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Coding the urban curriculum: Technology as thematic infrastructure in urban design education

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Abstract

As debates continue over how to articulate the disciplinary scope of urban design education, several researchers examined how pedagogical models are shaped by specific thematic priorities, particularly ecological, socio-political, or technological. As graduate programs navigate the tension between disciplinarity and interdisciplinarity, themes like resilience, climate adaptation, spatial equity, and digital urbanism have begun to function not merely as curricular content, but as structuring frameworks that govern how urban design is taught and practiced. This paper addresses the question of how certain themes infiltrate or govern urban design education by examining the Master of Urban Design and Digital Environments (MUDDE) program. In MUDDE, foreground technological tools, in particular virtual reality (VR), augmented reality (AR), and artificial intelligence (AI), are employed not as discrete subjects, but as a pedagogical infrastructure through which students interrogate, simulate, and communicate complex urban conditions. Using a qualitative case study, the research analyzes curricular documents, classroom observations, student projects, and survey responses to understand how these tools influence inquiry, design workflows, and representation. Through analysis of two courses in particular, findings indicate that the MUDDE curriculum moves beyond skill acquisition toward thematic mediation, where technology becomes a method for exploring and constructing urban narratives. These tools support design process at multiple stages. They inform data-rich site analysis, allow producing multiple design outcomes through generative and parametric workflows, and expand the communicative potential of student projects by offering immersive and interactive visualizations for engaging with diverse stakeholders. In this way, themes in MUDDE operate not as isolated topics, but as conceptual operating systems, organizing inquiry, shaping design workflows, and guiding modes of representation. This pedagogical approach aligns with an international shift toward reflexive, exploratory, and projective models of urban design education, where the governance of themes is enacted through the integration of method, technology, and class culture. The study contributes to debates on the future of urban design pedagogy by demonstrating how technology can reorganize learning environments and extend the epistemic foundations of the field.

Keywords: MUDDE, pedagogy, technology, urban design

1. Introduction: Urban Design Pedagogy Between Ambiguity and Plurality

Urban design field has long been a contested ground between architecture, planning, landscape, and civil engineering (Lang, 2017). Its hybridity enriches the field, and thus its pedagogy, but leaves it with a transient theoretical core. This in-betweenness is often considered as a source of richness, but it has also led to what Lang (1994) once called an unresolved identity problem. Students trained in urban design are expected to master spatial composition, socio-economic analysis, and political negotiation all at once, yet often existing frameworks do not organize these competencies. Madanipour (2006) captures this condition as both an asset and a liability: the flexibility to draw from multiple traditions, coupled with the risk of intellectual fragmentation. Çalışkan (2012) argues that this ambiguity persists because programs often borrow heavily from their parent disciplines without articulating distinct epistemological foundations.

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Since the 1960s, attempts to resolve this ambiguity, which was common across design disciplines of the built environment, seem to have taken two directions. First approach sought to impose rational procedures to the design process (Jones, 1970), however, these models often ignored the situated, iterative nature of practice. Second, the reflective approach, led by Schön (1983) and later advanced by Lawson (2004) and Cross (2006), reframed design as an abductive, experimental activity. In this way, studios became sites of reflection-in-action, where knowledge is produced through cycles of doing and thinking. Urban design pedagogy, however, has remained uneven in absorbing this perspective. This reflective turn gave urban design educators a vocabulary to describe tacit knowledge, iterative reasoning, and abductive leaps. By the way, as Çalışkan (2012) states, urban design pedagogy has not fully absorbed this epistemology; instead, it has remained caught between inherited proceduralism and fragmentary appropriations of reflective practice.

This absence of disciplinary closure together with the challenges of rapid urbanization (such as environmental concerns) and ongoing technological advancements, led many urban design programs to organize their curricula around thematic priorities (Yavuz Özgür & Çalışkan, 2025). Among many, three themes of environmental sustainability, socio-political engagement, and technology seem to stand out internationally.

