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CTMT FRAMEWORK: A TRANSFERABLE DESIGN COGNITION PERSPECTIVE TOWARDS ARCHITECTURAL DESIGN

Nor Haliza Johari[1], Rusmadiah Anwar[2] & Nor Nazida Awang[1]

[1]Faculty of Art and Design, Universiti Teknologi MARA Cawangan Perak, 32610 Seri Iskandar, Perak, Malaysia.

[2]Institut Seni Kreatif Nusantara, Universiti Teknologi MARA , 40450 Shah Alam. Selangor, Malaysia

Email correspondence: norha542@uitm.edu.my

ABSTRACT

Architectural design is a complex cognitive process in which designers continuously integrate conceptual intentions, technical reasoning, material considerations, and technical refinement throughout the design development process. Although existing architectural design methodologies have advanced understanding of design processes and decision-making, they primarily describe procedural stages and iterative workflows, offering limited explanation of the cognitive interactions that shape design reasoning. Addressing this theoretical gap, this study proposes the Concept–Technical–Material–Technical (CTMT) Framework as a transferable design-cognition perspective for architectural design. The framework conceptualises design development as an iterative interaction among conceptual exploration, technical reasoning, material evaluation, and technical refinement, offering a structured perspective on how architectural decisions evolve throughout the design process. Through a conceptual synthesis of design cognition and architectural design theories, this study examines the theoretical relevance of the CTMT Framework for architectural design development. It demonstrates its potential to complement existing design methodologies by integrating conceptual, technical, and material reasoning within a unified cognitive model. The study establishes the CTMT Framework as a transferable perspective on design cognition in architecture, providing a theoretical foundation that advances contemporary discourse on design cognition and supports the integration of conceptual, technical, and material reasoning in architectural design development.

Keywords: CTMT Framework; architectural design; design cognition; design development; design thinking

1. INTRODUCTION

Design is increasingly recognised as a cognitive activity that extends beyond the production of physical artefacts to encompass the generation, evaluation, and refinement of knowledge throughout the design process. Contemporary design practice requires designers to integrate creative exploration with technical feasibility, material considerations, functional performance, and contextual responsiveness to develop meaningful and sustainable design solutions. Consequently, design thinking has evolved from a problem-solving methodology into a broader cognitive perspective that explains how designers generate, organise, and transform knowledge during design development. Understanding these cognitive processes has therefore become a significant area of inquiry within design research, advancing theories that explain how design decisions are formulated, evaluated, and refined across diverse disciplinary contexts (Hay et al, 2020; Cross, 2023, 2011; Lawson, 2006; Schön, 1983).

Within this broader discourse, architectural design is among the most cognitively demanding design disciplines because it requires the continuous integration of conceptual creativity, technical knowledge, material understanding, and contextual considerations throughout the design process. Architectural design is also inherently situated within cultural contexts that influence spatial organisation, material expression, environmental adaptation, and users' experiences of the built environment. Consequently, architectural reasoning extends beyond technical problem-solving by requiring designers to interpret cultural values, local contexts, and societal needs alongside functional, environmental, and technological considerations throughout design development.

Rather than progressing through a linear sequence of activities, architectural design evolves through iterative reasoning in which designers continuously negotiate conceptual intentions with structural feasibility, material performance, environmental responsiveness, and technological opportunities while progressively refining design solutions. As architectural practice becomes increasingly influenced by digital technologies, sustainability, and interdisciplinary collaboration, architectural reasoning has evolved into a dynamic process of knowledge generation and informed decision-making (Lawson, 2006; Oxman, 2008; Fang et al., 2025).

Architectural design is supported by a wide range of methods, theoretical frameworks, and analytical tools that assist designers in structuring complex design problems and informing decision-making throughout the design development process (Plowright, 2014). Collectively, these approaches have advanced understanding of design reasoning, iterative problem-solving, reflective practice, and knowledge generation within architecture and related design disciplines (Cross, 2011; Lawson, 2006; Schön, 1983; Gero & Kannengiesser, 2014). Recent reviews further indicate that research on architectural design cognition is increasingly focused on conceptual design, collaborative ideation, sustainability, and data-informed design processes, reflecting the growing complexity of architectural decision-making (Yuhaniz, 2025). Nevertheless, existing studies continue to explain particular dimensions of design cognition or design processes independently. At the same time, comparatively limited attention has been devoted to understanding how conceptual, technical, and material reasoning operate as an integrated cognitive system throughout architectural design development (Cross, 2023; Dorst, 2011; Oxman, 2008).

