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THE TRANSFORMATION OF DESIGN KNOWLEDGE IN THE AGE OF ARTIFICIAL INTELLIGENCE

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Abstract

The integration of artificial intelligence (AI) into design processes fundamentally transforms the nature of design knowledge. Traditional approaches often conceptualize the design process through a binary framework of black-box and glass-box metaphors. However, these metaphors are insufficient to capture the simultaneous, interactive, and permeable nature of knowledge production in AI-assisted design. Accordingly, this study examines the transformation of design knowledge in the AI era from an epistemological perspective, aiming to reconsider the processes that shape both knowledge and its production. The research employs a theory-building methodology situated within qualitative research paradigms. The findings reconceptualizes design knowledge not as a linear production chain, but as a multi-layered knowledge ecosystem in which human intuition, AI inference, and explainability layers are interwoven. In this respect, the study distinguishes itself from existing research by emphasizing a multi-layered knowledge ecosystem, moving beyond the black-box/glass-box duality, and proposing a third epistemological approach.

Keywords: Design knowledge, epistemology, black-box, glass-box, explainable AI

1. INTRODUCTION

The discipline of design has historically been shaped by epistemological debates focusing on the nature of knowledge production, modes of thinking, and creative processes. Since the 1970s, a significant body of work has emerged examining the structure of architectural design knowledge. Questions regarding what constitutes design knowledge, the types of knowledge it encompasses, the reasons for including specific knowledge, its sources (Friedman, 2000), the ways in which it is produced or communicated (Uluoğlu, 2000), as well as its nature, quality, and the methods for acquiring it (Manzini, 2009), have driven much of the research in this field.

In parallel with the evolving definitions of design, debates on design knowledge have continuously centered on the dilemma of whether its source lies in reason or experience (Uluoğlu, 1988). Cross's (1982) framing of the "designer's way of knowing" and Schön's (1983) conceptualization of

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"reflection-in-action" emphasizes the intuitive, experiential, and context-sensitive character of design knowledge. These early approaches primarily sought to explain design knowledge through the cognitive processes of the designer, treating the process either as an invisible black box or as a systematically analyzable and glass-box model. However, both approaches generally assumed knowledge production as a linear process progressing from designer to process to product.

In the 2000s, the advent of the information age and the accompanying digitalization initiated a new transformation in design knowledge. During this period, the transition from analog processes and tools to digital environments such as computer-aided design (CAD) and parametric design enabled design knowledge to be produced not only through physical objects or drawings but also through computational processes in digital media. Today, also the emergence and increasing adoption of AI, which can be considered a new turning point, has created a fresh domain of inquiry in design epistemology, raising questions regarding the production, sources, and traceability of design knowledge.

These inquiries have brought the black-box and glass-box metaphors back into focus, but this time attention has also turned to the black-box processes of AI in addition to those of human designers. Moreover, as AI technologies have advanced, processes such as Explainable AI (XAI) have aimed to render the AI black box more transparent, providing explanations for the actions performed within it. In this context, AI systems have become not merely tools but collaborative knowledge producers. This development reveals a new epistemological structure in which design knowledge is generated not from a single source (the human) but multidirectionally through the interaction of humans, algorithms, and systems. While AI inherently possesses a black-box nature, XAI approaches partially render this black box transparent, enabling the design process to become visible, explainable, and open to critical discussion.

In this context, explaining design knowledge solely through black-box or glass-box metaphors is no longer sufficient. Current design processes are shaped by the simultaneous interaction of tacit-human knowledge, computational-AI knowledge, and explainable-interpretative knowledge layers. This necessitates redefining design knowledge not as a linear chain of information but as a multi-layered and permeable knowledge ecosystem. As El Moussaoui (2025) emphasizes, this transformation highlights the multifaceted and dynamic nature of design knowledge, which evolves and adapts alongside cultural, technological, and philosophical currents.

In parallel with the multifaceted, dynamic, and evolving nature of design knowledge, different approaches have emerged in the literature. Oxman (2006) emphasizes the need to reassess existing theories and methodologies to examine the increasing impact of transformations in digital design on design knowledge. Similarly, Oxman (2008) highlightes that the evolving digital media should be considered an integral part of design knowledge. These perspectives indicate that digitalization and AI systems represent not merely a tool-based transformation but also an epistemological restructuring of the very nature of design knowledge.

In another approach, El Moussaoui (2025) emphasized the need to reassess both explicit and tacit knowledge that constitutes design knowledge in light of the rise of AI, arguing that the integration of AI into educational environments transforms the ways in which knowledge is produced, shared, and validated. Similarly, Chen (2025) discussed not only how AI tools are used but also how the inclusion of AI in knowledge production environments redefines the role of the human designer. This study further highlights that the processes of accessing, understanding, disseminating, and validating knowledge in conjunction with AI have not been sufficiently examined in the literature.