The ecological turn in urban design is perhaps the most visible thematic reorientation of the past two decades. Confronted with climate change, biodiversity loss, and resource scarcity, design schools have reframed their mission around resilience and adaptation. Mostafavi and Doherty's Ecological Urbanism (2010) articulated a vision where ecological thinking is not an add-on but the very substrate of design pedagogy. The implication of this theory for curricula is profound as the studios then regularly incorporate environmental modeling, climate scenario planning, and landscape ecology. Beatley (2010) extends this argument by advocating biophilic cities, in which urban designers must learn to work with natural systems as co-producers of urban form. For students, this thematic emphasis cultivates multi-scalar reasoning, forcing them to situate small-scale interventions within long-term ecological dynamics.

Running alongside ecological concerns is a second thematic orientation: socio-political engagement. Sanoff (1999) and Fainstein (2010) remind us that design is always a political act, shaping who benefits, who is excluded, and how public space mediates social relations. As a result, more community-based studios and participatory projects have emerged in teaching and practice. Here, students learn to treat local knowledge and stakeholder perspectives not as external constraints but as generative inputs. Healey's (1997) framework of collaborative planning resonates in this context, as it frames design not as the imposition of form but as the co-construction of visions for shared space. In practice, this thematic emphasis has produced graduates skilled in negotiation, facilitation, and collective authorship, competencies once considered marginal to design but increasingly central to professional legitimacy.

The third thematic strand, and the one most relevant for this study, is the integration of digital technology. Whereas ecological and socio-political priorities are largely thematic in content, technology functions at once as a theme and as a structuring method. Digital tools have redefined how students analyze sites, generate alternatives, and communicate proposals. Batty (2018) describes this shift as a new epistemology of urbanism, one grounded in data, simulation, and systemic modeling. The rapid uptake of GIS, 3D visualization, VR, AR, and AI reflects more than a change in representational media; it signals a deeper restructuring of design cognition. Recent research in design-related education reinforces this trajectory. For instance, Afacan (2016, 2018) shows that digitally mediated and blended learning environments enhance students' reflective practices and support more iterative, feedback-driven studio cultures. Studies in urban pedagogy have expanded this perspective. For example, Meshkani (2024) shows how machine learning can be embedded in studio workflows to shape urban problem, framing and scenario development, while Palazzo and Shirleyana (2022) highlight how digital and transdisciplinary tools can support adaptive and experiential learning in urban design studios. Taken together, these emerging directions suggest that digital technology in design education increasingly operates not just as

representational enhancement, but as an epistemic driver that reorganizes how students think, inquire, and act within complex urban conditions.

Al-Kodmany's (2002) work on visualization for participatory planning demonstrates that the tools themselves alter the dynamics of engagement in a way that immersive or interactive media can flatten hierarchies, making complex projects legible to non-experts. Similarly, studies on the application of VR and AR in design pedagogy highlight that immersion is not limited to representational upgrade, but perhaps equally important, it is also a cognitive extension, allowing students to reason spatially in ways that drawings or static models cannot (Whyte, 2002). Machine learning and AI introduce another dimension by augmenting generative and evaluative tasks, enabling students to test hundreds of scenarios, recognize hidden patterns, and explore probabilistic outcomes (Mitchell, 2017).

To understand technology's role in urban design education, it is useful to look at it not simply as a collection of tools but as an epistemic infrastructure that could potentially reshape the thinking process and thought. Several studies and theories addressed this matter or can support its role in pedagogy. For example, Schön's (1983) idea of reflection-in-action finds a clear analogue in VR. When students step into immersive environments, they are able to interrogate spatial decisions in real-time, revising and rehearsing alternatives as if in conversation with the space itself. This medium of design facilitates an iterative process and associated reflection at a scale and immediacy unavailable in conventional drawings. To take another example, theories of embodied cognition (for example see Clark, 1997; Gallagher, 2005) suggest that thinking is distributed across brain, body, and environment. AR exemplifies this principle by embedding digital overlays into physical sites. Students using AR are not simply visualizing data; they are reasoning through bodily interaction with layered realities. The pedagogical effect is to tether abstract analysis to lived, situated experience. In another case, AI extends cognitive capacity by generating and evaluating options beyond human scale in terms of prototyping, process, and time. Far from being a neutral assistant, algorithms could shape the design space itself through foregrounding certain logics while marginalizing others.

