Published by Avanti Publishers
International Journal of Architectural Engineering Technology
ISSN (online): 2409-9821

Educating for Unbuilt Futures: AI as a Co-Speculative Partner in Climate-Resilient Architectural Pedagogy

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ARTICLE INFO

Article Type: Research Article

Guest Editor: Ferdinando Salata

Keywords:
Human–AI co-agency
Cognitive systems in design
Ethics and empathy in design
AI-driven architectural pedagogy
Climate-resilient design education

Timeline:
Received: August 01, 2025
Accepted: November 10, 2025
Published: November 30, 2025

Citation: Makakli ES. Educating for unbuilt futures: AI as a co-speculative partner in climate-resilient architectural pedagogy. Int J Archit Eng Technol. 2025; 12: 145-157.

ABSTRACT

Architectural education stands at a critical intersection of accelerating climate crises, technological transformation, and social complexity. At the center of this transition lies Artificial Intelligence (AI)—a defining technology reshaping both design processes and cognitive paradigms. Although AI is becoming increasingly embedded in architectural practice, its pedagogical potential remains predominantly instrumental, often limited to applications in form generation and performance optimization. This study reframes AI as a co-speculative pedagogical partner—a reflective agent capable of nurturing ethical, ecological, and contextually responsive design intelligence. Responding to contemporary challenges such as climate instability, resource scarcity, and spatial inequality, the research aligns with the Sustainable Development Goals (SDGs 4, 11, and 13). A multi-layered qualitative methodology was adopted to: (i) synthesize theoretical perspectives from speculative design, cognitive science, and environmental philosophy; (ii) examine international frameworks (NAAB, RIBA, UNESCO) to understand how AI's pedagogical dimension is articulated; and (iii) compare traditional studio pedagogies with emerging AI-augmented workflows. Together, these layers construct a reproducible framework for evaluating AI's educational integration. The findings identify five interconnected competency domains—technological literacy, strategic design thinking, environmental sensitivity, ethical awareness, and collaborative agency—derived from recent studies and international educational frameworks. While these domains resonate with existing institutional standards, they also reveal the need for new pedagogical models that situate AI within broader ecological and ethical objectives. The study argues that AI can function as a medium for contextual intelligence—bridging computational logic with embodied, climate-responsive creativity. The proposed framework reimagines architectural education as a reflective and adaptive ecosystem where AI enhances, rather than replaces, human judgment. It fosters a synergistic dialogue between data-driven reasoning and embodied design intelligence, preparing future architects to act ethically, creatively, and ecologically within complex design environments.

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1. Introduction

Architectural education has continually evolved in dialogue with technological and cultural transformations. From the prescriptive traditions of the Beaux-Arts ateliers to the Bauhaus's synthesis of art, craft, and industry, each pedagogical paradigm has redefined how design is conceived, represented, and taught. The late twentieth century's digital turn—marked by the emergence of CAD, parametric modeling, and computational design—introduced a profound shift in architectural pedagogy, reshaping not only the act of drawing but also the cognitive frameworks that underpin design thinking [1- 2]. However, despite these advances, digital tools have often been instrumentalized, serving primarily as means of efficiency and optimization rather than as catalysts for critical reflection or ethical awareness.

As architectural pedagogy continues to evolve, the design studio has persisted as a dynamic environment for cultivating experimental and reflective intelligence. Through its exploratory nature, the studio encourages students to question conceptual and physical realities, explore open-ended problems, and engage with diverse contextual conditions that anticipate the unknown challenges of the future. Learning within the studio evolves through iterative experimentation, critical dialogue, and a sustained engagement with uncertainty and ambiguity [3- 4]. This tradition values the maturation of ideas, where learning through creative engagement [5] is inseparable from learning through being—a process rooted in material experimentation, contextual awareness, and the embodied experience of place. Such pedagogical grounding fosters originality, critical sensibility, and a tacit ecological intelligence vital to architecture's dialogue with both human and non-human worlds. The architectural design studio continues to evolve as it encounters the expanding complexities of climate, technology, and society. Its enduring emphasis on creativity and reflection is now being complemented by a broader pedagogical vision—one that embraces collective, ecological, and ethically responsive dimensions of design learning.

In contemporary architectural education, Artificial Intelligence (AI) is emerging as a transformative medium that reshapes how design problems are conceived, visualized, and critically reflected upon—opening new pedagogical trajectories for design learning and creative inquiry. Yet, despite its growing visibility, AI is frequently approached as a hyper-efficient generator or visualization tool—one that risks privileging output over inquiry and simplifying design's relational and ethical complexity into questions of optimization. Consequently, its use often remains confined to isolated tasks of form-generation or visual representation, detached from broader pedagogical, ethical, and ecological dimensions of architectural thinking.