In this context, the present study is structured based on current debates and gaps in the literature regarding design knowledge in the age of AI. The research aims to examine the transformation of design knowledge from an epistemological perspective, seeking to reconsider the processes that shape both knowledge and its production in AI-assisted design.

In conclusion, this article aims to elucidate the transformation of the epistemological nature of design knowledge through the conceptualization of a "multi-layered knowledge ecosystem" in the age of AI. Within this framework, black-box, glass-box, and explainable AI approaches are reconsidered not as oppositional, but as complementary layers that collaboratively generate knowledge. In this regard, the study is expected to stimulate new debates on the subject and make a theoretical contribution to the relevant field.

2. METHOD

The methodology of this research is based on the theory-building approach, which is situated within qualitative research methods. According to Yıldırım and Şimşek (2021), theory-building refers to a type of research that provides an original contribution to existing concepts and understandings. Groat and Wang (2013) define this approach as the generation of a new theory from existing ones. In such studies, the aim is not to collect data, but to reinterpret the existing body of knowledge and propose a conceptual framework or a novel theoretical contribution.

In this type of research, documents serve as the primary data sources. One of the key characteristics of the theory-building approach is the concurrent execution of data collection and analysis processes,

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often referred to as continuous reciprocal analysis. In this process, data are collected and analyzed, and the phenomena, concepts, and processes emerging from these analyses are incorporated into subsequent data collection phases (Yıldırım & Şimşek, 2021).

Accordingly, the initial indications for the proposed approach emerge from the concepts and themes derived from the collected data. The researcher continuously tests and supports these concepts and themes with additional data. Throughout this process, the researcher develops provisional assumptions regarding the concepts, themes, and their interrelations, and seeks data that can help explain and substantiate these assumptions. On the other hand, not every qualitative study conducted using the theory-building approach is expected to propose a completely new theory. Therefore, the research outcomes may focus on offering new insights, introducing new concepts, or providing alternative perspectives on existing theories or paradigms rather than generating an entirely new theory (Yıldırım & Şimşek, 2021).

This study aims to examine the transformation of design knowledge in the age of AI from an epistemological perspective, seeking to reconsider both the knowledge itself and its production processes. Accordingly, the research is based on a theoretical design and proposes a new paradigm by employing literature analysis, conceptual analysis, and critical theoretical evaluation techniques. The steps followed in the study can be outlined as follows. In the first stage, relevant literature was searched in the Google Scholar database using the selected keywords (epistemology of AI, black box and AI, AI and design knowledge, design knowledge), and the bibliographies of directly relevant sources were further examined to expand the data set. Subsequently, the key concepts related to the topic were defined, and existing theories were analyzed comparatively. This analysis identified gaps in the current theories, and based on the transformations that artificial intelligence brings to design knowledge, a new paradigm was proposed.

3. THEORETICAL BACKGROUND

3.1. Design Knowledge and Epistemological Approaches

The design discipline is built upon an epistemological foundation concerned with the nature of knowledge production. Cross's (1982) conceptualization of "designerly ways of knowing" argues that design knowledge cannot be reduced solely to scientific or artistic knowledge; rather, it must be understood as a distinct mode of knowing specific to design. This type of knowledge develops through both tacit and explicit components, evolving via intuitive decision-making processes and experiential learning (Polanyi, 1966; Schön, 1983).

According to Schön (1983), designers know more than they can articulate, and such knowledge is approached as tacit knowledge. Through reflecting on their intuitive understanding during action, designers' tacit knowledge becomes manifest in their activities. Accordingly, in the "reflection-in-action" model, Schön presents the designer as a subject who continuously questions and reshapes their own decisions during the design process. However, in this model, knowledge remains largely human-centered and predominantly subjective.

Lawson (2004) defines design knowledge under two categories: knowledge provided to the designer and knowledge produced by the designer. In this approach, the information provided to the designer constitutes the data of the design, whereas the knowledge generated by the designer forms the designer's own understanding. The formation of design knowledge is thus related to the integration of pre-existing data with the designer's subjective inputs. In this model, design knowledge contains both objective and subjective elements and is nourished by a wide range of experiences and accumulated expertise.

In Manzini's (2009) approach, design knowledge is formed through the combination of cognitive knowledge serving different purposes. Kurt Çavuş and Kaptan (2019) also emphasize that design knowledge is both intuitive and analytical. They highlight that while generating design knowledge, it is important to consider not only the experiential component but also the underlying theories of the relevant field, thereby acknowledging both the objective structure and the subjectivity arising from intuition.