The above-mentioned themes, though, function as more than curricular topics. They operate as frameworks that organize inquiry and pedagogy. Environmental and social agendas reshape problem definition and evaluation, while digital technologies restructure design workflows, collaboration, and presentation. Within this purview, and along with third thematic cluster described above, this paper examines that proposition through a case study of the Master of Urban Design and Digital Environments (MUDDE) program. By analyzing how emerging technologies are embedded across MUDDE curriculum, the paper argues that the MUDDE program demonstrates a shift from mere skill acquisition to thematic mediation, where technology acts as a conceptual operating system that organizes inquiry, shapes design workflows, and guides modes of representation in urban design education (triadic aspects). The aim is to identify the cognitive, procedural, and experiential outcomes of technology-mediated pedagogy and to assess how these outcomes contribute to cultivating resilient, adaptive, and future-oriented approaches to urban design.

The next section of the paper illustrates the methodology for analyzing this argument. It then continues with an analysis of MUDDE curricula with examples from three courses, highlighting how technology has been used in selected courses and how their application supports triadic aspects mentioned above.

2. Methodology

This research employs the case study method to investigate how emerging digital technologies could potentially function as a conceptual operating system within urban design pedagogy. Case study method is well suited to contexts where the object of inquiry is complex, situated, and evolving, and where the goal is to generate analytical insight rather than universal law. The Master

of Urban Design and Digital Environments (MUDDE) program was selected precisely because it positions digital technology not as an ancillary subject but as a foundation of its pedagogical strategy. MUDDE is a two-year program within the School of Architecture, Art, and Design at American University in Dubai (AUD). It prepares students to confront today's complex urban challenges by combining cutting-edge technologies with forward-thinking design practices. This study focuses specifically on two courses within the program including 'Digital Techniques for Urban Design' and 'Urban Design Studio II' in order to examine in depth how VR, AR, and AI function as pedagogical infrastructure in distinct modes of analysis, design development, and representation.

The program's recent curricular transformation and systematic integration of VR, AR, and AI make it a fertile site for exploring how tools reorganize design thinking and studio practice. The program consists of ten courses in total: nine core courses and one elective. The core curriculum encompasses three thematic studios that address infill development, master planning for new neighborhoods, and future urbanism. It also includes three workshop courses emphasizing the use of GIS, AI, parametric and generative design tools, and VR/AR technologies, as well as one research-oriented course focused on sustainable infrastructure. The program features a two-semester thesis sequence: the first semester centers on research, while the second emphasizes design. The table below outlines the various emerging tools employed across these courses.

Table 1 The Use of Selected Emerging Tools in MUDDE Courses (Note: Normative 3D spatial modelling, rendering and visualization tools are excluded)

Course type	Digital tools
Studio	VR, AI
Workshop courses	GIS, AI, VR, AR
Research (including thesis research)	GIS
Elective	Depends on the offered course

Table 2 Pedagogical Roles of Technology in MUDDE Courses

	Course	Role of Technology	Explanation
Year I	Urban Design Studio I Urban Design Studio II Sustainable Infrastructure	Amplifier	Enhances spatial comprehension and feedback but does not define pedagogy
	Digital Techniques for Urban Design Geographic Information System	Infrastructure	Tools support reasoning, simulation, and iterative analysis
	Artificial Intelligence in Urban Design	Driver	Frames spatial exploration and evaluation
Year II	Urban Design Studio III	Driver	Frames spatial exploration and evaluation
	Thesis Research	Infrastructure	Tools support reasoning, simulation, and iterative analysis
	Thesis Studio Elective (workshop/research)	Driver / Infrastructure	Depends on topic direction

As outlined in Table 1 and 2, these tools are embedded across the curriculum with varying levels of pedagogical intensity. The subsequent analysis draws specifically on two mentioned courses supported by observations, course materials, and student survey responses, which collectively inform the study's examination of how technology operates as a conceptual pedagogical infrastructure.