Recent scholarship has highlighted the risks of reducing AI to a purely instrumental or operational role, emphasizing concerns such as algorithmic bias and the erosion of creative authorship [6]. These debates open a space for rethinking how AI can contribute meaningfully to architectural pedagogy not as an automated assistant, but as a reflective collaborator in learning and design thinking. Building upon the perspectives of speculative design [7], human-centered AI [8], and ethical intelligence frameworks that emphasize responsibility and reflection in technological practice [9], this study situates its inquiry within the evolving discourse on human–AI creativity in architecture [10]. It repositions AI as a co-speculative pedagogical partner—a medium through which critical reasoning, ethical awareness, and ecological imagination can be cultivated in design education.

This paper explores the pedagogical potential of AI as a catalyst for strategic design thinking, ethical awareness, and environmental sensitivity in architectural education. As the effects of climate change intensify and spatial inequalities persist, architecture must prepare future practitioners not only to engage with data and computation but also to think critically about responsibility, uncertainty, and long-term impact. The urgency of aligning architectural education with the United Nations Sustainable Development Goals (SDGs) makes this transition even more compelling.

Despite the growing urgency of this paradigm shift, the pedagogical potential of AI remains insufficiently articulated. A significant gap persists between its technological capacity and its meaningful application within design education. Existing international frameworks NAAB [11], RIBA [12], UNESCO–UIA [13, 14], though addressing sustainability and technology in broad terms, place limited emphasis on embedding AI as a pedagogical agent. This highlights the need to reconceptualize design education not merely as technical training but as an ethical and ecological endeavor shaped by evolving forms of intelligence, creativity and responsibility.

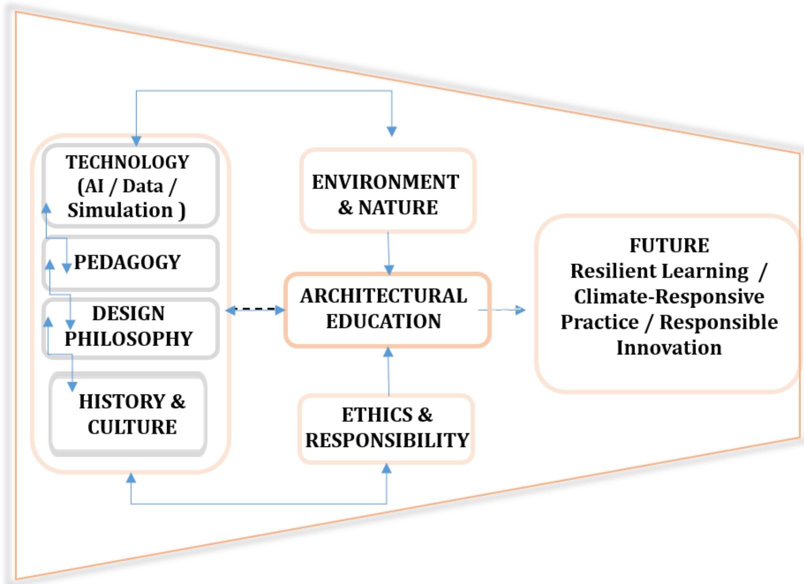

Figure 1: AI-Integrated architectural education.

Accordingly, this study explores the following guiding question:

"*How might Artificial Intelligence be positioned as a co-speculative pedagogical partner in architectural education to foster ethical awareness, strategic design thinking, and ecological sensitivity in alignment with the Sustainable Development Goals (SDGs 4, 11, and 13)?*"

To reflect upon this question, the paper adopts a multi-layered qualitative methodology outlined in Section 3. It synthesizes theoretical strands from speculative design, cognitive science, and post-humanist environmental philosophy [15]; critically examines the aforementioned frameworks; and undertakes a pedagogical reflection on the evolving relationship between traditional studio workflows and AI-augmented approaches. Rather than seeking definitive answers or empirical validation, the study aims to open a reflective space for reconsidering how design education might integrate digital fluency with ethical responsibility and ecological awareness.

2. Theoretical Framework

As global ecological urgencies call for context-sensitive and adaptive design strategies, architectural pedagogy faces a pressing challenge. It is increasingly challenged to explore how students might engage with Artificial Intelligence (AI) as a medium for systemic insight, environmental responsiveness, and critical reflection. Drawing upon intersecting theories from design pedagogy, speculative design, and human–AI collaboration, this study proposes positioning AI as a co-speculative partner in architectural learning—one that provokes reflection rather than replaces reasoning.