Goel (1995) identifies the designer as the primary source of knowledge throughout all stages of the design process. From this perspective, he argues that the majority of design knowledge used to solve design problems is contributed by the designer as an active subject in the process (as cited in Lawson, 2004). Similarly, Friedman (2000) notes that design knowledge encompasses both explicit and tacit components, emphasizing that the main challenge lies in making tacit knowledge accessible and articulable.

Lawson (2004) further elaborates on the topic by noting that design knowledge has both subjective and objective sources and can originate from a wide variety of data. Supporting this view, Paker Kahvecioğlu (2001) states that designers utilize different sets of knowledge throughout the design process. These knowledge sets consist not only of designers' prior experiences, perceptions, and preferences but also of newly acquired experiences and practices, highlighting the subjective and objective sources of design knowledge.

Aydınlı (2015) adds a new perspective to existing approaches by emphasizing that design knowledge comprises both the designer's experiential knowledge and information obtained from digital environments, thereby incorporating the technological dimension into the sources of knowledge. Uluoğlu (2004) asserts that throughout historical processes technology, its underlying ideology, the tools it enables, and the production domains it transforms are key determinants in the evolution of design knowledge.

When considering the dynamic nature of design knowledge shaped by changes, one of the contemporary developments driving such transformation is the emergence of AI technologies. Therefore, this study approaches the subject within the framework of AI technologies. AI not only provides tools for accessing information but also performs interpretative functions on behalf of the human designer, albeit with limited transparency, representing the intensification of these transformations (Chen, 2025). Accordingly, the present study examines the transformation of design knowledge in the age of AI, aiming to discuss the topic based on existing epistemological paradigms in the literature.

3.2. Black-box and Glass-box Metaphors

In design research, the black-box and glass-box metaphors represent the degree of visibility in knowledge production processes. The black-box approach seeks to understand the design process solely through input–output relationships, without observing its internal cognitive mechanisms. In this approach, knowledge production is intuitive, tacit, and personal in nature (Archer, 1979; Cross, 2001). In contrast, the glass-box approach advocates for rendering the design process visible. Cognitive design research (Gero and Kannengiesser, 2004) has accordingly focused on the systematic analysis of design decisions, sketches, thinking protocols, and strategies. The glass-box approach embodies the effort to make design knowledge traceable, reproducible, and teachable.

However, these two metaphors are structurally based on opposing poles: the black box represents an intuitive domain inaccessible to knowledge, while the glass box represents an explicated cognitive domain. This binary structure and its oppositional framework are insufficient to account for contemporary AI-assisted, dynamic, and multi-actor design processes.

In the black-box process, defining the concept of tacit knowledge in abstract terms is straightforward, but reaching consensus on a concrete decision is far more challenging. In this approach, "tacit" is defined as knowledge that is not explicitly expressed but implied. Polanyi (1966) describes tacit knowledge as "knowing more than we can tell" and argues that tacit knowledge is primarily observed through an individual's actions rather than what they consciously know. This form of knowledge is generally acquired through experience and learning by doing rather than through theoretical study. Consequently, it is intuitive, grounded in personal experience, and difficult to transfer, except when it is embodied in the individual (Cross, 1982). By comparison, knowledge that may be clearly expressed, codified, and systematically shared is defined as explicit knowledge. Such knowledge can be transmitted between individuals through structured communication systems, formal languages, or symbolic codes (Wong & Radcliffe, 2010). The characteristics and mechanisms of these modes of observation and knowledge transfer are commonly interpreted through the black-box and glass-box metaphors.

Traditional design processes are based on black-box processes that contain more tacit knowledge than explicit knowledge. However the integration of computational models and digital technologies into the design domain has contributed to the explicability of these cognitive mechanisms, as well as to production and evaluation processes, thereby transforming them into glass boxes (Oxman, 2006). With these transformations in the field of digital design, new forms and relationships between design and knowledge have been explored (Oxman, 2006). Approaching digital design as a design logic has necessitated a coherence between the production and materialization of design, introducing new dimensions to the designer, the process, and design knowledge (Oxman, 2008). Moreover, AI technologies, which can be considered a further step beyond digital design, have also prompted new inquiries into design knowledge and the black-box and glass-box processes.

The motivation behind these investigations arises from the new challenges and possibilities that the emergence of AI introduces to architectural epistemology. According to El Moussaoui (2025), AI technologies generate significant epistemological shifts, particularly through the difference between tacit and explicit knowledge. Explicit knowledge consists of codifiable principles, including geometric rules and structural reasoning, that can be readily translated into datasets and computational frameworks for AI systems. Because of its formalizable nature, this type of knowledge can be systematically captured and embedded within computational models. Tacit knowledge, on the other hand, encompasses intuitive, experiential, and practice-based understanding that resists direct codification. Since such knowledge is difficult to verbalize or digitize, AI systems may reproduce outputs derived from existing data but cannot genuinely "know" in the same way human designers do, particularly in situations involving uncertainty, interpretation, and novelty. For this reason, the discussion emphasizes the importance of combining human design expertise with knowledge generated through AI systems.

