*, *15*(4), 1012–1025. https://doi.org/10.14716/ijtech.v15i4.5484

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*.

Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *366*(1881). https://doi.org/10.1098/rsta.2008.0118

Woodbury, R. (2010). *Elements of parametric design*. Routledge.

Yu, R., Gu, N., & Ostwald, M. (2021). *Computational design: Technology, cognition, and environments*. CRC Press.

Zhang, J., Xie, H., & Li, H. (2017). Competency-based knowledge integration of bim capstone in construction engineering and management education. *International Journal of Engineering Education*, *33*(6), 2020–2032.