The theoretical foundation of this study is built upon three interconnected strands. The first, computational co-creation, explores AI as a collaborator in ideation and scenario testing. The second, strategic pedagogy, links design education to broader societal and ethical imperatives. The third, climate-adaptive intelligence, positions environmental data as a formative agent in early-stage design thinking. The tension between the immediate, associative generation of AI and the in-depth, reflective reasoning required for ethical and ecological design finds a conceptual analogue in D. Kahneman's [16] model of cognitive systems. Kahneman distinguishes between two modes of cognition: System 1, characterized by immediacy, intuition, and associative reasoning; and System 2, defined by depth, reflection, and analytical rigor, requiring focused attention for ethical and critical thought. In its prevalent application, generative AI mirrors the associative tendencies of System 1, whereas architectural pedagogy has long cultivated the reflective and critical virtues associated with System 2. This cognitive framing illuminates the central pedagogical challenge: the task is not to substitute one cognitive mode for another, but to design an educational partnership in which AI's generative capacities provoke, rather than replace, the human ability for thoughtful and ethical judgment. This analogy is intended not as a strict cognitive mapping, but as a conceptual device for framing complementary reasoning modes.

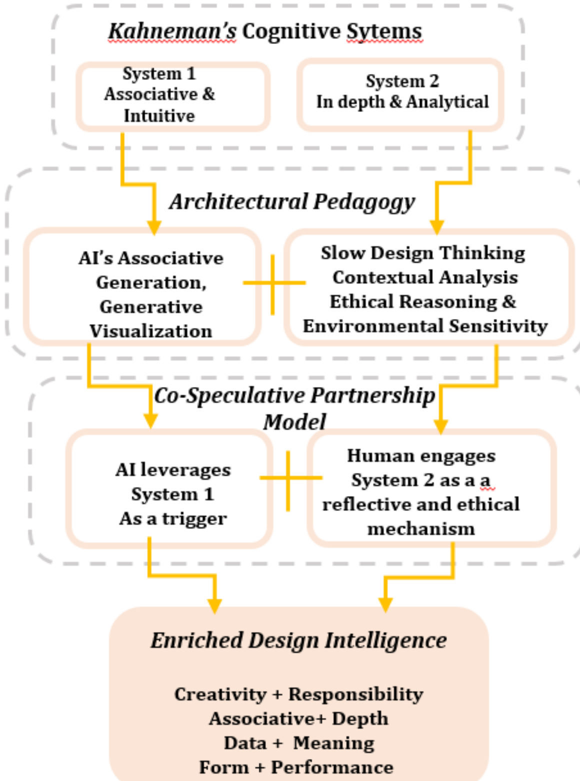

Figure 2: The Co-Speculative Partnership Model linking AI's fast generative logic (System 1) with human reflective judgment (System 2) in architectural pedagogy.

This necessity for a reflective partnership is further underscored by perspectives from computation theory. Scott Aaronson, a theorist on the foundations and limits of AI, observes that although AI demonstrates remarkable capacities in pattern recognition and symbolic manipulation, it still lacks the embodied understanding, conscious intentionality, and lived experience that define human cognition [17]. These limitations, while describing AI's current state rather than its ultimate potential, serve as an important reminder that meaningful design intelligence arises through interpretation and reflection. Within this pedagogical view, AI becomes not an autonomous originator of form, but a catalyst for exploration, speculation, and ethical imagination—a partner that expands rather than replaces the interpretive agency of the designer.

While theoretical reflections delineate the cognitive boundaries of AI, contemporary design research increasingly reframes these technologies as active participants in creative and environmental reasoning. Recent scholarship signals a profound shift in AI's role—from peripheral visualization aid to cognitive collaborator within early-stage design thinking [18-21]. Generative and simulation-based systems that integrate climatic parameters such as energy use, daylight, and airflow now allow students to test spatial hypotheses through real-time environmental feedback [22]. These tools extend the pedagogical space of design, cultivating foresight, adaptability, and ecological awareness. Yet, this transformation requires more than technical proficiency. As Oxman [2] emphasizes, digital pedagogy must advance beyond instrumental mastery toward critical reasoning and ethical reflection. Accordingly, AI literacy should encompass not only algorithmic fluency but also a critical understanding of bias, transparency, and the socio-ecological consequences of automated processes [23, 24]. Within this framework, the notion of "deliberate incompleteness" gains renewed pedagogical significance—inviting students to engage AI not as a producer of resolved outcomes, but as a medium for interpretation, speculation, and participatory exploration in design learning.