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The process of knowing in AI is based on algorithmic inferences. Although these inferences may be adaptive, their scope is quite limited. Consequently, the capability of AI is constrained by the information encompassed within its algorithmic framework. This information primarily consists of tacit and experiential activities, which are difficult to codify because they remain collective forms of knowledge that are learned and executed only by humans (Sanzogni, et al., 2017).

This situation brings discussions of the AI black box alongside the human designer's black box. AI, particularly through generative models, deeply infiltrates design processes. However, these systems are often criticized due to their black-box nature. They generate outputs from inputs, but their decision-making mechanisms are typically opaque to the user (Burrell, 2016). In this context, the concept of Explainable AI (XAI) has emerged. XAI aims to make the decision-making processes of AI systems visible, interpretable, and justifiable (Gunning & W. Aha, 2019; Miller, 2019).

3.3. Artificial Intelligence, Design Knowledge, and Explainability

The rise of artificial intelligence (AI) has generated significant transformations across a wide range of disciplines, altering established practices, conventions, and epistemological frameworks. In the field of architectural design, this transformation stems from AI-assisted tools' ability to simulate complex processes, generate extensive outputs, and produce striking visual forms rapidly. However, this transformation also raises critical questions regarding how AI reshapes architectural design knowledge, as well as the creation and production of knowledge itself (El Moussaoui, 2025).

Furthermore, the incorporation of AI into educational environments has generated a distinctive epistemological condition in which the boundaries separating human and machine-based knowledge production have become increasingly ambiguous. Unlike earlier technological developments, AI has initiated extensive debates regarding the ways rapidly operating AI systems may fundamentally reshape the production, validation, and dissemination of knowledge within educational contexts. This transformation calls for a critical examination of the evolving relationships established between human designers and AI-supported systems (Chen, 2025). Such developments indicate a broader paradigm shift in which machines function not only as producers of outputs but also as entities that consume, reinterpret, and reproduce knowledge (El Moussaoui, 2025).

According to Chen (2025), the forthcoming challenge requires conceptual approaches capable of capturing the nuanced interactions between technological systems and human knowledge practices. These approaches suggest focusing not on viewing AI tools as neutral additions to existing educational environments, but rather on how they epistemologically reshape these contexts.

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In this regard, the current literature evaluates the impact of AI in the design field from a dual perspective, suggesting that subjectivity, which has traditionally dominated architectural discourse and production processes, is beginning to be disrupted by AI. At the same time, it argues that the future of architectural design knowledge will depend on a balanced integration of AI's data-driven insights and recommendations with the qualified human knowledge that defines the field (El Moussaoui, 2025). This integration, however, raises certain debates. AI deeply infiltrates design processes, yet these systems are often criticized due to their black-box nature (Adadi & Berrada, 2018). They generate outputs from inputs, but their decision-making mechanisms are typically opaque to the user.

In the context of AI, the black box refers to the difficulty of understanding how AI systems process data and generate predictions or decisions. This gives rise to debates concerning transparency, accountability, and trustworthiness (Thalpage, 2023). In other words, considering AI as a technology that generates epistemological effects, the challenges represented by this black-box or opacity condition become evident. Since the outputs produced by AI are neither transparent nor human-readable in terms of how and why they are generated, AI is attributed as a black box that produces tacit knowledge (Barelli, et al., 2025).

At this stage, Explainable AI (XAI) has emerged as a significant field focused on overcoming the limited transparency and interpretability of AI models (Thalpage, 2023). The primary objective of XAI is to render the decision-making mechanisms of AI systems understandable and interpretable to users. Within the design discipline, XAI extends beyond merely clarifying algorithmic operations; it also contributes to making the design process itself more transparent and explainable.

The field of XAI focuses on methods for generating explanations regarding the behaviors and internal structures of these systems (Lam, 2022). XAI conveys understanding of AI models to end-users by highlighting the underlying decision paths in the model and allowing human interpretability at various stages of the decision-making process (Thalpage, 2023). In this context, XAI functions not only as a technological transparency tool but also as an epistemic interface. This interface enables the translation between human intuitive knowledge and AI's computational knowledge. From the designer's perspective, XAI allows comprehension of the logic behind AI decisions; from the AI's perspective, it converts human guidance into interpretable inputs. This bidirectional interaction facilitates the visibility of knowledge within the design process.

