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Logic-Driven and Technology-Supported Creativity Development Model in Open-Ended Design Tasks

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Abstract: The increasing reliance on digital tools in architectural education has transformed design workflows, offering new opportunities for creativity while posing challenges to students' logical reasoning and structured problem-solving abilities. While digital tools facilitate automation and generative design, over-reliance on them can limit students' ability to navigate design complexity independently. Addressing this issue, this study develops the Logic-Driven and Technology-Supported Creativity Development Model to examine the roles of logical frameworks, digital tools, and open-ended design tasks in fostering structured creativity. The findings reveal that logical frameworks provide essential cognitive scaffolding, helping students balance creative exploration with structured decision-making. Digital tools enhance form generation but introduce challenges such as automation bias and steep learning curves. Open-ended tasks promote design flexibility, yet their effectiveness depends on logical structures to maintain coherence. This study highlights the importance of curriculum design in supporting structured creativity, emphasizing the integration of technical training, interdisciplinary methods, and reflective learning. The findings contribute to design education theory and provide practical insights for improving course structures and pedagogical approaches in digital design environments.

Keywords: creativity development; logical frameworks; digital design tools; open-ended design tasks; digital education

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1. Introduction

With the continuous advancement of digital technology, architectural design education is experiencing a paradigm shift from traditional manual methods to digitally integrated design workflows [1]. Digital design tools, including parametric design, generative algorithms, and virtual modeling, have profoundly reshaped design education [2]. As articulated in Oxman's theoretical framework, these tools facilitate four core components of digital design—representation, generation, evaluation, and performance—while introducing novel methods for design exploration, interaction, and creative expression [3].

These tools significantly enhance the efficiency and broaden the scope of design innovation, offering unprecedented opportunities for fostering creativity. However, the widespread adoption of digital tools also presents notable challenges, particularly in nurturing students' design thinking. While digital tools improve efficiency and visualization, they risk promoting over-reliance on automated processes, potentially limiting the development of logical reasoning and creativity. To address this issue, integrating logical frameworks into design curricula has emerged as a critical focus in contemporary education [4].

Creativity, a cornerstone of design education, plays a pivotal role in driving innovative and value-oriented solutions in architectural design. Digital tools demonstrate immense potential in stimulating creativity, especially through their support for randomness and parametric design, enabling students to transcend the constraints of traditional design thinking and explore a broader spectrum of ideas [5]. However, existing research highlights that the steep learning curve, preconfigured logic, and implicit guidance embedded in these tools can inadvertently restrict students' creative freedom. These constraints often lead to mechanization and homogenization in design outcomes, as students become overly reliant on predefined commands and frameworks, thereby limiting opportunities for originality and exploration [6].

Balancing technological support with logical reasoning remains a pressing challenge in design education. Open-ended design tasks, characterized by adaptability and dynamic complexity, offer an effective pedagogical approach. Unlike traditional tasks, they grant students the freedom to explore diverse and innovative solution paths, fostering deeper engagement with uncertainty and complexity [7]. By reducing constraints such as size, function, or context, open-ended tasks provide broader opportunities for exploration and innovation. Nevertheless, excessive freedom without structured logical frameworks can lead students to lose direction, highlighting the importance of balancing openness with guided methodologies to ensure meaningful outcomes [8]. The effective implementation of open-ended tasks relies heavily on students' ability to establish clear objectives and construct logical pathways, enabling them to navigate inherent complexities while maintaining a coherent direction [9]. Logical frameworks, therefore, serve not only as tools to inspire creativity, but also as essential mechanisms to manage the uncertainty introduced by high degrees of freedom.

Although recent research has extensively explored the role of digital tools in enhancing design efficiency and creativity [10,11], studies examining the interplay between digital tools, logical frameworks, and open-ended tasks remain scarce. A critical challenge in design education is that while digital tools provide powerful means for exploration, over-reliance on automated processes can hinder students' ability to engage in structured problem-solving and logical reasoning. Without explicit cognitive scaffolding, students may struggle to navigate the complexities of open-ended design tasks, leading to incoherent design outcomes or excessive dependence on predefined algorithmic solutions. This gap raises a pressing pedagogical question: How can digital tools be effectively integrated into design curricula without diminishing students' ability to think critically and develop independent creative strategies?

To address this issue, this study examines the graduate-level course "Mars Habitat Design" at Tsinghua University's School of Architecture as a case study. Employing semi-structured interviews and Procedural Grounded Theory methodology, this research constructs a Logic-Driven and Technology-Supported Creativity Development Model to systematically analyze the roles and mechanisms of logical frameworks, digital tools, and open-ended tasks. By exploring how structured reasoning and digital exploration can coexist in design education, this study provides theoretical and practical insights for optimizing course design, fostering independent creativity, and equipping students with essential problem-solving skills.

2. Related Works

2.1. Creativity Theory and Approaches for Fostering Creativity

Creativity has long been recognized as a core component of architectural design education and a foundational ability for generating innovative and valuable solutions [12]. Guilford's three-dimensional model of creativity—fluency, flexibility, and originality—remains a classic framework for understanding creativity [13]. Fluency refers to the ability to generate a large quantity of ideas, flexibility denotes the ability to approach problems from multiple perspectives, and originality emphasizes the uniqueness of solutions. This foundational framework has been further expanded in design research. Amabile's task motivation theory highlights the critical role of intrinsic logic and goal-setting in fostering creativity [14].

Recent research in cognitive psychology suggests that creativity is influenced by a range of cognitive factors, including semantic and episodic memory, association, and a combination thereof [15–17]. The cognitive spiral model proposes that creative thinking follows a structured sequence: cognitive planning, risk analysis, engineering, and assessment [18,19]. These phases highlight the interaction between structured reasoning and spontaneous idea generation. Furthermore, cognitive flexibility, working memory, and problem representation play critical roles in creative problem-solving, supporting the idea that creativity is not an innate talent but a skill that can be developed through structured pedagogical approaches [20–23].

Various teaching methods have been explored in design education to enhance students' creative abilities. Divergent thinking exercises encourage the generation of multiple solutions to a given problem [24–26], while problem-based learning (PBL) fosters creativity by engaging students in real-world, ill-structured problems [27]. Research has shown that gamification techniques can enhance creativity by stimulating motivation and engagement, as found in studies using game-based learning environments [28,29].

In addition, creativity training techniques such as the SCAMPER method [30,31] have been widely applied to stimulate innovation. The method of focal objects (MFO) and forced relationships encourage associative thinking, helping students generate novel ideas by linking unrelated concepts [32]. Mandala thinking, a structured brainstorming technique, has been shown to improve idea generation by systematically exploring different aspects of a design challenge [33].

While various pedagogical approaches have been shown to enhance creativity, recent studies highlight the importance of integrating structured reasoning with exploratory engagement in fostering creative development [34]. In design education, creativity is increasingly understood as a skill cultivated through the interplay of cognitive abilities, task environments, and external supports—including digital tools. Open-ended design tasks, in particular, serve as a powerful pedagogical tool, providing students with the freedom to explore multiple solution paths while incorporating structured decision-making processes.