Within this broader transformation, architectural education remains a fertile ground for examining how AI engages with the reflective ethos of design inquiry. Design, in this sense, operates as a mode of investigation that transforms uncertainty into knowledge through acts of making, iteration, and critical engagement. The studio environment nurtures this process as a situated form of reasoning—where ideas are materialized, tested, and reframed through both conceptual and tactile exploration. Perspectives from speculative design [7] and human-centered design thinking [25] further illuminate design as a practice that unites cognition and ethics. Dunne and Raby foreground design's speculative capacity to question the present and imagine alternative futures, while Brown situates it within a collaborative and empathic process of experimentation. Together, these perspectives resonate with the pedagogical culture of the studio, where envisioning, testing, and reframing become integral to learning. Building on this synthesis, the framework proposed here positions Artificial Intelligence (AI) as a mediator within this pedagogical ecosystem. Drawing on human-centered AI principles [8]—which emphasize agency, transparency, and collaboration—it aligns with an ethic of care and responsibility central to architectural practice. Rather than displacing the embodied and contextual intelligence cultivated in studio learning, AI has the potential to extend it: rendering tacit reasoning visible, simulating complex spatial dynamics, and opening new domains for ethical and ecological reflection within architectural thought. Within this theoretical construct, Artificial Intelligence (AI) is not conceived as a substitute for human creativity but as a speculative and dialogic partner that supports complex reasoning, expands design agency, and enables ethical reflection. This redefinition situates AI within a broader pedagogical discourse that seeks to reconcile technological innovation with ecological responsibility and social awareness. In doing so, it bridges cognitive, technical, and ethical dimensions of learning and provides the conceptual basis for defining five thematic competency domains that guide AI's integration into architectural education.

Drawing from the reviewed literature and cross-analysis of international frameworks, these five competency domains are identified as: (1) technological literacy, (2) design integration, (3) ethics and responsibility, (4) climate responsiveness, and (5) interdisciplinary collaboration. They are informed by recent scholarship in AI pedagogy and climate-adaptive design [13, 26-31] and align with critical discourses in architectural education that advocate for technological fluency combined with ethical and ecological awareness [32, 33]. Collectively, these references establish a validated foundation for structuring pedagogical competencies that connect digital innovation, ethical agency, and environmental responsibility. At the institutional level, frameworks such as NAAB [11], RIBA [12], and UNESCO–UIA [13] offer valuable guidance on innovation and sustainability but provide limited articulation of how AI-related competencies can advance climate-responsive and ethically grounded design education. This absence underscores the need for models that embed AI within holistic educational goals—particularly those aligned with SDGs 4 (Quality Education), 11 (Sustainable Cities and Communities), and 13 (Climate Action). Building upon this context, the present framework advances the notion of AI as a strategic pedagogical partner—an interpretive and generative medium that deepens reflective practice and strengthens the ethical and ecological orientation of architectural learning. By reframing AI as a co-educator, the study contributes to an evolving vision of architectural pedagogy where innovation, responsibility, and empathy coalesce within a shared human–machine dialogue.

As summarized in Table **1**, the proposed model situates architectural education at the center of a multi-domain ecosystem that interconnects technology, ethics, design philosophy, and environmental awareness. This integrative structure illustrates how AI mediates between these domains—fostering the design studio into a reflective, ethically grounded, and ecologically attuned learning environment for architectural reasoning.

3. Methodology

This study employs a multi-layered qualitative methodology to investigate how Artificial Intelligence (AI) can be meaningfully integrated into architectural education—not merely as a technical instrument, but as a pedagogical agent that shapes reflective and value-based learning. Conceived as a conceptual and comparative inquiry, the research aims to construct a framework that connects AI with the ethical, ecological, and cognitive dimensions of design education.

The first analytical layer establishes the study's conceptual foundation through a critical synthesis of literature across intersecting theoretical strands: speculative design and critical futures [7]; human-centered AI and ethics

Table 1: Mapping the co-speculative partnership: AI's role across pedagogical domains and associated dimensions.

Core Domain	Associated Concepts	Pedagogical Function	Relation to AI Integration
Architectural Education (Center)	Learning through reflection, discovery, and contextual reasoning	Serves as the integrative field connecting all other domains	Becomes a living framework where AI acts as a co-speculative partner
Technology	AI, computation, simulation, digital literacy	Provides tools and data for inquiry and testing	Moves from instrumental use to dialogic and reflective intelligence
Pedagogy	Design studio, reflection-in-action, learning by doing	Cultivates critical, ethical, and systemic thinking	Embeds AI as a pedagogical agent to enhance reflection and foresight
Design Philosophy	Speculative design, co-speculation, critical imagination	Expands creative thinking toward possible futures	Frames AI as a medium for exploring the "adjacent possible"
Ethics & Responsibility	Care, virtue, agency, bias awareness	Guides moral reasoning and value-based decision-making	Encourages students to question and act responsibly within AI systems
Environment & Nature	Climate, ecology, material intelligence	Grounds design thinking in planetary awareness	Enables climate-responsive and sustainable approaches
History & Culture	Tradition, continuity, contextual intelligence	Connects future-oriented design to inherited knowledge	Uses AI for reinterpreting and recontextualizing heritage data
Human	Agency, co-creation, empathy, embodiment	Maintains the central role of human judgment and creativity	Positions AI as augmenting—not replacing—human imagination
Future	Speculative foresight, resilience, adaptability	Orients learning toward uncertain, plural futures	Uses AI to simulate scenarios and test ethical/ ecological alternatives