This limitation has become increasingly significant because contemporary architectural practice depends on the continuous integration of conceptual exploration, technical feasibility, material performance, sustainability, and digital technologies within a unified design process. Rather than emerging from isolated conceptual ideas, technical requirements, or material considerations, architectural decisions evolve through iterative interactions among these domains of reasoning as designers evaluate alternatives, respond to constraints, and progressively refine design solutions (Lawson, 2006; Nilsson, 2013; Pallasmaa, 2009). Recent research further emphasises the need to strengthen the connection between advances in architectural cognition research and their practical application within professional design practice (Hoelscher et al., 2024). Accordingly, there remains a need for a transferable design-cognition perspective that explains how conceptual, technical, and material reasoning interact throughout the development of architectural design.

In response to this theoretical need, this paper proposes the Concept–Technical–Material–Technical (CTMT) Framework as a transferable perspective on design cognition for architectural design. Rather than functioning as a prescriptive design methodology, the CTMT Framework conceptualises architectural design development as an iterative cognitive process that integrates conceptual exploration, technical reasoning, material evaluation, and technical refinement. Accordingly, this research examines the theoretical relevance of the CTMT

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Framework to architectural design and positions it as a transferable perspective on design cognition that complements existing architectural design methodologies. Through a conceptual synthesis of design cognition and architectural theory, this study contributes a unified cognitive framework that advances the current understanding of architectural design reasoning by integrating the conceptual, technical, and material domains into a coherent model of design development. The CTMT Framework extends existing architectural design frameworks by explaining how conceptual, technical, and material reasoning interact throughout the development of architectural design. This distinction represents the study's principal theoretical contribution.

2. LITERATURE REVIEW

2.1 Design Cognition

Design cognition refers to the mental processes through which designers interpret problems, generate ideas, evaluate alternatives, and refine design decisions throughout the design process. Rather than viewing design as solely a technical or artistic activity, design cognition conceptualises designing as a knowledge-based process in which reasoning, reflection, and iterative learning transform ill-defined problems into coherent design solutions (Schön, 1983; Cross, 2006, 2023). This perspective positions design as an active process of knowledge construction, in which designers continuously interpret and reorganise information while responding to evolving design situations.

Within design research, cognition is recognised as a fundamental component of design development because design problems are inherently open-ended and subject to multiple interpretations. Design knowledge, therefore, emerges through iterative cycles of problem framing, solution exploration, evaluation, and refinement rather than through predetermined procedures (Lawson, 2006; Dorst, 2011). Consequently, effective design development depends upon balancing creativity with technical judgement, practical constraints, and contextual understanding, enabling designers to construct meaningful design knowledge throughout the design process.

Design cognition further extends beyond idea generation by integrating conceptual intentions, technical knowledge, material considerations, functional requirements, and contextual influences into a unified reasoning process (Cross, 2023; Dorst, 2011; Oxman, 2008). Although existing studies have significantly advanced understanding of reflective practice, knowledge generation, and iterative decision-making, comparatively limited attention has been devoted to explaining how conceptual, technical, and material reasoning operate as an integrated cognitive system. This theoretical limitation establishes the foundation for positioning the Concept–Technical–Material–Technical (CTMT) Framework as a transferable perspective on design cognition for architectural design.

2.2 Architectural Design Thinking

Architectural design thinking extends the principles of design cognition by recognising architecture as a multidisciplinary process that integrates conceptual creativity, technical knowledge, material understanding, environmental responsiveness, and contextual awareness throughout design development. Rather than progressing through a predetermined sequence of activities, architectural design evolves through iterative reasoning in which ideas are continuously interpreted, evaluated, and refined in response to functional requirements, construction constraints, environmental conditions, and cultural contexts (Lawson, 2006; Oxman, 2008; Plowright, 2014).

Within architectural practice, design thinking reflects the continuous interplay between thinking and making, whereby conceptual intentions are progressively transformed through technical exploration and material engagement. Material knowledge is therefore not simply applied after conceptual development but actively informs design reasoning and contributes to the generation of architectural knowledge (Nilsson, 2013; Pallasmaa, 2009). As architectural practice increasingly incorporates computational design, digital technologies, sustainability, and evidence-based decision-making, designers are required to integrate diverse forms of knowledge while responding simultaneously to spatial, structural, environmental, technological, and social considerations (Fang et al., 2025; Hoelscher et al., 2024).

Consequently, architectural design thinking extends beyond procedural design methods by emphasising the continuous integration of conceptual, technical, and material considerations throughout the design process. Existing architectural studies have examined these dimensions from various perspectives, including conceptual design, material practice, design cognition, and knowledge representation (Lawson, 2006; Nilsson, 2013; Oxman, 2008; Pallasmaa, 2009). Similarly, architectural conceptual frameworks have explained relationships among architectural form, context, structure, and design knowledge (Dahabreh, 2014).