Building on these insights, this study focuses on digital tools and open-ended design tasks as key external supports for creativity development in architectural education. While recognizing the value of diverse pedagogical strategies, this research investigates how digital tools, when integrated with logical frameworks, can serve as cognitive scaffolds to support students' structured creativity development. By examining the relationship between logical reasoning, digital exploration, and open-ended problem-solving, this study aims to contribute to the understanding of how structured approaches can enhance creativity in design education.

2.2. The Role of Digital Design Tools in Design Education

The introduction of digital design tools has fundamentally transformed how creativity is cultivated in architectural education. Tools such as parametric modeling software (e.g., Rhinoceros 3D, Grasshopper) and generative algorithms enable students to efficiently explore complex design forms and test innovative solutions [35]. Research has demonstrated that these tools significantly impact creativity in several key ways:

(1) Generating Unexpected Design Outcomes

The ability of tools to produce unexpected design results is considered one of the key factors enhancing creativity. Danhaive et al. [36] emphasize that parametric design tools facilitate the exploration of complex geometric forms that are difficult to achieve through traditional methods. This functionality enables students to break away from conventional design paradigms and explore novel design ideas [37–40].

(2) Rapid Prototyping and Iteration

Digital tools allow for rapid prototyping and iterative adjustments, enabling students to focus on creative problem-solving rather than repetitive technical tasks [41–44]. For instance, Dominik Holzer's research [45] highlights how parametric design tools enable users to engage in form-finding processes enriched by real-time feedback on the physical performance of architectural forms.

(3) Challenges and Limitations

Despite their significant advantages in supporting creativity, digital tools also present certain challenges [46–48]. Kvan [49] notes that the steep learning curve of complex tools may limit students' creative freedom, especially for beginners. Additionally, Jonas Frich et al. [50] point out that certain functionalities of digital tools may implicitly guide users toward specific problem-solving directions, potentially constraining the diversity of design outcomes.

While existing studies underscore the potential of digital tools to foster creativity, they also highlight the need for a balanced integration. However, the increasing reliance on digital tools raises concerns about students' ability to maintain logical frameworks in open-ended design tasks. A growing body of research suggests that the use of logical frameworks can provide a cognitive structure to navigate complex design challenges, mitigating the risk of overreliance on technology. Therefore, understanding the role of logical frameworks in design thinking is essential for ensuring a balanced and effective integration of digital tools in design education.

2.3. Logical Frameworks in Design Thinking

Logical frameworks are essential cognitive structures that facilitate structured problem-solving and decision-making in design processes. In contrast to intuition-driven creativity, logical reasoning provides a systematic approach to navigating complexity, ensuring coherence and direction in open-ended tasks [51,52].

In design education, logical frameworks serve as scaffolds that help students structure their ideation process, clarify objectives, and maintain rational consistency [53]. The concept of frame-driven design thinking [51] suggests that designers use cognitive frameworks to define and redefine problem spaces, allowing them to systematically explore innovative solutions. Research also indicates that logical frameworks enhance creative potential by fostering a balance between divergent and convergent thinking [54].

Furthermore, logical frameworks play a critical role in mediating the relationship between digital tools and creativity. While computational tools enable parametric flexibility and generative randomness, logical frameworks ensure coherence and feasibility in design outputs [3]. Without a logical foundation, students may struggle to effectively integrate digital tools, leading to fragmented design processes and incoherent outcomes.

In the context of open-ended tasks, logical frameworks help students navigate uncertainty and manage complexity. Research suggests that when students lack logical framework strategies, they may experience decision paralysis or become overwhelmed by excessive freedom [55]. Therefore, embedding logical reasoning into design curricula is essential for fostering both creative autonomy and structured problem-solving.

2.4. Open-Ended Design Tasks

Open-ended design tasks are a pedagogical approach that emphasizes student autonomy, uncertainty, and the multiplicity of solutions, providing a broad creative space by reducing external constraints [7]. However, without logical frameworks, students may struggle to manage this freedom effectively. As discussed in the previous section, logical frameworks offer a structured approach to navigating uncertainty, enabling students to define clear design pathways. By integrating logical reasoning with open-ended tasks, students can balance free exploration with structured problem-solving, fostering both creative expression and design coherence. Research has shown that this type of task can stimulate students' innovative potential while enhancing their ability to solve complex problems [56]. For instance, Bartholomew et al. [57] found that high degrees of freedom in task environments encourage students to explore diverse solution paths actively. Similarly, Arulmalar Ramaraj et al. [58] demonstrated that open-ended design tasks significantly foster students' creative thinking and heuristic strategies, particularly when addressing complex problems.

However, the high degree of freedom in open-ended tasks can also lead to a loss of direction, especially in the absence of a supporting logical framework [8]. Stam et al. [9] emphasize that students must construct clear design pathways through logical reasoning and problem definition when engaging with open-ended tasks.

This study further investigates the integration of logical frameworks and technological support within open-ended design tasks, exploring how these elements help students balance free exploration with achieving defined design objectives.

3. Materials and Methods

3.1. Materials

3.1.1. An Open-Ended Design Project: The Mars Habitat Design Project

This study uses the Mars Habitat Design Project, a graduate course offered by the School of Architecture at Tsinghua University, as a case study to investigate how digital design tools influence students' creative performance in open-ended design projects. This project was chosen over other open-ended design tasks because it presents unique educational challenges that require students to fully engage in logical reasoning, problem-solving, and digital tool integration.

The Mars Habitat Design Project requires students to design a new residential unit for a small family (two to four individuals) on Mars, emphasizing the adaptation of architectural forms to extreme environmental conditions, such as low pressure, high radiation, and reduced gravity. Given the limited precedents for extraterrestrial habitation, students are encouraged to synthesize scientific knowledge, logical reasoning, and creative thinking to propose innovative and functional solutions.

Unlike conventional architectural design projects, which often involve well-documented site conditions and extensive precedents, the Mars Habitat Design Project operates in a context with only limited design references. Students must develop solutions for an extreme environment wherein existing architectural models are scarce and highly conceptual, requiring them to synthesize scientific knowledge, logical reasoning, and creative thinking to propose innovative solutions. This project is particularly suitable for this study for the following reasons:

(1) Represents a Highly Flexible Open-Ended Task

The Mars Habitat Design Project eliminates conventional environmental constraints, requiring students to envision architectural solutions in a largely undefined context. While some conceptual precedents exist, they are insufficient for providing comprehensive design guidelines, compelling students to rely on logical reasoning to justify their design decisions.

(2) Emphasizes Logical Frameworks in Problem-Solving

Unlike urban or interior design tasks, where spatial constraints and user needs are well-documented, this project requires students to define functional requirements based on limited existing research and speculative design approaches. This encourages structured reasoning in decision-making while allowing space for creative exploration.

(3) Requires Deep Integration of Digital Tools

The project mandates the use of parametric design, generative algorithms, and digital modeling tools throughout the entire design process. This ensures that computational design methods play a central role in form generation and optimization, making it a more suitable case study than projects where digital tools are secondary or optional.

Due to these factors, the Mars Habitat Design Project serves as an ideal platform for exploring the interplay between creativity, digital tools, and logical reasoning in open-ended design education.