According to Tables 1 and 2, the program's courses collectively equip students with the skills to integrate emerging technologies into various stages of urban analysis, design, and visualization. While digital tools are integrated in almost all courses to varying degrees, their pedagogical roles differ in both depth and intent. In certain courses, emerging tools form the core pedagogical framework, as pedagogical infrastructure and driver. For instance, in Artificial Intelligence in Urban Design, AI serves as an analytical and generative partner in design process, used in all tasks of the course. Students use AI to simulate urban scenarios, extract spatial patterns from large datasets,

and generate design alternatives, thus engaging critically with the implications of algorithmic decision-making in urban contexts. So, AI is a tool that all course content, assignments, and deliverables are developed around it. Similarly, in the Future Urbanism Studio, VR plays a direct pedagogical role by immersing students in all stages of design and visualization, enabling them to experience and evaluate spatial futures. Through VR-based design exploration, students interrogate how emerging technologies can redefine perception, scale, and the experiential dimensions of future cities, such as vertical or gravity-defying urban forms.

In contrast, in several other courses, these emerging tools function as a pedagogical infrastructure or amplifier rather than pedagogical drivers. They enhance analytical precision, visualization, and communication but do not fundamentally shape the course's epistemological or methodological foundation. For example, parametric modeling or VR may be integrated to strengthen spatial analysis or design efficiency, however, the core learning outcomes remain centered on critical urban theory or design synthesis rather than on technological innovation itself. This distinction underscores a spectrum within the curriculum, from technology-centered learning to technology-assisted learning, reflecting a balanced pedagogical approach that situates emerging tools both as enablers and subjects of critical inquiry in urban pedagogy.

The analysis in this paper focuses on two courses in which emerging tools function as pedagogical infrastructure, amplifier and assistive rather than core pedagogical driver. The first, Digital Techniques for Urban Design, introduces students to generative design processes, immersive visualization, and augmented reality methods through a series of intensive workshops. Here, technology serves as a means of exploration, enhancing students' technical fluency and expanding their capacity to experiment with form, data, and perception within urban contexts. The second, Urban Design Studio II, focuses on the principles of master planning addressing local regulatory frameworks, while incorporating virtual reality as a medium for site analysis, spatial testing, and final visualization. In this course, VR acts as a pedagogical amplifier, supporting iterative feedback, participatory engagement, and spatial understanding rather than defining the studio's epistemological core.

Together, these courses exemplify the dual pedagogical approach of the program: combining technical literacy in emerging tools with critical application in complex design problems. The analysis employed a qualitative approach combining content analysis of syllabi and project briefs, interpretation of classroom observations, and coding of student survey responses. Data were collected across the 2024–2025 academic years and include two iterations of the relevant courses, with sustained observations in two studios and two workshops. The survey responses were collected from eleven students in Urban Design Studio II. Recurring patterns related to inquiry, workflow, and representation were identified through open coding, allowing the study to connect empirical findings to the broader conceptual proposition of technology functioning as a pedagogical operating system.

3. Analysis of Two Courses

The pedagogical practices of the two MUDDE courses, Digital Techniques for Urban Design and Urban Design Studio II: Neighborhood Masterplan, reveal how emerging technologies operate as epistemic environments that shape reasoning, the organization of design practice, and representation. The analysis presented below draws from classroom observation, student projects, and survey data. Together, they suggest that within the MUDDE program, analyzed emerging digital tools serve as the infrastructure through which students learn to question, think, visualize, and act spatially.