However, these studies generally address conceptual, technical, and material considerations as complementary aspects of architectural design rather than as an integrated design-cognition perspective that explains their continuous interaction throughout design development. Consequently, there remains an opportunity to extend existing architectural design theory by proposing a transferable design-cognition perspective that explains how these reasoning domains interact across the activities of ideation, development, evaluation, and refinement. This theoretical gap establishes the foundation for proposing the Concept–Technical–Material–Technical (CTMT) Framework as a design cognition principle for architectural design.

2.3 Existing Design Framework

The increasing complexity of contemporary design practice has led to the development of numerous methodologies and theoretical frameworks that explain how designers generate ideas, structure design processes, and develop design knowledge. Although these frameworks differ in their theoretical perspectives and intended applications, they collectively recognise design as an iterative process involving exploration, evaluation, reflection, and refinement rather than a linear sequence of activities (Cross, 2011; Plowright, 2014). The following discussion reviews four influential frameworks—Design Thinking, the Double Diamond model, Reflective Practice, and the Function–Behaviour–Structure (FBS) ontology—to examine their respective contributions to architectural design cognition and identify the theoretical limitations that motivate the development of the Concept–Technical–Material–Technical (CTMT) Framework.

Design Thinking is widely recognised as a human-centred methodology for addressing complex and ill-defined design problems through iterative exploration, collaboration, and innovation (Brown, 2008). Operationally, the framework is commonly represented through five iterative stages—Empathise, Define, Ideate, Prototype, and Test—which support designers in understanding users, reframing design problems, generating ideas, developing prototypes, and evaluating solutions through continuous feedback (Plattner, 2010). As illustrated in Figure 1, this iterative process has been widely adopted across multiple design disciplines because it promotes creativity, collaboration, and user-centred innovation

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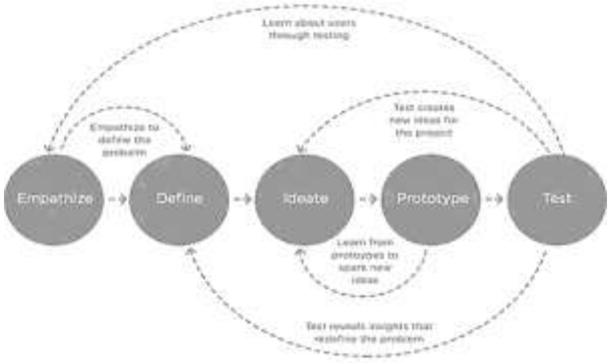

Figure 1: Design Thinking process (adapted from Plattner, 2010).

Design Thinking provides a valuable methodology for innovation by encouraging iterative learning and creative problem-solving. However, its primary emphasis remains on user-centred design activities rather than the cognitive mechanisms through which conceptual, technical, and material reasoning are integrated during design development. Consequently, while the framework explains how innovative solutions are generated, it offers limited insight into how these reasoning domains interact to support the generation of architectural knowledge and the refinement of design.

In contrast to Design Thinking, which primarily emphasises innovation and user-centred problem-solving, the Double Diamond model provides a structured representation of the design development process by organising design activities into two iterative phases of divergent exploration and convergent refinement (Design Council, 2005). The framework comprises four interconnected stages—Discover, Define, Develop, and Deliver—which guide designers from problem identification to solution implementation. As illustrated in Figure 2, the model offers a structured approach for expanding and progressively narrowing the design space, enabling systematic movement between exploration and decision-making throughout design development.

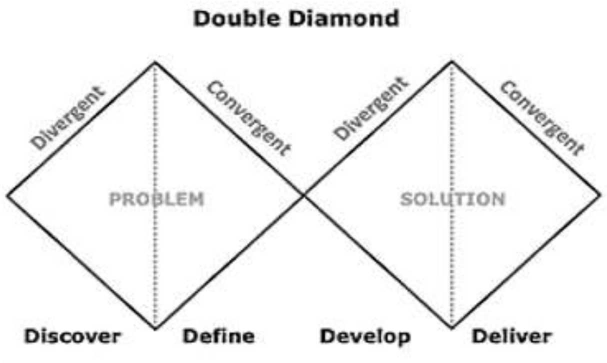

Figure 2: Double Diamond design process (adapted from Design Council, 2005).