3.1.2. Digital Design Tools

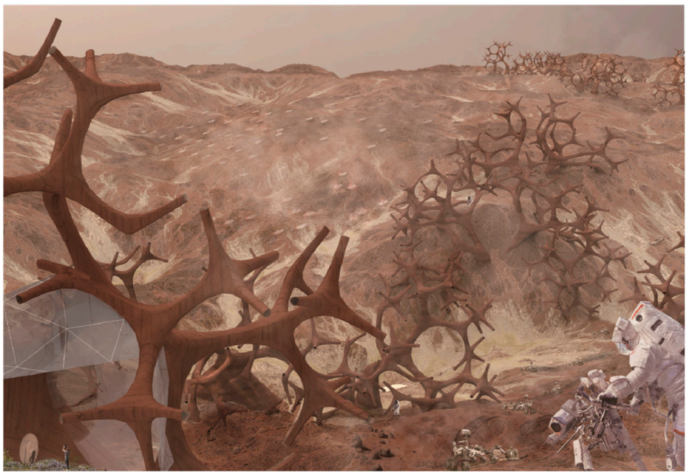
One of the core materials for this study is the suite of digital design tools used by students during the open-ended design tasks. Throughout the design process, participants primarily utilized the following tools:

(1) Rhinoceros 3D 7.0 and Grasshopper. These parametric modeling tools provided students with the ability to generate complex architectural forms and supported rapid design iteration. Grasshopper's algorithmic design features further stimulated students' creativity in exploring architectural forms;
(2) 3D visualization tools. Tools such as Keyshot 10 and Lumion 10 were used to render and communicate design concepts. These tools enabled students to present their design proposals with high-quality visual representations. Keyshot was chosen over Rhinoceros 3D for rendering due to its superior real-time visualization, material presentation, and lighting control, making it more effective for quick and high-quality design presentations;
(3) 2D drafting and documentation tools. Tools such as AutoCAD 2019 and Adobe Illustrator 2020 were employed to create drawings and final design documents.

3.1.3. Participants

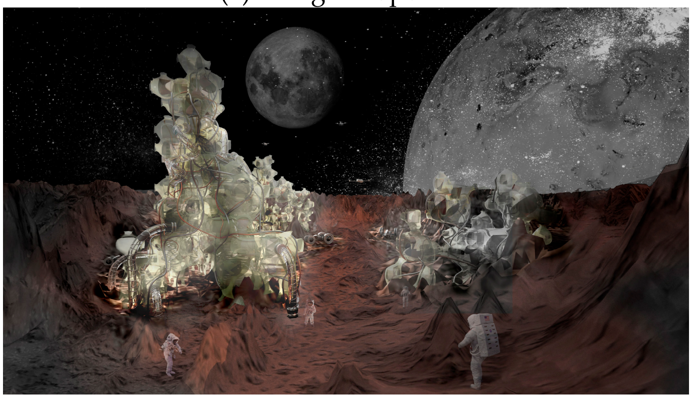
Since its inception in 2019, the Mars Habitat Design Project has been conducted annually during the spring semester, with approximately a dozen students participating in each studio. To date, nearly 90 students have participated in the project, resulting in 44 design proposals, as each group consisted of 2–3 students.

The examples presented in Figure 1 were randomly selected from these past design proposals to provide a representative overview of the design explorations conducted in the course, without being based on predefined success criteria.

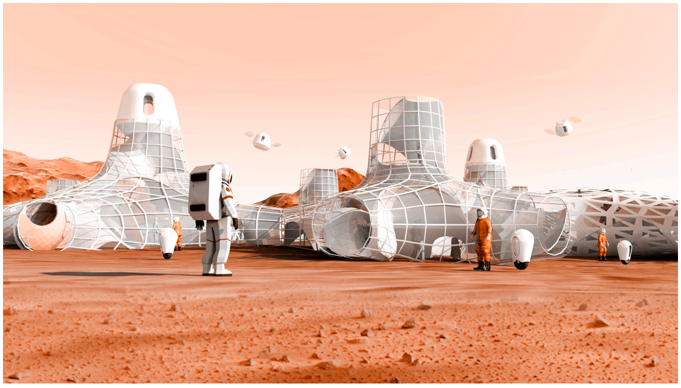


(a) Design Proposal 1

(b) Design Proposal 2



(c) Design Proposal 3



(d) Design Proposal 4

Figure 1. Some design proposals of the Mars Habitat Design Project.

To generate theoretical insights regarding the relationship between digital tools and creativity from students' subjective experiences, we conducted interviews with 10 students who participated in the Mars Habitat Design Project. To ensure the ethical integrity of this study, ethical approval was obtained from a university. All participants were informed of the study's purpose, procedures, and their right to withdraw at any time. Written consent was obtained prior to participation, and all data were anonymized to protect participant confidentiality. The criteria for participant selection were as follows: All participants were required to have completed the entire design project. All participants held a bachelor's degree in architecture or a related field, equipping them with fundamental design theory knowledge and practical experience. The participants included both experienced users and beginners with basic proficiency in digital tools. This diversity allowed for a comprehensive reflection on both the supportive and limiting aspects of digital tools. Participants were required to respond based on their personal experiences regarding creativity and the use of digital technologies. A summary of the participants' basic information is provided in Table 1.

Table 1. A summary of the participants' basic information.

Indicate	Options	Frequency	Percentage
Gender	Male	4	40%
	Female	6	60%
Diverse Familiarity with Digital Tools	Experienced Users	7	70%
	Inexperienced Users	3	30%

3.2. Methods—Grounded Theory

This study employs a qualitative research approach, utilizing Procedural Grounded Theory to systematically analyze how digital design tools influence students' creative performance in open-ended design projects. Grounded Theory is well-suited for this study as it allows for the emergence of conceptual insights directly from participants' experiences rather than imposing predefined theoretical frameworks. Given the exploratory nature of this research, this approach ensures that findings are deeply rooted in the data, capturing the nuanced ways in which students engage with digital tools in creative processes.

Grounded Theory encompasses three main variations: Classic, Procedural, and Constructivist [59]. This study employs Procedural Grounded Theory, which provides a structured yet flexible coding process, enhancing reproducibility and rigor in qualitative research. This approach is particularly relevant for design education research, where student experiences, creativity, and digital tool integration need to be analyzed systematically. The coding process—comprising Open Coding (identifying key concepts), Axial Coding (grouping related ideas), and Selective Coding (developing core themes)—ensures a structured yet emergent analysis that remains grounded in the participants' perspectives.

This study seeks to generate theoretical insights into the relationship between digital tools and creativity based on students' subjective experiences in open-ended design tasks. To ensure methodological transparency and reproducibility, Procedural Grounded Theory was selected as the primary method for identifying patterns, conceptualizing key themes, and constructing a theory derived directly from student reflections [60]. Figure 2 illustrates the structured workflow of Procedural Grounded Theory, which includes the following stages: data collection and cleaning, three-stage coding (Open, Axial, Selective), and final theory construction [61]. To support the validity of findings, representative participant excerpts are provided in the Section 5, demonstrating how core themes emerged from qualitative analysis.