[8, 9]; architectural computation and design cognition [20, 2]; and ecological philosophy [15]. To assess how current architectural education frameworks engage with the pedagogical potential of AI, a targeted document analysis was conducted on three globally recognized frameworks:

- *NAAB (National Architectural Accrediting Board) – 2020 Conditions for Accreditation (Revised May 2025)*, representing North American educational standards with a strong emphasis on digital and technological competencies.
- *RIBA (Royal Institute of British Architects) – RIBA AI Report (2024),* outlining the implications of Artificial Intelligence for architectural practice and its broader pedagogical context, with an emphasis on ethical responsibility, transparency, and human-centered creativity.
- UNESCO–UIA (United Nations Educational, Scientific and Cultural Organization – International Union of Architects) – 2023 Charter for Architectural Education (Revised), outlining a globally oriented educational vision grounded in sustainability, equity, and cultural responsiveness.

These reference systems were selected for their regional diversity, conceptual influence, and distinct educational priorities. Each document was examined through qualitative content analysis, using keyword scanning and thematic coding focused on AI-relevant pedagogical dimensions. The keyword set included: "artificial intelligence," "simulation," "data-driven," "generative design," "algorithmic," "digital literacy," "climate adaptation," "parametric," and "automation." Through this process, the documents were examined across five thematic competency domains distilled from the literature on AI pedagogy and climate-adaptive design.

- *Technological Literacy, encompassing digital fluency, simulation, and data processing.*
- *Design Integration, addressing generative workflows and algorithmic reasoning.*
- *Ethics and Responsibility, including issues of bias, authorship, and agency.*
- *Climate Responsiveness, involving performance modeling and environmental awareness.*
- *Interdisciplinary Collaboration, fostering cooperation with allied fields such as data science and engineering.*

Each reference within these documents was initially categorized as explicit, implicit, or absent, indicating the degree to which AI-related pedagogical themes were addressed. To enhance comparative clarity, these categories were later translated into a three-level coding scale (✓ = weak association, ✓✓ = moderate, ✓✓✓ = strong pedagogical potential) as presented in the findings tables.

The final methodological layer reflects on the pedagogical principles inherent in architectural studio culture and the evolving dynamics introduced through AI-augmented workflows. Rather than treating these pedagogical models as binary opposites, the analysis recognizes their points of convergence and shared educational intentions. It draws upon reflective insights from design studio observations, where hybrid analog–digital practices sustain the iterative and context-driven ethos of architectural learning.

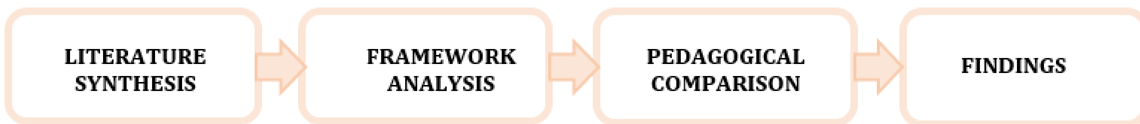

Figure 3: Research framework.

This study is conceptual in nature, and its analytical framework is interpretive—grounded in cross-disciplinary literature synthesis, institutional document analysis, and theoretical comparison, rather than empirical fieldwork or experimental testing. The findings are intended to offer transferable pedagogical insights rather than statistical generalizations.

4. A Pedagogical Framework for AI Integration

While Artificial Intelligence (AI) continues to evolve rapidly, its presence within global frameworks and pedagogical practices in architectural education remains uneven—strong in digital performance and technical literacy, yet limited in ethical, ecological, and collaborative dimensions. While institutions such as NAAB, RIBA (AI Report, 2024), and UNESCO–UIA (2023) acknowledge the importance of technological innovation, few articulate how AI can actively contribute to reflective, ethical, and climate-responsive modes of design learning.