The Double Diamond has significantly influenced architecture and other design disciplines by providing a clear process for managing uncertainty and supporting iterative design development. However, its principal contribution lies in structuring design activities rather than explaining the cognitive mechanisms that underpin design reasoning. Although the framework effectively indicates when divergence and convergence occur, it offers a limited explanation of how conceptual, technical, and material reasoning interact throughout these iterative cycles. Consequently, the model offers a valuable procedural perspective but comparatively limited insight into the integrated cognitive processes underlying architectural design development.

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Beyond process-oriented design frameworks, Reflective Practice conceptualises design as a continuous dialogue between thinking and action, in which designers construct knowledge by interpreting design situations, evaluating emerging outcomes, and modifying subsequent actions (Schön, 1983). Rather than viewing design as a predetermined sequence of activities, the framework explains design development as an iterative process of reflection-in-action, where understanding evolves through experience and continuous learning. As illustrated in Figure 3, reflective reasoning enables designers to transform evolving design situations into progressively refined design solutions.

Figure 3: Reflection-in-action model (adapted from Schön, 1983).

Reflective Practice has significantly influenced design research by demonstrating that knowledge is generated through iterative reflection rather than the application of fixed procedures. This perspective provides valuable insight into how designers interpret, evaluate, and refine design decisions throughout the design process. Although the framework explains the reflective nature of design cognition, it does not explicitly distinguish among conceptual, technical, and material reasoning as interconnected cognitive domains. Consequently, Reflective Practice contributes substantially to understanding reflective learning but provides only a limited explanation of the integrated reasoning processes underlying architectural design development.

Extending the discussion from reflective reasoning to formal knowledge representation, the Function–Behaviour–Structure (FBS) ontology provides one of the most influential theoretical models for explaining design reasoning and knowledge transformation throughout the design process (Gero, 1990; Gero & Kannengiesser, 2014).

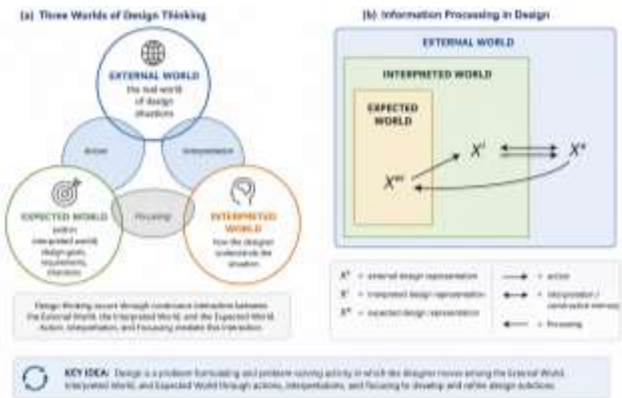

Figure 4: Function–Behaviour–Structure (FBS) ontology (adapted from Gero, 1990; Gero & Kannengiesser, 2014).

illustrated in Figure 4, the framework conceptualises design development as an iterative process in which functions, expected behaviours, and structural configurations are continuously analysed, synthesised, evaluated, and reformulated as design knowledge evolves. The preceding frameworks, which primarily emphasise innovation, design processes, or reflective learning, represent design as a structured reasoning system that transforms functional intentions into physical solutions through the interaction of Function (F), Behaviour (B), and Structure (S).

The FBS ontology has made a substantial contribution to design cognition research by providing a formal representation of design knowledge that is applicable across engineering, architecture, computational design, and other design disciplines. Its principal strength lies in explaining how designers transform design intentions into behavioural expectations and ultimately into structural solutions through iterative reasoning. Consequently, the framework has become an important foundation for computational design models, knowledge-based design systems, and research on design cognition because it systematically represents relationships among different forms of design knowledge.

Despite these contributions, the FBS ontology primarily represents the transformation of functional knowledge into behavioural and structural outcomes rather than the cognitive interaction through which designers integrate conceptual exploration, technical reasoning, and material considerations during design development. Although the ontology incorporates iterative reformulation, it does not explicitly distinguish these reasoning domains as interconnected cognitive processes. Consequently, while FBS provides one of the most comprehensive ontological representations of design reasoning, it offers comparatively limited explanation of how conceptual, technical, and material reasoning interact continuously throughout architectural design development. This limitation provides the closest theoretical rationale for developing the Concept–Technical–Material–Technical (CTMT) Framework.

Although these frameworks have substantially advanced design research, they differ in their theoretical perspectives, primary objectives, and representations of design reasoning. Collectively, they explain innovation, design processes, reflective learning, and knowledge representation from complementary viewpoints. To facilitate a systematic comparison of their contributions and identify the remaining theoretical limitations relevant to architectural design cognition, Table 1 summarises the principal characteristics of these frameworks.