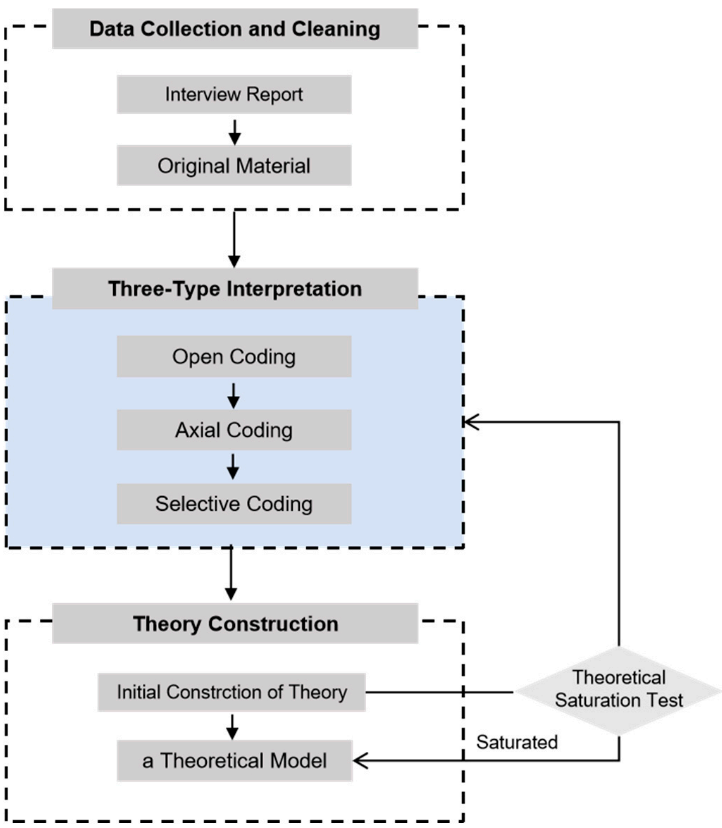


Figure 2. The workflow of procedural grounded theory.

(1) Data Collection and Cleaning

Data collection was guided by the needs of theory development. This study adopted semi-structured interviews, focusing on three key aspects: students' creative performance during the Mars Habitat Design project, their experiences using digital tools, and the role of the open-ended design context. The interview guide was structured around three core themes, as follows: First, exploring students' definitions of creativity and its manifestations in the design task. Second, investigating how digital design tools supported or constrained students' design ideation. Third, examining how the open-ended design context influenced students' creative thinking and behaviors. The specific interview questions are listed in Table 2.

Table 2. The specific interview questions.

NO.	Questions
1	How do you define creativity in the architectural design process?
2	Do you think the absence of typical constraints (e.g., site, local context) in the Mars Habitat Design Project supported your creativity? Why or why not?
3	After receiving the design brief, what were your initial ideas for the project?
4	Did digital tools (e.g., design software, digital fabrication) help you realize your ideas? If so, how?
5	Did digital tools enhance your creativity further? If yes, in what specific ways?
6	Were there instances where digital tools hindered your ability to realize your ideas? If so, how?
7	Besides digital tools, did you use any other methods to support your design? How do these compare to digital tools in terms of effectiveness?
8	Through this course, do you think your design skills have improved? Which aspects are related to creativity, and which are related to digital tools?
9	Beyond this project, what role do you think digital tools play in fostering creativity in architectural design?
10	What reflections did you have after completing this course, especially regarding creativity and digital tools?
11	In future projects, how will you approach creativity and the use of digital tools?

To ensure the relevance and validity of the questions, the interview guide was developed based on existing literature on creativity, digital design tools, and open-ended tasks in design education [51,53,61]. The questions were specifically designed for this study, following an iterative refinement process. Before conducting the formal interviews, the questions were reviewed by two experts in design education and tested in a pilot interview with two graduate students to ensure clarity and appropriateness.

The interviews were conducted either face-to-face or via online video calls, depending on the participants' availability. Each session lasted approximately 30 to 40 min, ensuring that participants had sufficient time to articulate their design experiences. To ensure the completeness and accuracy of the data, all interviews were fully recorded.

Data cleaning involved transcribing the recorded interviews into text and removing redundant or irrelevant information to ensure accuracy. These transcripts served as the primary data source for subsequent Grounded Theory analysis. During the interviews, the research team used guiding questions to encourage students to share genuine personal experiences while avoiding potential biases originating from the researchers' subjective interpretations during data collection.

(2) Three-Type Interpretation

Procedural Grounded Theory employs a multi-stage coding process to extract concepts, identify themes, and summarize core theories from participants' interview data. These stages include Open Coding, Axial Coding, and Selective Coding. Open Coding involves marking original sentences, abstracting and categorizing the identified labels, conceptualizing them, and further grouping concepts into broader categories. Axial Coding analyzes the relationships between categories, organizing them into main categories and subcategories. Selective Coding identifies core categories and establishes connections between the core categories and the main categories, forming a theoretical structure.

(3) Theory Construction

The preliminary theory emerges gradually through the process of three-type interpretation. Once a theory is established, it undergoes rigorous saturation testing to ensure its validity. If the theory is proven to be saturated, it is finalized as the conclusion of the study [62].

This structured process ensures that the theory development is grounded in the data, systematic, and robust, providing a reliable framework for understanding the role of digital design tools in supporting creativity in open-ended design tasks.

4. Results

Following the Procedural Grounded Theory, we manually coded the raw data through open coding, axial coding, and selective coding, ultimately developing the Logic-Driven and Technology-Supported Creativity Development Model.

4.1. Construction of the Logic-Driven and Technology-Supported Creativity Development Model

4.1.1. Open Coding

During the open coding phase, we conducted a line-by-line analysis of the 10 interview transcripts, extracting 57 initial concepts. These concepts spanned multiple research dimensions, including the sources of creativity, the dual roles of logical support and digital tools, the support and challenges of open-ended tasks, and the combination of multiple methods. To ensure the scientific rigor and systematicity of the coding process, we annotated key statements based on the participants' responses. We conceptualized them while excluding initial concepts with a frequency of less than two occurrences. Ultimately, we distilled these concepts into nine initial categories (Table 3).

Table 3. Initial categories formed by open coding.

Sample Data	**Open Coding**	
	Conceptualization	**Initial Categories**
Interview 1, 3, 6, 10	Creativity is based on logic and contextual framing.	Definition and Sources of Creativity
Interview 2, 4, 8, 9	Inspiration can arise from randomness and iteration.	
Interview 5, 7, 8	Interdisciplinary thinking enriches creative generation.	
Interview 1, 2, 3, 10	Logical frameworks underpin creativity.	
Interview 3, 6, 9	Creativity is a dynamic balance between conceptual generation and refinement.	
Interview 2, 4, 8, 10	Digital tools accelerate complex form generation and iterative optimization.	Supportive Role of Digital Technology
Interview 5, 7, 9	Technology enhances diversity and flexibility.	
Interview 3, 4, 6, 8	Randomness supports inspiration.	
Interview 4, 5, 7, 10	Parametric tools provide precise design representation.	
Interview 3, 6, 9, 10	Digital tools expand the possibilities of design expression.	