At this point, explainability is conceptualized through a distinction in which causality is considered a characteristic associated with individuals, while explainability is understood as an attribute directly

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related to the system itself. This differentiation establishes a conceptual framework for investigating and defining the diverse dimensions and requirements of explainability within AI systems (Thalpage, 2023). At the foundation of every AI system is data, regarded as a flexible and processable resource from which machine intelligence is generated. What is commonly described as the training process involves exposing algorithms to extensive datasets so they can detect patterns, identify relationships, and generate outputs that simulate analytical or creative forms of production (El Moussaoui, 2025).

When generalizing the distinction between tacit and explicit knowledge in the context of AI, explicit knowledge is associated with being readily observable or directly accessible, whereas tacit knowledge requires a form of inference or interpretation based on the system and its behavior. The way to define AI's tacit knowledge is understood as its causal role in generating specific outputs and its structuring in a manner consistent with a particular rule within the system (Lam, 2022).

Accordingly, the tacit understanding of these rules is considered to reside within the system itself. This suggests that an explanation based on the system's adherence to a rule extends beyond a purely statistical interpretation. The explanation concerns not only the resulting behavior but also the agent producing that behavior-namely, the system. Therefore, when a system is understood to possess tacit knowledge of a rule, the system itself becomes the subject of explanation, operating according to specific criteria through causal relationships embedded within its decision-making processes (Lam, 2022). In this sense, the system is regarded as containing tacit knowledge and functioning as a black box.

A clear understanding of how human cognition differs from artificial intelligence is necessary for the effective integration of AI into knowledge-based practices. Humans generate knowledge through lived experience, social interaction, and reflective awareness, while AI systems process information through parametric structures distributed across billions of computational parameters (Bommasani et al., 2022). Rather than relying on true conceptual or causal understanding, these systems operate by identifying statistical relationships within large-scale training datasets. Unlike AI, human cognition involves consciousness, intentionality, and embodied perception, all of which remain beyond the capabilities of current AI systems (Chen, 2025). At the same time, the expanding role of generative AI in activities such as modeling and feedback production has led to growing epistemological debates concerning the representation, construction, and interpretation of knowledge, producing new forms of duality within these processes (Billingsley, 2025).

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3.4. A New Epistemological Paradigm: A Multi-layered Knowledge Ecosystem

The growing prominence of AI within architectural design has generated new epistemological questions concerning the relationship between machine-based processes and human creativity, thereby marking the emergence of a new paradigmatic threshold. This stage of transformation requires going beyond the notion of simple automation and instead examining the conditions in which human creativity and machine intelligence can develop in a mutually supportive manner. Within this context, the interaction between designers and AI is described as a symbiotic or co-evolutionary relationship, based on the understanding that both human designers and AI systems possess distinct epistemological capacities as well as inherent limitations (El Moussaoui, 2025).

Within this emerging framework, human intelligence and AI collectively function as a unified design information processor, engaging in a continuous exchange of knowledge conceptualized as a flow of energy. In this process, human intelligence provides the design intentions and requirements, whereas AI adapts computational algorithms according to these inputs and produces alternative solutions from which stakeholders may choose. At the same time, human agents determine the criteria that define design quality, while AI translates these criteria into parametric structures, evaluates possible solutions, and repeatedly optimizes them to generate outcomes aligned with human expectations and directives (Liu & Fu, 2024). In these dynamic ecosystems, where humans and AI collaboratively generate and share knowledge, the integration of machine capabilities with human cognition creates opportunities for new forms of insight and innovative solutions (Eroğlu, 2025).

In the first of these insights, Youvan (2025) explains the dual relationship between AI and human intelligence through the concept of epistemic resonance. Rooted in the convergence of human symbolic intuition and the emergent pattern-recognition capacities of advanced AI systems, this paradigm shifts the basis of knowledge from evidence, deduction, or belief toward resonance. Epistemic Resonance invites recursive, intuitive, and relational alignment of meaning rather than seeking certainty through control or singular narratives. It posits that truth or knowledge is not only discovered but also co-produced within the dynamic interplay between human and machine cognition, operating within symbolic and structural coherence domains. In this context, Youvan (2025) proposes a redefinition of knowledge itself as a multilayered coherence.

According to El Moussaoui (2025), within this new epistemological paradigm, the layered structure of design knowledge is examined from a distinct perspective. Focusing on the limitations and potentials of both human and AI, this approach argues that AI's active participation in design knowledge production positions it not merely as a generative mechanism but as an epistemological collaborator that expands human access without replacing human judgment. This active interaction is proposed to enrich architectural design knowledge horizontally, by exploring diverse aesthetic possibilities, and vertically, by delving into deeper layers of critical, cultural, and philosophical insight, drawing nourishment from multiple interrelated layers.