Table 1 Comparative Analysis of Existing Design Frameworks in Relation to Architectural Design Cognition

Framework	Primary Focus	Design Domain	Major Contribution	Limitation
Design Thinking (Brown, 2008; Plattner, 2010	Human-centred innovation	Human-centred design	Supports creativity, empathy, and iterative problem-solving.	Limited explanation of Concept–Technical–Material interaction.
Double Diamond (Design Council, 2005)	Design process	Design management	Structures: divergent and convergent design development	Emphasises procedural stages over cognitive interaction.
Reflective Practice (Schön, 1983)	Reflective cognition	Design cognition	Explains reflection-in-action during design development.	Does not distinguish conceptual, technical, and material reasoning.
FBS Ontology (Gero, 1990; Gero & Kannengiesser, 2014	Design reasoning	Design cognition	Represents relationships between function, behaviour, and structure.	Focuses on knowledge representation rather than dynamic Concept–Technical–Material reasoning.

As summarised in Table 1, existing design frameworks have collectively advanced the understanding of design innovation, process development, reflective reasoning, and knowledge representation. Nevertheless, each framework explains only particular dimensions of design cognition and provides limited insight into how conceptual, technical, and material reasoning operate collectively throughout architectural design development. This limitation becomes increasingly significant as contemporary architectural practice requires designers to integrate

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multiple forms of knowledge while responding to functional, material, technological, environmental, and contextual requirements. Consequently, a broader perspective on design cognition is needed to explain these integrated reasoning processes. The following section, therefore, examines the evolution of Concept–Material–Technical integration, which establishes the theoretical foundation for the proposed Concept–Technical–Material–Technical (CTMT) Framework.

2.4 Evolution of Concept–Material–Technical Integration Towards the CTMT Framework

The preceding discussion demonstrates that existing architectural theories and design frameworks have contributed substantially to understanding design cognition, architectural reasoning, design processes, reflective practice, and knowledge representation. Collectively, these studies recognise the importance of conceptual thinking, technical knowledge, and material considerations in architectural design. However, they primarily address these dimensions independently or within broader procedural and theoretical models, providing comparatively limited explanation of how they function as interacting reasoning domains throughout architectural design development. This theoretical limitation provides the foundation for examining the evolution of Concept–Material–Technical integration and for proposing the Concept–Technical–Material–Technical (CTMT) Framework as a transferable design cognition principle.

One of the earliest studies to explicitly integrate these design domains was Anwar's (2015) Concept–Material–Technical (ConMaTech) model. The model conceptualised Concept, Material, and Technical knowledge as mutually dependent components that collectively influence design development rather than as isolated design variables. By emphasising the complementary relationships among these three domains, ConMaTech established an important theoretical foundation for understanding integrated design reasoning, particularly within product design and manufacturing contexts. The model highlighted that successful design outcomes depend upon balancing conceptual intentions with material characteristics and technical feasibility throughout the design process.

Building upon this theoretical foundation, subsequent research introduced the Standard–Treatment–Formulation (STF) Framework, which further structured the interaction among the Concept, Material, and Technical domains in design development (Johari, 2022). The STF Framework interprets Standard as the conceptual direction that defines design objectives, Treatment as the exploration and manipulation of material properties, and Formulation as the technical refinement through which design solutions are progressively developed. Rather than representing a linear sequence of activities, the framework emphasises the continuous interaction among these domains throughout the design reasoning process, thereby providing a more structured perspective on design decision-making and knowledge integration.

Subsequent work further expanded this perspective by examining the role of design thinking within socio-technical activities for product manufacturing (Johari, 2024). This research demonstrated that effective design development extends beyond the interaction of conceptual, material, and technical domains to include broader cognitive processes through which designers negotiate technological capabilities, production requirements, organisational contexts, and human-centred considerations. By positioning design thinking as an integrative cognitive activity, the study broadened the theoretical scope of Concept–Material–Technical integration and reinforced the importance of understanding design reasoning as a dynamic, knowledge-intensive process rather than a purely procedural one.