3.1. Digital Techniques for Urban Design

This course introduces students to data-driven and generative modes of design inquiry. It begins with the construction of a mini static digital twin, where urban datasets such as topography, spatial layers (roads, pathways, building outlines, 3D model of buildings, land-use, etc. are layered to

expose spatial dependencies. Similar to the cognitive-mapping exercises described by Batty (2018), this process externalizes reasoning: students learn to read the city as a system of parameters rather than a fixed morphology. Using Grasshopper scripting, they then run a series of simulations such as visibility, Isovist, shadow and radiation analysis to deepen their site analysis. The act of scripting relationships between variables moves the site analysis from descriptive to operational, enabling students to think through code. In this respect, the course re-stages Schön's (1983) reflection-in-action within a computational medium, where adjustment of parameters becomes a dialogue between designer and algorithm.

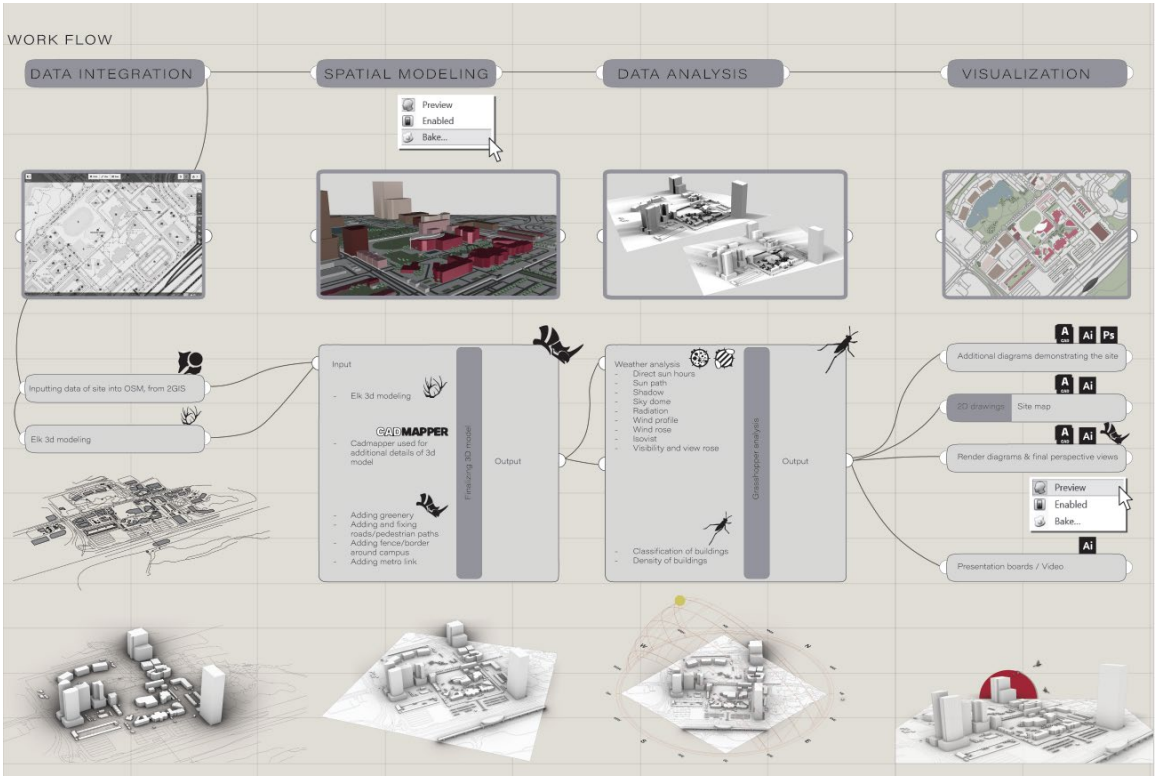

Figure 1 Workflow for developing a mini-twin for the studied site and example of simulations, produced by students (Source: Safi et. al, 2024)

As students progress to generative modeling, the iterative logic of parametric design expands from producing forms to constructing hypotheses. Put another way, they do not use tools merely to generate forms, but each iteration becomes an experiment, perhaps mirroring what Cross (2006) calls designerly ways of knowing: a cyclical reasoning process that oscillates between conjecture and evaluation. Students' observations show that the speed and reversibility of generative coding fostered a new form of attentiveness: students evaluated not single outcomes but the 'behavior' of the system producing them. Such responsiveness constitutes a subtle cognitive shift from solution-making to system-learning, aligning with emerging theories of design cognition in digital pedagogy (for example see Oxman 2017).