Similarly, Moleka (2025) argues that moving beyond the traditional epistemological framework requires a paradigm shift in consciousness and knowledge production, proposing an interdisciplinary epistemological framework to redefine intelligence and knowledge production as a multilayered, dynamic, and emergent phenomenon. The study also addresses the layered transformation of design knowledge through AI technologies. AI reconfigures the way knowledge is synthesized, requiring human actors to reposition themselves within a substantially expanded epistemological space. For the field of architectural design, this means redefining design and the production of design knowledge not as a linear action, but as a layered, probabilistic, and computationally mediated system (El Moussaoui, 2025).

This perspective clarifies how understanding is developed through dialogical exploration and inquiry within AI-mediated or co-creative environments, drawing attention not only to the outcomes of learning but also to the processes through which knowledge is actively constructed rather than passively received. It further underlines the transformative and co-evolutionary character of these interactions, where both human participants and technological systems gradually develop new forms of adaptation and strategic behavior over time. Taken together, these approaches position AI tools not simply as supportive instruments but as active contributors to the co-production of knowledge, thereby revealing emerging epistemological configurations within human–AI ecologies (Chen, 2025).

Unlike traditional epistemology, where knowledge is discovered or extracted, every interaction between humans and AI forms a feedback loop. In this loop, the human designer presents a knowledge query, and the AI responds with different syntheses that may lead to unexpected alignments. The human then reflects, perceives, and redirects. Each subsequent query incorporates both insight and intuition. This process repeats, often spiraling inward toward an epistemic center. Over time, these cycles increase coherence, as ideas are revisited, reframed, and refined. This process advances not linearly but through iterative deepening (Youvan, 2025). As Moleka (2025) also notes, this emphasizes the emergent, co-constructed, and non-hierarchical nature of knowledge.

In other words, rather than accepting the AI output as final, the human designer questions its appropriateness and sensitivity, then reshapes it using experience, intuition, and contextually derived insights. In this context, the resulting design and design knowledge become a hybrid outcome, not solely human nor solely machine, but a synthesis emerging from an active and ongoing negotiation between the two (El Moussaoui, 2025). This creates an interactive, reflexive, shared (networked), and multi-layered structure in the production of design knowledge.

This structure emphasizes that AI systems have become a component of the epistemic infrastructure. However, these systems are viewed not as mere extensions of existing cognitive processes, but as active participants in the co-creation of knowledge and understanding (Chen, 2025).

As emphasized by Anlı (2025), these developments necessitate understanding the role of AI in knowledge production not simply as a technological shift, but as a profound epistemological rupture. This transformation affects not only the substance of knowledge itself, but also the ways in which knowledge is produced, regulated, and legitimized through evolving authority structures. In this context, conventional theories of knowledge appear increasingly insufficient for explaining the implications of this emerging phenomenon. Accordingly, AI is framed not merely as a technical instrument, but as an epistemological actor capable of reshaping existing knowledge regimes, thereby underscoring the need to critically reconsider and reformulate established assumptions and theoretical frameworks concerning knowledge.

In this new epistemological paradigm, where design knowledge encompasses various propositions and debates regarding its nature and modes of production, this study approaches the subject through the ways design knowledge is produced. In the age of AI, design knowledge is examined along three dimensions: the human subject's intuitive knowledge (human black box), AI's algorithmic inferences (AI black box), and explainability (glass box). By linking these dimensions to the box metaphors, the study discusses the evolving, transforming, and multi-layered nature of design knowledge from a distinct perspective.

4. THEORETICAL FINDINGS AND DISCUSSION

In classical design theories, knowledge is generally approached as a linear, one-way process progressing from designer-process-product. In this framework, the black box and glass box metaphors represent either the opacity or the transparancy of the process. However, in the age of AI, as emphasized by Anlı (2025), these explanations become insufficient and the linear structure breaks down. Knowledge is no longer produced from a single source (the designer), nor does the process operate unidirectionally. The product itself becomes not merely an outcome but also a layer of knowledge that generates feedback. Consequently, black box and glass box metaphors can no longer be explained as sequential or opposing stages. These approaches are inadequate for explaining contemporary design knowledge because, with AI and especially XAI, these layers are no longer sequential stages but epistemic layers that mutually permeate each other.

In AI-assisted design processes, these boxes no longer function as separate entities but operate in an intertwined manner. As supported by Youvan (2025), the designer's tacit intuitions guide the AI's suggestions, while the AI's data-driven inferences prompt the designer to recognize relationships they might not have perceived. When the process is structured to be explainable, XAI ensures that design decisions are justifiable, bringing transparency to knowledge. In this way, the two black boxes begin to become transparent; knowledge is revealed, made explainable, and open to discussion. Consequently, in the design process, knowledge is not only produced but the mode of its production also becomes visible and explicable.