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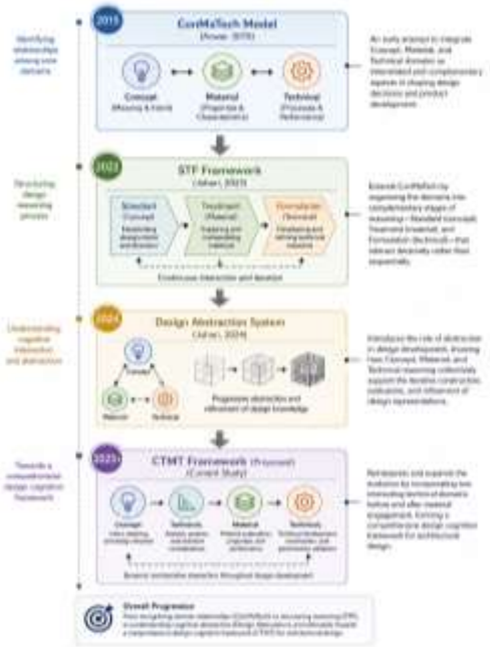

Figure 5: Evolution of Concept–Material–Technical integration towards the proposed Concept–Technical–Material–Technical (CTMT) Framework

Figure 2.5 illustrates the theoretical progression from the ConMaTech model, through the STF Framework and design thinking within socio-technical activities, to the proposed Concept–Technical–Material–Technical (CTMT) Framework. Collectively, these developments demonstrate an evolution from identifying relationships among Concept, Material, and Technical domains towards a broader understanding of design cognition and integrated design reasoning. While these studies have significantly advanced knowledge within product design and manufacturing, their theoretical principles remain applicable beyond their original disciplinary context.

Building on this progression, the present study extends these developments by proposing the Concept–Technical–Material–Technical (CTMT) Framework as a transferable design-cognition perspective for architectural design. Rather than introducing an entirely new design methodology, the CTMT Framework reinterprets the accumulated theoretical understanding of Concept–Material–Technical integration as an iterative cognitive process that supports architectural design reasoning through the continuous interaction of conceptual exploration, technical reasoning, material evaluation, and technical refinement

3. FRAMEWORK DEVELOPMENT METHODOLOGY

This study adopts a conceptual research methodology to establish the Concept–Technical–Material–Technical (CTMT) Framework as a transferable design cognition principle for architectural design. Unlike empirical studies that generate new knowledge through primary data collection, conceptual research advances theory by synthesising, interpreting, and extending existing bodies of knowledge to develop new theoretical perspectives (Gilson & Goldberg, 2015; Jaakkola, 2020). Accordingly, this study employs conceptual synthesis and theoretical reinterpretation to integrate established theories of design cognition with the progressive evolution of Concept–Material–Technical integration in design research.

Rather than developing the framework through a new empirical investigation, this study builds upon the established theoretical evolution of Concept–Material–Technical integration. The conceptual foundation originated from the Concept–Material–Technical (ConMaTech) model,

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which identified the complementary relationships among Concept, Material, and Technical domains in design development (Anwar, 2015). This foundation was subsequently refined through the Standard–Treatment–Formulation (STF) Framework, which organised these domains into a structured design reasoning process (Johari, 2022). Further theoretical development extended this perspective by examining the role of design thinking within socio-technical activities, highlighting the interaction between human cognition, technological capability, and design decision-making during product development (Johari, 2024). Collectively, these studies provide the theoretical foundation for the development of the CTMT Framework.

Building upon this theoretical progression, the present study reinterprets the relationships among Concept, Technical, and Material as interconnected cognitive domains rather than sequential procedural stages. Following the principles of conceptual theory development, these established theoretical relationships are synthesised and reconstructed into the Concept–Technical–Material–Technical (CTMT) Framework as a transferable design cognition principle for architectural design (Jaakkola, 2020). Within the framework, technical reasoning is positioned at two complementary stages: first, to evaluate the feasibility of conceptual intentions, and second, to refine design solutions following material evaluation. This reinterpretation transforms the original Concept–Material–Technical relationship into an iterative model that explains how architectural knowledge evolves throughout the design development process.

The transferability of the CTMT Framework rests on the premise that design cognition is a fundamental process shared across design disciplines (Cross, 2023; Lawson, 2006). Although architecture differs from product design in scale, context, and application, both disciplines require continuous interaction among conceptual exploration, technical reasoning, and material understanding throughout design development. Consequently, the CTMT Framework is proposed as a transferable design cognition principle that provides a theoretical explanation of how these reasoning domains interact during the design development activities of ideation, development, evaluation, and refinement. The following section presents the implementation of the CTMT Framework within the context of architectural design.

4. RESULT AND DISCUSSION

The principal outcome of this study is the implementation of the Concept–Technical–Material–Technical (CTMT) Model Framework as a design-cognition principle in architectural design. Rather than proposing a new design methodology, this study reinterprets the existing CTMT Model Framework in an architectural context to demonstrate its applicability as a transferable perspective on architectural design cognition. Through conceptual synthesis and theoretical reinterpretation, the framework explains how the Concept, Technical, Material, and Technical (CTMT) reasoning domains interact dynamically throughout architectural design development, supporting the continuous generation, evaluation, and refinement of architectural knowledge.