Across the three frameworks, technological literacy emerges as the most explicitly articulated area, particularly within NAAB's emphasis on digital tools, computational representation, and performance-based analysis. Yet, explicit references to Artificial Intelligence, machine learning, or data-driven workflows remain largely absent, limiting their relevance to emerging design practices. Strategic design thinking and collaborative agency appear only implicitly, framed through objectives of problem-solving, interdisciplinary engagement, and adaptability—without clear guidance on how such competencies might evolve through AI-enhanced pedagogies. Ethical awareness, while consistently acknowledged across all frameworks—and particularly emphasized in the RIBA AI Report tends to overlook AI-specific issues such as algorithmic bias, data transparency, and authorship ambiguity. By contrast, environmental sensitivity is most clearly foregrounded in the UNESCO, which positions sustainability and cultural responsibility at the core of architectural education. However, even within this framework, the pedagogical potential of AI-driven tools—such as climate simulation, energy modeling, or life-cycle analysis—remains underexplored as a means of fostering climate-responsive design learning.

This absence of explicit integration contributes to a fragmented understanding of AI's pedagogical value, reinforcing its perception as a technical supplement rather than a strategic partner in design learning. The five interrelated competency domains identified through theoretical synthesis and institutional analysis demonstrate how AI can strengthen architectural education by aligning digital innovation with ethical, social, and ecological responsibility. To visualize these relationships, Table **2** maps the relevance of four major AI tool categories—AI as Cognitive Partner, Generative Design Tools, Climate Simulation Tools, and AI Ethics Modules—across the five competency domains.

Table 2: Mapping of AI tool categories to pedagogical competency domains.

Pedagogical Competencies	AI as Cognitive Partner	Generative Design Tools	Climate Simulation Tools	AI Ethics Modules
Technological Literacy	✓	✓✓	✓✓✓	✓
Strategic Design Thinking	✓✓	✓✓	✓✓	✓
Environmental Sensitivity	✓	✓	✓✓✓	✓✓
Ethical Awareness	–	–	–	✓✓✓
Collaborative Agency	✓✓	✓	✓	✓

(✓ = weak association, ✓✓ = moderate, ✓✓✓ = strong pedagogical potential).

The scoring reflects how strongly each tool category supports reflective, strategic, or climate-responsive reasoning, informed by cross-analysis of literature and framework gaps.

4.1. Technological Literacy

This competency extends beyond the mastery of digital tools to include an understanding of their computational logic, constraints, and ethical or ecological implications. Students are encouraged to question how AI-driven systems generate, filter, and visualize data—whether through generative modeling, environmental simulation, or performance analytics.

Technological literacy thus entails not only fluency in software operation but also the capacity to interpret, evaluate, and critically situate algorithmic outputs within design reasoning. In studio contexts, this may take the form of reflective exercises where students compare AI-generated outputs with their own sketches or physical models, examining issues of authorship, accuracy, and intention. Through such practices, AI becomes a pedagogical mediator that fosters metacognitive awareness and critical engagement with digital processes. In this way, the competency directly advances SDG 4 (Quality Education) by strengthening critical digital literacy and reflective design judgment.

4.2. Strategic Design Thinking

AI-augmented workflows redefine the design process as a dynamic system of reasoning and decision-making under conditions of complexity. Prompts become strategic instruments, and design options are navigated through cycles of rapid iteration and evaluation. This fosters procedural intelligence but also demands careful pedagogical framing to ensure that students cultivate agency rather than dependency. The strategically minded designer thus employs AI not as a substitute for judgment, but as a collaborator in framing, testing, and refining design intentions.

Within this pedagogical framework, educators are tasked with guiding students to engage AI as a co-thinking partner—one capable of extending speculative reasoning and scenario-based exploration. For example, iterative comparisons can be used to test spatial strategies for climate-responsive envelopes, transforming data-driven feedback into opportunities for critical and strategic reflection. This domain directly supports SDG 11 (Sustainable Cities and Communities) by fostering adaptive, integrative, and system-oriented approaches to spatial problem-solving.

4.3. Environmental Sensitivity

AI platforms offer real-time insights into parameters such as energy performance, solar exposure, and material life cycles. Within design pedagogy, such tools can enhance students' ability to link formal experimentation with the ecological implications of design. However, true ecological literacy extends beyond simulation; it is grounded in an ethic of care—for resources, for place, and for the long-term impact of architectural decisions on ecosystems.

In studio contexts, students may employ AI-assisted analyses to model heat gain, airflow, or embodied carbon, yet such exercises must be accompanied by critical reflection on the ethical and experiential implications of these metrics. Integrating digital performance data with site-based observations and sensory mapping fosters a more holistic understanding of sustainability—as a lived and perceptual practice rather than a purely quantitative pursuit. This competency directly contributes to SDG 13 (Climate Action) by reinforcing the role of design in cultivating ecological empathy and long-term responsibility.