Table 3. *Cont.*

Sample Data	Open Coding	
	Conceptualization	**Initial Categories**
Interview 3, 5, 8, 10	Steep learning curves hinder digital tool adoption.	Limitations of Digital Technology
Interview 5, 6, 9	Functional constraints impede creative expression.	
Interview 4, 7, 10	Tools' inherent logic can constrain design reasoning.	
Interview 2, 6, 9	Over-reliance on technology may lead to creativity stagnation.	
Interview 3, 8, 10	Disconnection between digital technology and real-world needs limits design implementation.	
Interview 1, 3, 7, 9	Unconstrained design environments encourage divergent thinking.	Supportive Role of Unconstrained Environments
Interview 5, 7, 10	Open environments inspire innovative exploration.	
Interview 3, 4, 6	Open tasks encourage logical structuring and multidirectional attempts.	
Interview 2, 5, 9	Open design contexts break traditional design paradigms.	
Interview 2, 6, 10	Excessive design freedom can lead to directionlessness.	Challenges of Unconstrained Environments
Interview 3, 4, 7	Lack of clear frameworks makes it difficult for students to focus on goals.	
Interview 2, 5, 8	Students need to construct logical frameworks to address uncertainties brought by freedom.	
Interview 3, 7, 9	High freedom increases task complexity and psychological pressure.	
Interview 4, 5, 7, 9	Sketching helps capture ideas quickly.	Integration and Optimization of Methods
Interview 3, 6, 8, 10	Physical models provide intuitive feedback and spatial validation.	
Interview 2, 5, 7, 9	Literature research provides theoretical support for design logic.	
Interview 3, 4, 6, 8	Combining methods compensates for the limitations of digital tools.	
Interview 2, 4, 8, 10	Combining randomness and logical frameworks fosters creativity.	Interaction Between Technology and Creativity
Interview 3, 5, 9	Technology clarifies students' design logic.	
Interview 5, 6, 8	Automation and visualization deepen design exploration.	
Interview 4, 7, 10	Combining digital and manual methods enhances flexibility.	
Interview 1, 5, 10	Students recognize the importance of logical chains in design.	Students' Reflection and Skill Development
Interview 3, 6, 9	Coursework improves students' technical and innovative capabilities.	
Interview 2, 7, 9	Students reflect on balancing technological dependence and creativity.	
Interview 4, 8, 10	Parametric and interdisciplinary learning enhance the ability to manage design complexity	
Interview 3, 5, 9	Open-ended tasks cultivate logical reasoning skills.	Educational Significance of Open-Ended Tasks
Interview 2, 6, 10	Open design promotes creative expression.	
Interview 4, 7, 8	Combining technology and logic in coursework supports learning growth.	

4.1.2. Axial Coding

In the Axial Coding phase, we further analyzed the internal relationships between the nine initial categories and integrated them into six axial categories (Table 4). These higher-level categories reflect students' primary experiences and cognitive patterns within open-ended design tasks. For instance, the categories "support from unconstrained environments" and "challenges of unconstrained environments" were grouped under the axial category "the dual impacts of open-ended tasks," revealing the dual influence of task contexts on students' creativity. Similarly, the categories "supportive roles of digital technology" and "limitations of digital technology" were consolidated into the axial category "the dual roles of digital design tools," capturing the dual nature of digital tools in design tasks.

Table 4. Main categories formed by the Axial Code.

Main Categories	Initial Categories
Sources and Manifestations of Creativity	Definitions and Sources of Creativity
Support and Limitations of Digital Design Tools	Supportive Role of Digital Technology Limitations of Digital Technology
Dual Impacts of Open-Ended Tasks	Supportive Role of Unconstrained Environments Challenges of Unconstrained Environments
Diversification and Optimization of Methods	Integration and Optimization of Methods
Interaction Between Technology and Creativity	Interaction Between Technology and Creativity
Support Mechanisms from Educational Backgrounds and Curricula	Students' Reflection and Skill Development Educational Significance of Open-Ended Tasks

4.1.3. Selective Coding

During the selective coding phase, the axial categories were further consolidated into three core categories. The first one is the Logic-Driven and Technology-Supported Creativity Development Framework. The second one is the Dual Impacts of Open-Ended design tasks. The third one is the supporting mechanisms of educational context and curriculum design.

These core categories formed the basis of the final theoretical model. This model elucidates the dynamic relationships among logical frameworks, technological tools, and open-ended tasks, showcasing the key mechanisms underlying the development of students' creativity in complex design tasks.

4.2. Explanation of the Logic-Driven and Technology-Supported Creativity Development Model

After completing the phases of Open Coding, Axial Coding, and Selective Coding, we conducted saturation tests focusing on the integrity of category attributes and the stability of category relationships. These tests enabled us to develop a Logic-Driven and Technology-Supported Creativity Development Model (Figure 3). Additionally, we identified the dual impacts of open-ended design tasks and the supporting mechanisms of educational context and curriculum design, all of which are relevant to this study.

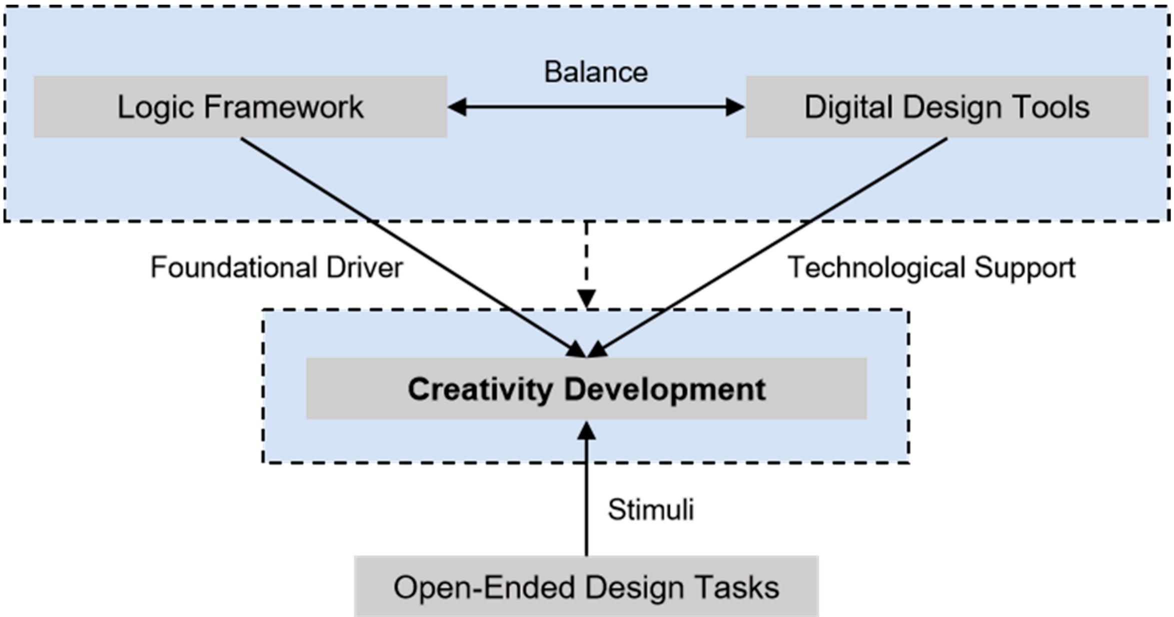


Figure 3. The Logic-Driven and Technology-Supported Creativity Development Model.