In AI-supported design environments, knowledge no longer exists as a singular epistemic form but embodies a layered totality. These layers—intuitive (black box), algorithmic (black box), and explanatory-transparent (glass box)-(XAI)—continuously permeate one another, generating new meanings. Moreover, XAI's transformation of the traditionally opaque black-box nature of AI into epistemological transparency carries significant implications for this newly emergent, multilayered form of knowledge.

The first of these is the increased reflexivity of design knowledge. The human designer is now required to observe not only what they design but also how they design it. Similarly, AI systems must provide explanations for what they design and why. This reflexive structure necessitates mutual reflection on the knowledge that is produced or revealed.

The second effect concerns the change in the status of knowledge. Design knowledge no longer relies solely on individual intuition (human designer as a black box) but also draws on AI's algorithmic data and inferences (AI' black box) and explainable decision chains (glass box). Explainable AI (XAI) opens these two opaque systems to each other, making the process visible, discussable, and teachable. It enables knowledge to be reproduced in a shareable, critiquable, and improvable way. Instead of sharp boundaries between human intuition and machine inference, there is a continuous transition. As supported by Billingsley (2025), Chen (2025), El Moussaoui (2025), and Youvan (2025) this transition renders knowledge a hybrid product of both human and computational elements.

All of this carries the third effect: the potential to redefine the epistemological structure of design knowledge, as emphasized by Anlı (2025) and Chen (2025). Design knowledge is no longer solely tied to the designer subject nor static and hierarchical, as also noted by Moleka (2025); instead, it is emergent and co-created. At the same time, it becomes computable, explainable, and shareable. This transformation fundamentally changes the epistemological nature of design knowledge. Individual intuition-based knowledge gives way to collective, explainable, and systematic knowledge production. Consequently, the question “what does the designer know?” evolves into “who produces knowledge, under what conditions, and at what level of explainability?”

In this regard, the study argues that design knowledge in the age of AI no longer emerges from a single source or a linear process. Instead, knowledge takes the form of a multilayered epistemic network generated through the simultaneous interaction of human intuition (the human black box), algorithmic inference (the AI black box), and explanation processes (the glass box). Approaches in the literature, including those of Eroğlu (2025), El Moussaoui (2025), and Liu and Fu (2024), also support this discussion of a networked structure. From this perspective, knowledge is not merely produced; it is continually shaped within the network through ongoing feedback between humans, AI, and explanation systems, ultimately taking on a network-like form. These three layers are not stacked but interwoven. Each layer transforms the others, and knowledge flows not in a fixed direction but in a circular and interactive manner.

In this study, these layers are defined as follows: The human layer encompasses intuitive, experiential, and context-sensitive knowledge; the artificial intelligence layer generates data-driven, pattern-extractive, and computational knowledge; the explanation layer (XAI) provides meaning, justification, and visibility (transparency) between these two domains of knowledge.

These three layers are not discrete but permeable. Knowledge leaks from one layer into another, is reshaped, and thus the production of meaning becomes continuous. Consequently, design knowledge is neither solely intuitive nor entirely computational; it exists in a hybrid, reflexive, and plural form. Subject-centered knowledge gives way to shared knowledge, as knowledge in this system does not belong to a single subject. As also argued by Anlı (2025), AI enters the process as an epistemological agent that reshapes knowledge regimes. Knowledge emerges through the interaction between humans and systems. From another perspective, the black boxes are no longer entirely closed; each leaks information into the other. This condition can be associated with the increasing permeability of design knowledge.

In other words, when AI enters the design process as a cognitive actor, the black box itself becomes plural: both the human and the machine bring their own black boxes into the process. XAI functions as an epistemic interface between these two black boxes; it not only provides explanations but also

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enables the emergence of new forms of knowledge. Accordingly, design knowledge becomes a process generated through the circulation of knowledge between humans and machines—comprising the human black box, the AI black box, and the glass boxes that render the dialogue between these two domains visible through explainable processes.

In this regard, the study argues that, in the age of AI, design knowledge is no longer a linear chain of production but a multilayered knowledge ecosystem. In this ecosystem, black boxes and glass boxes cease to function as sequential or opposing stages; instead, they become epistemic layers that exchange data, intuition, and meaning with one another. Thus, the linear progression from black box to glass box is replaced by a layered, feedback-oriented, permeable, and dynamic knowledge network. This shift necessitates a reconsideration of the very nature of design knowledge, as knowledge is no longer purely intuitive nor entirely computational; rather, it evolves into a hybrid, permeable form that is continuously reproduced.