The implementation of the CTMT Framework addresses the theoretical limitation identified in the preceding sections. Existing design frameworks have contributed significantly to understanding innovation, procedural development, reflective learning, and knowledge representation (Brown, 2008; Design Council, 2005; Schön, 1983; Gero & Kannengiesser, 2014). However, these frameworks predominantly explain design processes or particular dimensions of design cognition independently, providing comparatively limited explanation of how multiple reasoning domains interact throughout design development. In response, the CTMT Framework conceptualises Concept, Technical, and Material as complementary reasoning domains that operate continuously throughout architectural design development rather than as isolated procedural stages.

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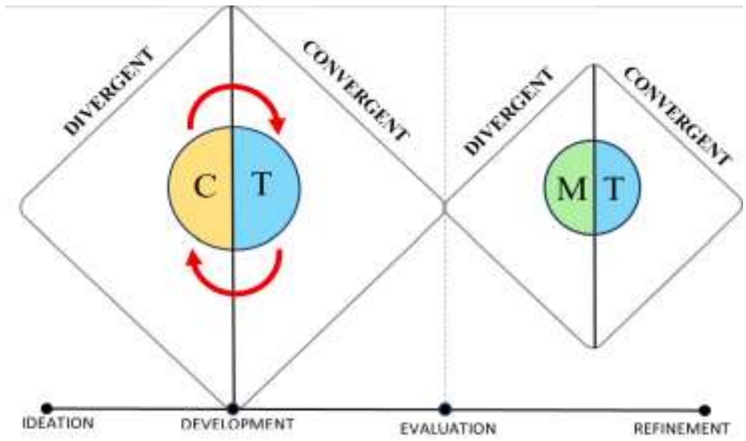

Figure 6: CTMT Model Framework as a design cognition principle for architectural design.

Figure 6 illustrates the implementation of the CTMT Model Framework as a transferable design cognition principle for architectural design. The theoretical foundation of the framework is rooted in the progressive evolution of Concept–Material–Technical integration in design research (Anwar, 2015; Johari, 2022, 2024). In this study, the framework is reinterpreted in an architectural context, in which Concept, Technical, Material, and Technical represent the principal reasoning domains. In contrast, Ideation, Development, Evaluation, and Refinement represent the design development activities through which these domains interact.

Unlike conventional process models, the CTMT Framework should be interpreted as a model of design cognition rather than a procedural workflow. Although the framework adopts the divergent–convergent logic of the Double Diamond model, its emphasis extends beyond process organisation to explain how reasoning domains interact during architectural design development. The first design diamond represents the interaction between the Concept and initial Technical reasoning domains during ideation and development. In contrast, the second design diamond illustrates the interaction between Material and Technical reasoning during evaluation and refinement. Consequently, the framework explains not only how architectural design progresses but also how architectural knowledge evolves through continuous cognitive interaction.

Table 2: Architectural interpretation of the CTMT Framework

CTMT Reasoning Domain	Design Development Activity	Architectural Interpretation	Typical Architectural Considerations
Concept	Ideation	Establishes the overall architectural intention and design direction.	User requirements, spatial concept, site context, design objectives
Technical I	Development	Evaluates the feasibility of conceptual proposals.	Structural systems, environmental performance, regulations, and construction feasibility
Material	Evaluation	Examines how material characteristics influence design decisions.	Material performance, durability, sustainability, aesthetics, constructability
Technical II	Refinement	Integrates conceptual and material decisions into a coherent architectural solution.	Detailing, building systems, fabrication, and construction integration

The framework begins with the Concept reasoning domain, where architects establish design intentions by interpreting user requirements, spatial functions, site conditions, cultural values, environmental contexts, and project objectives. During the ideation activity, conceptual

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reasoning supports problem framing, the generation of design alternatives, and the establishment of an overall architectural direction before technical feasibility is systematically examined.

The design process subsequently enters the first Technical reasoning domain, where conceptual propositions are evaluated in relation to structural feasibility, functional performance, environmental responsiveness, regulatory requirements, and construction strategies. At this stage, technical reasoning serves as a cognitive bridge between conceptual exploration and practical implementation, enabling architects to assess the viability of emerging design propositions while preserving their conceptual integrity.

Following this evaluation, the framework progresses to the Material reasoning domain, where architectural decisions are further developed by considering material characteristics, construction methods, environmental performance, durability, and aesthetic expression. Material reasoning extends beyond material selection by enabling architects to evaluate how material properties influence structural behaviour, spatial quality, constructability, and user experience. Consequently, material considerations frequently reshape earlier conceptual and technical decisions, contributing actively to the evolution of architectural knowledge.