4.2.1. Logic-Driven and Technology-Supported Creativity Development Model

(1) Logic Framework as the Foundational Driver for Creativity Development

The interview data reveal that students universally view logical reasoning and contextual framing as critical for ensuring clarity and scientific rigor in their design direction. For example, Interview 1 stated, "In open-ended tasks, the logical chain helped me clarify the basis for each step of my design; otherwise, I could easily get lost in the complexity of the task". This highlights that a logic framework provides directional guidance, helping students find entry points for their designs amid uncertainty.

At the same time, the dynamic development of creativity depends on the stimulation of inspiration, particularly through the support of randomness and interdisciplinary associations. Interview 4 shared, "The freedom of the task allowed me to combine mathematics and natural forms, uncovering unexpected possibilities in my design". The randomness features of digital design tools further expanded students' design ideas, enabling them to discover more possibilities within the support of a logical framework.

(2) Digital Design Tools as the Technological Support for Creativity Development

The interviews also show that students utilized digital tools to generate complex forms and deduce design logic. As Interview 6 noted, "Parametric tools allowed me to quickly generate and adjust design forms, saving a significant amount of time". Additionally, the randomness features of digital tools served as a key source of inspiration. Interview 8 shared, "The algorithm-generated forms often led me to discover new directions, something that hand-drawing couldn't achieve".

However, digital tools also come with limitations. Some students reported steep learning curves, especially for beginners who needed to invest significant time to familiarize themselves with tool operations. Interview 3 remarked, "At the beginning of the task, I spent most of my time learning the tools, which limited my focus on the design". Furthermore, the functional boundaries of tools sometimes constrain students' creative expression. Interview 10 explained, "The results generated by the tools occasionally did not align with my original intentions, requiring repeated adjustments to match my vision".

Thus, the logic provides directional support for students' creativity development, while digital tools expand design possibilities through form generation and inspiration. The combination of these two elements forms the dynamic mechanism for students' creativity development.

4.2.2. The Dual Impacts of Open-Ended Design Tasks

(1) Open-Ended Tasks as Stimuli for Creativity

The high degree of freedom in open-ended tasks provides significant incentives for creativity while also placing higher demands on students' logical reasoning and framework construction abilities. The interview data show that the flexibility of the task context stimulated students' innovative thinking and interdisciplinary associations. Interview 2 noted, "The open-ended design context of the Mars Habitat freed me from the constraints of traditional architectural typologies and prompted me to think about design from behavioral patterns and survival needs". This unconstrained task environment, devoid of limitations like site and context, gave students the space to explore new forms and methods.

(2) The Challenges of High Freedom

However, high freedom can also lead to students losing direction in their designs. Interview 7 shared, "At the start of the task, I felt lost without clear constraints, which made the design more challenging". Some students addressed this by conducting literature research and defining their task frameworks to navigate the uncertainty brought by high freedom. Interview 6 explained, "I reviewed materials and established my own design rules, which helped me concretize my ideas and proceed with the design process more logically".

Another challenge posed by open-ended tasks lies in the psychological impact of task complexity on students. Some students expressed feeling overwhelmed when facing entirely open design problems. Interview 3 stated, "The complexity of the task left me feeling somewhat at a loss, and I had to spend more time building an overarching framework". This demonstrates that while high freedom offers opportunities for creativity, it also demands strong logical reasoning and resilience from students.

In summary, open-ended design tasks stimulate creativity and challenge students' construction of logic. High-freedom tasks encourage innovative exploration but require logical reasoning to manage complexity effectively.

4.2.3. Supporting Mechanisms of Educational Context and Curriculum Design

(1) Enhancing Logical and Technical Capabilities through Education

Open-ended design tasks cultivate students' design thinking abilities through the demand for logical reasoning. Interview 5 shared, "The task taught me how to structure design steps through logical chains, which not only helped me complete the task but also improved my ability to address complex problems". Additionally, technical courses guide students in mastering digital tools. Interview 10 stated, "The technical training in the course helped me quickly grasp the core functions of parametric tools, avoiding unnecessary time waste".

(2) Multi-Method Educational Models for Comprehensive Support

The integration of digital tools with traditional design methods emerged as a frequently mentioned learning experience. Interview 8 remarked, "Hand-built models allowed me to express my design intent intuitively, while digital tools helped me optimize the solution further". This combination of technologies and traditional methods not only enhanced the diversity of design expressions, but also mitigated the limitations of relying on a single method.

(3) Encouraging Reflection on the Balance Between Technology and Creativity

The curriculum also guided students to reflect on the balance between technological reliance and creative expression. Interview 9 observed, "I realized that technology is just a tool, and true creativity still requires the support of logic and ideas". This reflection on the relationship between technology and design provided valuable insights for students' future design practices.

In conclusion, the educational context supports students' development in logic, technical skills, and creativity through task design and technical training. Additionally, the integration of multiple methods and reflective education lays a foundation for the comprehensive development of students' design abilities.

5. Discussion

5.1. The Role of Logic-Driven and Technology-Supported Frameworks in Creativity Development

This study, through the construction of the Logic-Driven and Technology-Supported Creativity Development Model, highlights the dual role of logical frameworks and technological tools in fostering students' creativity. The findings reveal that logical frameworks provide directional support for students' designs, while digital tools enhance opportunities for exploration through form generation and randomness. Importantly, the study emphasizes the complementary relationship between logical frameworks and technological support.

5.1.1. The Role of Logical Frameworks as Core Support in Design Tasks

Logical frameworks play a critical role in providing students with clear pathways and direction in design tasks.

Firstly, in open-ended design tasks, students must employ logical reasoning to address the uncertainties brought by high freedom. This finding aligns with Dorst's concept of "frame-driven design thinking" [51], which asserts that logical reasoning enables students to identify clear entry points into complex problems, ensuring coherence and rationality through structured logical chains. Similarly, Brown's work [54] emphasizes the importance of logical reasoning and systems thinking in supporting design stability, thereby fostering creative expression. Interviews conducted in this study corroborate these perspectives. For example, Interview 1 and 3 noted that logical chains helped them maintain design consistency while balancing inspiration and constraints. This suggests that logical frameworks not only inspire creativity, but also guide students in achieving design objectives through structured constraints.

Secondly, logical frameworks are particularly vital in constructing design directions during the early stages of open-ended tasks. Kimbell [8] argues that while open-ended tasks stimulate innovation, a lack of logical guidance often leaves students feeling directionless. The findings in this study indicate that students who established logical frameworks early were more able to manage the complexities of open-ended tasks and avoid ambiguity in task objectives.

5.1.2. The Multifaceted Role of Technological Support in Creativity Development

Technological tools provide multi-dimensional support for students, including form generation, logical validation, and design representation.