4.4. Ethical Awareness

Ethical reasoning is fundamental to navigating the socio-technical dimensions of AI in architectural design. Students are encouraged to ask: What is being optimized, for whom, and at what cost? Rather than approaching AI as a neutral instrument, design education must expose its cultural, political, and historical dimensions. The pedagogical emphasis thus shifts from procedural correctness to moral imagination—the ability to anticipate consequences, recognize embedded biases, and critically examine the values encoded within data and algorithms [6, 9].

In pedagogical practice, this awareness can be cultivated through structured debates, ethical mapping exercises, and reflective journals where students analyze their AI-assisted workflows in relation to questions of authorship, transparency, and data accountability. Ethics, in this sense, functions not as a constraint but as an enabling framework-one that embeds fairness, care, and responsibility within creative action and decision-making.

4.5. Collaborative Agency

Contemporary architectural practice increasingly operates through interdisciplinary collaboration. AI reinforces this condition by demanding fluency across technical, social, and design vocabularies. Within the design studio, engaging with AI as a non-human collaborator introduces new modes of co-authorship—requiring students to articulate, negotiate, and reflect within hybrid workflows that merge human and computational reasoning.

This competency develops through project-based teamwork in which students with diverse skill sets co-develop design strategies using shared AI platforms. Such practices extend beyond digital cooperation; they foster empathy, negotiation, and transdisciplinary literacy—qualities essential for navigating the complex interfaces of design, data, and society [8]. Collaborative agency thus reframes design learning as a collective, iterative act of meaning-making.

Together, these five domains define a pedagogical model that integrates technological innovation with ethical, ecological, and social consciousness. Rather than a fixed framework, they function as an interconnected ecosystem of competencies—each reinforcing the other through reflection, iteration, and co-speculative inquiry. By positioning AI as a catalyst within this ecosystem, architectural education can evolve toward a future that is critically aware, environmentally responsive, and ethically grounded.

4.6. Studio-Level Reflections

Architectural design processes inherently resist formalization, as they are grounded in tacit, interpretive, and context-dependent knowledge. Although bounded by regulatory, spatial, climatic, and economic constraints—as well as by the necessity to meet defined standards—design practice remains driven by originality and the continual generation of new ideas. Design thinking therefore unfolds not through linear or prescriptive procedures but through processes of uncertainty, iteration, and reflection, sustaining the discipline's enduring pursuit of critical and creative distinction. Within this pedagogical framework, formal experimentation and iterative dialogue become essential tools for cultivating creative awareness and design maturity, allowing each stage of exploration to be revisited, critiqued, and refined in light of emerging insights.

In architectural education, these qualities are foundational. The pedagogical frameworks of design studios seek to simulate this open-ended and reflective process that balances contextual sensitivity with creativity. Design learning, therefore, becomes a holistic practice—responsive to history, environment, and society, and mindful that human well-being cannot be reduced to physical comfort alone. It must also engage with the cultural codes, emotional resonances, and psychological needs that shape how people inhabit space. This broader perspective grounds architectural education not merely in the development of skills but in the cultivation of empathy, critical awareness, and a deeper sense of human connection.

Within this evolving context, AI-augmented workflows introduce new temporal and epistemic dimensions to studio practice. Generative algorithms, environmental simulations, and data-driven analyses inform early-stage decision-making and expand the range of design possibilities. At the same time, they produce an excess of visual and quantitative data, requiring students to cultivate discernment, contextual awareness, and interpretive judgment. By externalizing tacit reasoning, AI tools reveal new layers of design cognition, opening pedagogical opportunities for reflection and feedback. This reflection does not seek to establish a hierarchy between conventional and AI-mediated approaches but to position both within a broader conception of studio culture—one that integrates human–machine co-agency, information literacy, and strategic interpretation as central components of design learning. In this framework, AI acts not as an autonomous generator but as a pedagogical catalyst: a medium that heightens awareness of how design reasoning develops and evolves. Integrating AI into studio culture highlights three key capacities that reshape design learning:

1. Cognitive transparency, where design reasoning becomes traceable through data visualization, simulation, and iterative feedback;
2. Ethical judgment, as students engage critically with questions of authorship, bias, and accountability in algorithmic processes;
3. Ecological sensitivity, as AI-driven simulations enhance awareness of material behavior, energy performance, and climate responsiveness.

These emerging capacities resonate with the five competency domains proposed in this study and align with SDGs 4, 11, and 13 by preparing learners to move fluidly between technological innovation, ethical reflection, and ecological awareness. Ultimately, the AI-augmented design studio can be understood as a reflective laboratory for critical, ethical, and environmental learning—where algorithmic intelligence does not automate creativity but amplifies reflection, agency, and ecological understanding within the design process.