The final Technical reasoning domain represents technical refinement. Unlike the initial technical stage, which focuses on feasibility evaluation, this stage integrates conceptual intentions and material decisions into coherent architectural solutions. During refinement, architects resolve structural detailing, construction integration, building systems, fabrication strategies, and implementation requirements to ensure that the proposed design can be effectively realised. Technical reasoning, therefore, performs two complementary cognitive functions within the CTMT Framework: evaluating conceptual feasibility and refining architectural solutions following material evaluation.

The significance of the CTMT Framework lies in the continuous interaction among its reasoning domains. Rather than progressing through a fixed sequence of activities, architects repeatedly revisit conceptual intentions, reassess technical requirements, reconsider material performance, and refine technical solutions as new information emerges throughout the design development process. This iterative interaction enables architectural knowledge to evolve in response to changing design constraints, technological opportunities, cultural considerations, and contextual requirements.

From an architectural perspective, the CTMT Framework provides a structured explanation of how design cognition supports the integration of creativity and constructability throughout the design development process. Successful architectural outcomes emerge not from isolated conceptual, technical, or material decisions but from the continuous interaction of these reasoning domains as architectural knowledge is progressively generated, evaluated, and refined.

The broader contribution of the CTMT Framework lies in extending the explanatory scope of existing design frameworks. Whereas Design Thinking emphasises human-centred innovation (Brown, 2008; Plattner, 2010), the Double Diamond model structures design activities (Design Council, 2005), Reflective Practice explains reflective learning (Schön, 1983), and the Function–Behaviour–Structure (FBS) ontology represents relationships among function, behaviour, and structure (Gero, 1990; Gero & Kannengiesser, 2014), the CTMT Framework explains how multiple reasoning domains interact throughout architectural design development. Rather than replacing these established frameworks, CTMT complements them by providing a unified cognitive perspective that links conceptual exploration, technical feasibility, material understanding, and technical refinement within a single theoretical model. Consequently, the framework offers a transferable design cognition principle applicable to architectural practice, architectural education, and future research on design cognition across multidisciplinary design contexts.

Rather than replacing these established frameworks, the CTMT Framework complements them by providing a unified cognitive perspective that links conceptual exploration, technical feasibility, material understanding, and technical refinement within a single theoretical model. Unlike previous architectural frameworks that primarily explain design processes, reflective practice, or knowledge representation, the CTMT Framework explicitly conceptualises Concept, Technical, and Material as interacting reasoning domains that operate continuously throughout architectural design development. Consequently, the framework offers a transferable design cognition principle applicable to architectural practice, architectural education, and future research across multidisciplinary design contexts.

5. CONCLUSION

This research has presented the Concept–Technical–Material–Technical (CTMT) Framework as a transferable design cognition principle for architectural design. Responding to the growing complexity of contemporary architectural practice, the study identified a theoretical limitation in existing design frameworks, which predominantly explain procedural activities, reflective practice, or knowledge representation, while offering only a comparatively limited understanding of how multiple reasoning domains interact throughout design development. Through conceptual synthesis and theoretical reinterpretation, the CTMT Framework was implemented within an architectural context to demonstrate its relevance as a cognitive perspective explaining the continuous interaction among the Concept, Technical, Material, and Technical reasoning domains throughout the design development activities of ideation, development, evaluation, and refinement.

The study contributes to architectural design research by extending the application of the CTMT Model Framework beyond its original product design context and establishing its potential as a transferable model of design cognition. Rather than functioning as a prescriptive design methodology, the framework provides a theoretical explanation of how architectural knowledge is progressively generated, evaluated, and refined through continuous interaction among conceptual, technical, and material reasoning. In doing so, the CTMT Framework complements established design frameworks by offering an integrated perspective on the cognitive processes that underpin architectural design development.

Consequently, the CTMT Framework offers a transferable design cognition principle applicable to architectural practice, architectural education, and future research across diverse cultural, environmental, and multidisciplinary design contexts. The framework may also assist educators in structuring design studios and design thinking pedagogy by emphasising reasoning domains rather than isolated procedural stages.

Although the present study establishes the theoretical implementation of the CTMT Framework within architectural design, its application remains conceptual. Future research should therefore undertake empirical investigations involving architectural designers, design studios, and professional practice to examine how the CTMT reasoning domains operate during architectural design development. Such studies would provide opportunities to further validate, refine, and expand the framework across different architectural contexts and multidisciplinary design environments.

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