Firstly, the findings show that technological tools not only improve design efficiency, but also inspire students through their random features. This aligns with Oxman's theory of "digital design thinking" [3], which highlights that digital tools extend design boundaries through complex form generation and real-time feedback, fostering creative expression. Interview 8 observed, "The forms generated randomly by the tools provided me with novel design directions". Kolarevic [63] similarly emphasizes that the randomness features of parametric tools introduce opportunities for unique and complex designs that surpass traditional manual methods.

Additionally, technological tools translate logical reasoning into tangible design outcomes. Interview 6 shared, “Parametric modeling tools allowed me to adjust design logic in real time and validate my ideas through automated generation”. This supports Burry’s argument [5] that technological tools operationalize logical thinking into visual expressions, thereby enabling creativity at every stage of the design process.

However, technological tools also pose limitations. For example, their steep learning curve can hinder creativity. Kvan [49] notes that mastering tool functionalities can impede beginners’ learning efficiency and consequently their creative performance. Interview 3 confirmed this, stating, “I spent so much time learning how to use the tools in the early stages that it reduced my time for design thinking”. Furthermore, functional constraints within tools may restrict design expressions. Interview 10 noted, “Some tool-generated forms didn’t align with my design goals, requiring significant manual adjustment”. This echoes Mitchell’s critique [6] that tools’ inherent logic can limit creative expression, particularly in areas outside their designed functionalities.

5.1.3. The Combined Role of Technological Support and Logical Frameworks in Fostering Creativity

This study extends the existing literature by emphasizing the critical interplay between technological support and logical frameworks. While prior research often highlights how technology supports efficiency and inspiration [10], this study demonstrates that technological tools can only truly enhance creativity when combined with logical frameworks. Interview 9 emphasized, “The random forms generated by the tools require the support of a logical framework; otherwise, they become meaningless”. This underscores the need for logical reasoning to transform inspiration into actionable design outcomes.

Additionally, the study stresses the importance of balancing technical training and logical reasoning in design education. Cross [53] suggests that combining technical proficiency with critical thinking fosters both technical mastery and creativity. The findings indicate that students need to continually reflect on the interplay between technology and logical frameworks to ensure the effective utilization of tools to enhance creativity.

Logical frameworks provide a foundational structure and direction for creativity, while technological tools expand design exploration possibilities through randomness and parametric generation. The dynamic combination of these elements enables students to navigate the complexities of open-ended tasks and achieve meaningful creative outcomes. Future design education should emphasize integrating technical training with logical reasoning to maximize the potential of both elements in fostering creativity.

5.2. The Dual Role of Open-Ended Design Tasks in Supporting Creativity

The findings of this study indicate that the high degree of freedom in open-ended design tasks stimulates students’ creativity and places greater demands on the construction of logical frameworks.

5.2.1. The Stimulating Effect of Task Freedom on Innovation

The study shows that an open task environment provides students with opportunities to redefine design rules, fostering interdisciplinary connections and innovative thinking. According to the interview data, students were able to break free from the constraints of traditional architectural rules and incorporate knowledge from other disciplines into their designs. For example, Interview 2 noted, “The openness of the task allowed me to combine technical knowledge and scientific exploration to create more experimental solutions”. Similarly, Participant 9 stated that the high freedom of the task encouraged them to focus more on meeting functional requirements, rather than being restricted by traditional architectural forms.

These findings align with the theories of Beghetto et al. [64], who emphasized that open task environments effectively unleash individuals' creative potential by providing more exploratory space, enabling innovative solutions that transcend traditional constraints. Runco [65] also noted that high-freedom design tasks encourage designers to leverage interdisciplinary resources, break through disciplinary boundaries, and create new possibilities for design.

5.2.2. Balancing Task Freedom with Logical Frameworks

As discussed in Section 5.1, while high freedom in design tasks stimulates creativity, it can also lead to a risk of losing direction. Therefore, design education must emphasize the balance between high freedom and logical frameworks when setting up tasks.

(1) Teaching Logical Framework Construction

Educators should design courses that help students master the methods of constructing logical frameworks. For example, guiding students to build task-appropriate logical systems through literature reviews and case studies can provide critical structure. As Cross [53] pointed out, the ability to reason logically is an essential component of cultivating creative thinking in design students.

(2) Providing Tools and Guidance

Educators need to equip students with clear tools and guidance to manage uncertainty in high-freedom tasks. Kvan [49] suggested that in open-ended tasks, educators should provide mentorship and facilitate teamwork to help students progressively build customized logical frameworks, thereby overcoming the ambiguity of the design process.

5.2.3. Combining Freedom with Contextual Constraints

The design of open-ended tasks should include moderate contextual constraints to prevent students from engaging in aimless exploration. For instance, Ramaraj et al. [58] proposed that providing partial constraints (such as clear objectives or functional requirements) can help students maintain a sense of direction while exploring freely.

The findings of this study validate this strategy. The interview data suggest that students, guided by logical frameworks, were more able to transform the freedom of the task into a driver of innovation, rather than an obstacle to design. For example, students who constructed logical systems to frame their exploration reported greater clarity and focus, which in turn enabled them to generate more innovative outcomes.

In conclusion, open-ended design tasks have a dual role in stimulating creativity while challenging students to construct logical frameworks. High-freedom tasks provide a platform for exploration and innovation. Still, their success depends on structured support from logical reasoning and educational guidance to help students manage uncertainty and maintain design direction. By balancing task freedom with logical frameworks, educators can maximize the potential of open-ended design tasks to foster creativity and innovation.

5.3. Supporting Mechanisms of Educational Background and Curriculum Design

Existing research suggests that educational background and curriculum design provide multi-level support for students' design capabilities through technical training and the integration of multiple methods [66]. The interview results indicate that traditional methods, such as physical models and sketches, not only offer flexibility for creative expression, but also play a complementary role in design validation. For instance, Interview 8 mentioned, "Handcrafted models helped me intuitively understand spatial proportions, while digital tools allowed me to optimize forms and rapidly iterate different design schemes".

The advantages of combining methods suggest that both digital tools and traditional techniques hold unique value, and their integration can provide more comprehensive design support. This finding aligns with Burry's research [5], which argues that the combination of digital tools and manual methods can mitigate their respective limitations while enhancing the overall quality of design through diversified modes of expression. For example, digital tools excel in generating complex forms and enabling rapid iterations, while physical models provide direct spatial feedback and physical validation. The interview data corroborate this perspective, demonstrating that students who combined multiple methods were more able to generate and validate creative ideas throughout the design process.

Additionally, the integration of methods fosters interdisciplinary collaboration and innovation in design education. For instance, Kamaraj et al. [67] emphasized that combining different approaches helps students understand design problems from multiple perspectives and develop innovative solutions using diverse means. In this study, students leveraged the intuitiveness of traditional methods with the efficiency of digital tools, not only improving their design representation abilities but also enhancing their comprehensive problem-solving skills in complex design tasks.