The third module of the course, designing parametric urban furniture, extends this logic into embodied experimentation through Augmented Reality (AR). Students transferred their coded geometries into AR environments and examined them live in full-scale spatial setting. The pedagogical benefit of such exercises extends beyond the visualization of form; it lies in the way AR unsettles and reorganizes spatial comprehension by merging perception with direct manipulation. When digital designs were observed and adjusted in the actual site, students' sense of proportion, form, and materiality evolved through bodily movement, negotiation with the physical surroundings, and the shared discussions as part of their teamwork. This interplay of computational reasoning and embodied appraisal softened the separation between abstract modelling and lived spatial experience. During review and critique sessions, the instructor and peers could enter these virtual environments together, providing feedback that are no longer just verbal commentary, but

is act of collective spatial negotiation. In this mode, learning dispersed across instruments, bodies, and communicative exchange, an ecology of practice resonant with theories of embodied cognition (Clark, 1997; Gallagher, 2005).

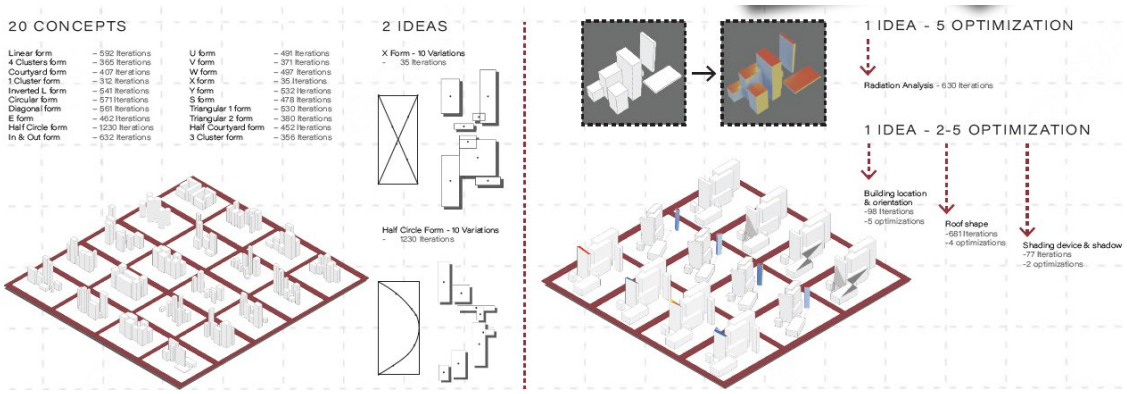

Figure 2 Example of students works using generative design for designing and optimizing building compounds (Source: Safi et al., 2024)