With these findings, the study emphasizes that design epistemology can no longer be explained through a singular, subject-centered model of knowledge production. Therefore, it proposes an approach that conceptualizes AI-supported design processes as a knowledge ecosystem formed by the triad of the human, the machine, and explanation.

5. CONCLUSION

This study opens a discussion on the profound transformation in the nature of design knowledge in the age of AI. In classical approaches, design knowledge was largely viewed as an intuitive domain generated within the designer's mental processes and described through the metaphor of the black box. Subsequent glass-box approaches sought to render this process visible and systematic, enabling analytical access to knowledge. However, with the integration of AI systems, particularly generative and explainable forms, into the design process, the boundaries of these two models begin to lose their validity. This is because AI not only plays an instrumental role but also enters the design process as an epistemic actor. This shift removes knowledge production from a single source and redefines it as a multilayered interaction among humans, algorithms, and explanation processes.

Thus, design knowledge no longer exists as a linear flow (input–output) but as a dynamic, permeable, and hybrid ecosystem. This ecosystem is built upon three fundamental components (Figure 1): Human layer (Human Black Box): Human-centered, experiential, and context-sensitive forms of knowledge. Artificial intelligence layer (AI Black Box): Data-driven, statistical, and pattern-extractive knowledge production. Explanatory layer (XAI) (glass Box): An interface that provides meaning, justification, and visibility across knowledge flows.

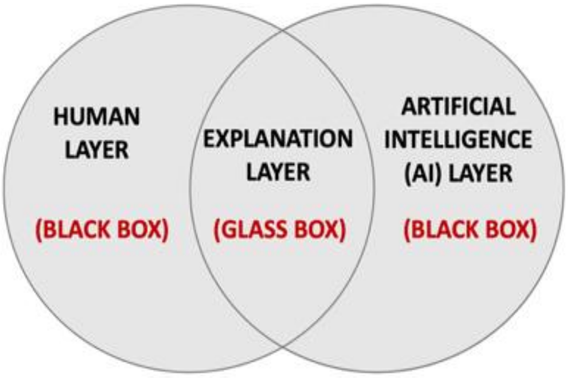

Figure 1. Multi-layered structure of design knowledge (Prepared by the author)

When these three layers operate together, knowledge no longer belongs to a single subject; it becomes a collective product of human–AI interaction. Consequently, design epistemology has evolved from a subject-centered approach to a networked and collective mode of knowledge production. This transformation has three primary implications. The first is hybridity in knowledge production. Knowledge exchanges between humans and machines integrate both the cognitive and computational dimensions of design. This permeable structure renders design knowledge a collective product of both human and computational (AI) elements, demonstrating that it relies on the dynamic balance between the two.

The second significant change concerns the reflexivity of design knowledge. Designer-actors (human and AI) are now required not only to produce but also to reflect on, explain, and justify their modes of production. This transforms design knowledge from a static output into a continuously reconstructed process. The third implication pertains to the nature of design knowledge. The influence of AI technologies necessitates a redefinition of design knowledge from an epistemological perspective. Design knowledge is no longer solely associated with the individual designer, nor is it static or hierarchical. Rather, it exists as a layered structure co-created through the integration of AI and explainability dimensions.

In this context, the study proposes a new paradigm in addition to existing theories of design knowledge. According to this paradigm, the sources of design knowledge consist of three components: human knowledge (acquired through intuition and experience), artificial intelligence inferences, and the reflexive and cyclical knowledge that emerges from the interaction between these two elements. Within this paradigm, the visibility of knowledge is addressed through an approach in which black boxes proliferate and the glass box refers not only to the visibility of the process but also to its explainability. In this framework, design knowledge is conceptualized as a multi-layered knowledge ecosystem. By extending the epistemological nature of design thinking beyond linear models, the study proposes a multilayered knowledge paradigm grounded in human-AI interaction. In this regard, the study distinguishes itself from existing research by emphasizing the multilayered knowledge ecosystem and introducing a third epistemological approach that transcends the traditional black box–glass box dichotomy, thereby highlighting its originality.

It is recommended that future research empirically test this conceptual approach or explore its integration into educational settings, where students can be assessed not only on their design outcomes but also on their ability to explain and justify their decisions. In conclusion, in the age of AI, design knowledge is no longer instrumental production knowledge but a multilayered knowledge ecosystem. Within this new plane, design epistemology is not tied to a single subject; it becomes networked, explainable, reflexive, and collective. Thus, AI not only transforms design knowledge but also necessitates a reconsideration of the very way in which design constitutes knowledge.

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The author has no conflicts of interest to declare.

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