5.4. Pedagogical Implications of Logical Frameworks and Digital Tools in Design Education

The findings of this study highlight the importance of integrating logical frameworks and digital tools into architectural education to support creativity. While digital tools provide efficiency and form-generation capabilities, they also introduce challenges related to cognitive dependency and automation bias [68]. Logical frameworks serve as cognitive scaffolds that guide students in navigating complexity and maintaining coherence in open-ended tasks [69].

(1) Enhancing Logical Frameworks in Design Education

Logical frameworks are critical for problem definition and iterative refinement in design education [70]. Without explicit reasoning structures, students may struggle with directionless exploration and fragmented design processes. Prior research suggests that scaffolded reasoning exercises, such as structured brainstorming and decision tree mapping, can enhance students' ability to synthesize design logic [71]. Integrating such methods into curricula may reinforce logical consistency in students' design workflows, ensuring a cohesive approach to problem-solving.

Additionally, logical frameworks provide essential cognitive support in open-ended design tasks, where students often face ambiguity and multiple possible solutions. By incorporating structured reasoning exercises, educators can help students navigate uncertainty while preserving creative autonomy.

(2) Balancing Digital Tool Usage with Critical Thinking

Although digital tools enable rapid prototyping and complex form generation, overreliance on computational processes can diminish critical evaluation skills. Studies indicate that incorporating manual sketching phases and design constraints before digital modeling can strengthen students' conceptual clarity and decision-making autonomy [70].

Furthermore, structured critiques and guided questioning techniques can encourage students to reflect on their design logic, preventing them from becoming overly dependent on algorithmic outputs. Educators can introduce iterative self-assessment models, ensuring that students develop both technical proficiency and structured decision-making skills.

By embedding logical frameworks and critical thinking strategies into architectural education, students can develop a balanced approach to creativity and technology integration. These pedagogical interventions align with existing literature on design thinking and cognitive development, providing a structured foundation for enhancing problem-solving abilities in open-ended tasks. Future research should explore longitudinal assessments of these strategies to further validate their impact on design cognition and professional practice.

5.5. Research Limitations and Future Directions

5.5.1. Research Limitations

While this study has made significant progress in uncovering the roles of logic-driven frameworks, technological support, and open-ended tasks in fostering students' creativity, several limitations remain, as follow.

(1) Sample Scope Limitations

This study's sample was limited to 10 graduate students from a specific educational background, which may restrict the generalizability of the findings. Future research could expand the sample size and diversity to enhance the broader applicability of the conclusions. Including students from various institutions, educational levels, and cultural contexts could offer more comprehensive insights.

(2) Task Type Limitations

This study focused exclusively on the Mars Habitat Design project as a specific open-ended task, without exploring other types of design tasks. Future studies could investigate the effects of open-ended tasks on students' creativity across a broader range of design scenarios, such as urban planning, interior design, or adaptive reuse projects. Examining different task types could provide a deeper understanding of how task characteristics influence the interplay between logical frameworks, technological tools, and creativity development.

(3) Data Source Limitations

This study primarily relies on qualitative interview data to explore students' engagement with logical frameworks and digital tools in open-ended tasks. While interviews provide in-depth insights into students' cognitive processes and design decision-making, they are inherently subjective and self-reported. As a result, this study does not include a direct analysis of students' learning products (e.g., final design outputs), which could offer additional validation of their design reasoning and creative development.

By addressing these limitations, future research could contribute to a more nuanced and comprehensive understanding of the mechanisms that support creativity in architectural design education.

5.5.2. Future Directions

Building on the findings and addressing the limitations outlined above, future research could focus on the following areas to expand and refine the Logic-Driven and Technology-Supported Creativity Development Model.

(1) Exploring Broader Task Types in Design Education

While this study centered on the Mars Habitat Design project, future research could examine how the proposed model applies to other types of open-ended tasks. Investigating diverse task scenarios would validate the adaptability of the model and offer deeper insights into how task-specific characteristics influence the interplay between logical frameworks, digital tools, and creativity development.

(2) Interdisciplinary Applications in Industrial Design and Engineering

Given that logical reasoning, digital tools, and open-ended tasks are not exclusive to architectural design, future research could explore how this model applies to other design-oriented disciplines such as industrial design, mechanical engineering, and product innovation. In these fields, digital tools such as parametric modeling, computational design, and AI-driven generative tools are widely used to enhance problem-solving and iterative prototyping. Understanding how logical frameworks support design ideation, material optimization, and performance-driven solutions across disciplines could broaden the impact of this study and provide insights into cross-disciplinary creativity development.

(3) Integration of Emerging Technologies

As digital tools continue to evolve, future studies could explore the integration of emerging technologies such as artificial intelligence (AI), virtual reality (VR), and augmented reality (AR) in open-ended design tasks. These technologies have the potential to provide real-time feedback, immersive environments, and enhanced interactivity, further enriching the creative process and expanding the possibilities for educational innovation.

(4) Longitudinal Studies on Creativity Development

To better understand the long-term impact of logical frameworks and digital tools, future research could conduct longitudinal studies tracking students' creativity development from education to professional practice. Such studies could reveal how the skills cultivated through this model influence graduates' ability to solve complex design challenges and adapt to evolving technological landscapes in their careers.

By pursuing these directions, future studies can further validate and enhance the applicability of the proposed model, contributing to a more comprehensive understanding of how to foster creativity in design education and across related disciplines.

6. Conclusions

This study developed the Logic-Driven and Technology-Supported Creativity Development Model, emphasizing the interconnected roles of logical frameworks, digital tools, and open-ended tasks in fostering creativity in design education. The findings demonstrate that logical reasoning provides students with structured guidance in open-ended tasks, enabling them to balance creative exploration with well-defined design objectives. Digital tools expand creative possibilities through form-generation and randomness features, yet their steep learning curve and inherent constraints present challenges in fully integrating logic-driven design thinking. Open-ended tasks act as a catalyst for creativity, allowing students to explore unconventional ideas while necessitating a structured approach to maintain coherence in design outcomes.

Beyond these findings, this study highlights the importance of curriculum design in shaping students' creative capabilities. The effective integration of technical training, interdisciplinary methods, and reflective learning can enhance students' ability to navigate the complexities of open-ended design tasks. Theoretical contributions from this study reinforce the necessity of bridging structured reasoning with exploratory digital engagement, providing a pedagogical foundation for cultivating creativity in architectural education and beyond.

Given the growing influence of computational tools and interdisciplinary approaches in creative fields, future research could explore the broader applicability of this model in other design disciplines such as industrial design, product development, and engineering. Additionally, further studies should consider expanding sample sizes, investigating diverse task types, and conducting longitudinal studies to assess the long-term impact of logical frameworks and digital tools on creativity development. The integration of emerging technologies such as AI, virtual reality (VR), and augmented reality (AR) could also be explored to enhance the adaptability of open-ended design tasks across disciplines.

By addressing these areas, future research can further refine the Logic-Driven and Technology-Supported Creativity Development Model, contributing to a deeper understanding of how structured creativity frameworks can be applied across various design fields. This study provides a foundation for enhancing pedagogical strategies that balance structured reasoning and exploratory creativity, ultimately supporting the development of innovative and adaptive design thinking in education.

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