5. Discussion

While structured workflows and optimization-driven tools generate vast amounts of information, this accumulation of data alone is insufficient to capture the essence of architecture. What becomes critical in education is not the volume of knowledge produced, but how students internalize, interpret, and transform it into meaningful design understanding. In studio learning, knowledge emerges through non-linear, iterative, and embodied encounters: site interpretations deepen through repeated observation, and form evolves through sketching, modeling, and dialogic critique. A bird's call, a shifting shadow, or a sudden gust of wind can reorient spatial perception, reminding students that place and meaning are inherently dynamic. These analog processes cultivate spatial empathy, tacit knowledge, and a situated design sensibility—qualities that are among the central aspects of architectural imagination and are sometimes difficult to encode within computational systems.

At its essence, design is shaped not only by data but by lived experience and intangible human values that give form to emotion, culture, and meaning. Together, these embodied dimensions anchor creativity in context, materiality, and sensory awareness. AI-assisted workflows operate through different cognitive rhythms, privileging data-driven reasoning and optimization. Generative and simulation platforms accelerate iteration and feedback—especially in climate-responsive design—yet they also risk replacing intuition with quantification. This transition—from experiential and embodied ways of designing to data-driven modes of reasoning—highlights a productive tension within architectural cognition. It reveals the interplay between Kahneman's System 1 (immediate, associative, intuitive) and System 2 (deliberative, reflective, ethical) modes of reasoning that shape how designers think and act.

This analysis suggests that architectural pedagogy should move beyond a binary framing of human and artificial intelligence by embracing a co-speculative partnership model in which AI operates as a provocation—stimulating human judgment rather than replacing it. Within this framework, studio-based practices remain essential as sites of iterative exploration, dialogue, and embodied reflection, cultivating agency through uncertainty, collaboration, and contextual interpretation. AI-enhanced methods, meanwhile, introduce feedbackrich environments that inform—but do not dictate—design outcomes, supporting critical awareness and strategic decision-making. When approached as complementary rather than oppositional, these modes can work in synergy—aligning computational precision with reflective practice, where algorithmic logic engages with the sensory realities of light, sound, and movement.

This synthesis reframes architectural learning as a dialogue between sensory intuition and algorithmic logic, bridging the generative vitality of System 1 with the analytical depth of System 2. Such an integrative responsiveness is increasingly vital amid accelerating environmental and social crises, aligning with the Sustainable Development Goals (SDGs 4, 11, and 13) and calling for pedagogical models that integrate ethical, ecological, and technological dimensions. While international frameworks emphasize sustainability, ethics, and social responsibility, they offer limited guidance on how AI can serve as a pedagogical catalyst. This absence underscores an urgent need for architectural education to articulate its own models for AI literacy—approaches that embed digital innovation within ethical, ecological, and human-centered frameworks. Accordingly, the challenge for design pedagogy is to cultivate practitioners capable of navigating technological complexity with care, adaptability, and critical foresight.

6. Conclusion

This study has argued that integrating Artificial Intelligence into architectural education represents not a mere technical adjustment but a pedagogical reorientation. By repositioning AI as a co-speculative partner, the research reframes the relationship between human creativity, ethical reflection, and technological mediation. Through an analysis of international frameworks, studio cultures, and identified competency domains, the study highlights both institutional orientations and areas that invite further pedagogical reflection. It proposes an integrative framework in which different categories of AI tools—when aligned with five key domains (technological literacy, strategic design thinking, environmental sensitivity, ethical awareness, and collaborative agency)—can support learning environments that are reflective, ethically grounded, and future-oriented.

Rather than displacing the embodied, intuitive, and situated intelligence cultivated through architectural education, AI acts as a catalyst for reflection. It can serve as a medium that renders tacit reasoning visible, simulates systemic complexity, and broadens the interpretive field of design learning. In this sense, AI functions as a bridge between data-informed environmental literacy and ethically grounded design agency, strengthening architectural education's role in shaping sustainable futures.

As climate disruption, displacement, and socio-political instability continue to reshape the contexts of architectural practice, the need for technological fluency coupled with ethical foresight becomes paramount. While international frameworks such as NAAB, RIBA, and UNESCO–UIA acknowledge sustainability and ethics, explicit strategies for integrating AI remain underdeveloped. Advancing such integration will require continued experimentation and dialogue across institutions, fostering new pedagogical models that balance digital innovation with humanistic and ecological sensibilities. Future research should extend this conceptual framework through studio-based experiments conducted in diverse pedagogical settings, testing how AI integration can meaningfully contribute to reflective, ethical, and climate-responsive design learning.

Conflict of Interest

The author declares that there is no conflict of interest.

Funding

No external funding was received for this study.

Acknowledgements

The author would like to thank the anonymous reviewers for their valuable feedback.

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