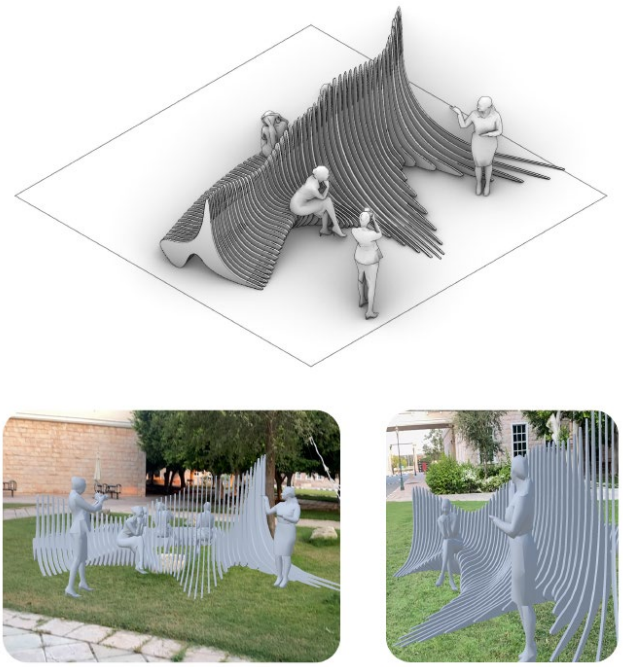

Figure 3 Example of students works using augmented reality for design and visualization (Source: Shakir & Almusalam, 2024)

Observation of students as well as analysis of their project outcomes provides evidence that application of technology as pedagogical infrastructure at urban level could create a design and analytical environment for in-depth reasoning as much as for representation. The projects indicated that digital tools revealed new patterns, exposed hidden relationships, and accelerated spatial discovery. The course thereby positioned computation as a medium for inquiry, not a skill to master. Within the program's broader trajectory, Digital Techniques for Urban Design course cultivated a mindset of adaptive experimentation that would later inform the immersive design thinking of the subsequent master planning studio.

These observations clarify how the two courses operationalize the central proposition that emerging digital technologies function as a conceptual operating system within the MUDDE curriculum. In the course Digital Techniques for Urban Design, computational tools structure the logic of inquiry by externalizing reasoning, transforming datasets into operational parameters, and enabling iterative hypothesis-testing. In the second course, Urban Design Studio II, immersive VR reshapes knowledge production through embodied evaluation, real-time spatial negotiation, and

collaborative feedback loops. Across both cases, technology mediates not just representation as used to be in the past but also the organization of design cognition and the relational dynamics of studio practice. These findings therefore demonstrate how tools and technologies actively configure the epistemic, procedural, and communicative dimensions of urban design learning.

3.2. Urban Design Studio: Neighborhood Masterplan

This studio course translated digital sensibilities to the scale of the city through purposeful use of virtual reality. Students developed masterplans for a neighborhood in Dubai and used VR in three sequential phases: site exploration, iterative design testing, and project presentation. A survey questionnaire was conducted with eleven students that provided empirical insight into how immersive technologies restructured their design learning.

Figure 4 Student using VR to explore spatial qualities in her design (left) and instructor using VR to provide feedback to student (right) (Source: Authors)

Across the responses, students consistently reported that VR provided a “much clearer understanding of spatial conditions” and “significantly influenced mass–void decisions.” Nearly all participants described a risen awareness of human scale and spatial sequence. These findings resonate with recent research showing that immersive simulation fosters situated design reasoning by coupling perception with decision-making (Portman et al., 2015). Instead of evaluating drawings from distance, which is common in the normative design process, students situated themselves in the evolving project, assessing visibility, pathway hierarchy, circulation, spatial organizations, enclosures, and scale as lived phenomena. The process demonstrates how immersion converts analysis into experience, effectively merging cognitive evaluation with spatial embodiment.

The representational consequences were equally significant. When asked to compare VR presentations with traditional methods, 90.9% of respondents found the experience “much more immersive and engaging,” and same percentage rated the realism achieved as “very high”. During critiques, instructors noted that discussions became grounded in spatial experience. The comments shifted from abstract notions of proportion to concrete experiential feedback such as “the pathway corridor feels compressed” or “the courtyard scale works.” Representation thus evolved from static illustration to dialogic environment; an arena for negotiation among students, tutors, and space itself.

Procedurally, VR altered collaboration and feedback loops. According to survey responses, 81.8% said that VR “enhanced the ability to receive and apply feedback” in the studio. It could be said that the immediacy of reviews shortened the distance between critique and revision, embedding responsiveness directly into the design workflow. While 18.1% of respondents found

the use of VR technology "significantly challenging," the majority of them described it as manageable and expressed strong intent to continue using VR in future projects. Every participant recommended its incorporation in subsequent studios, perhaps an indication that the technology has been normalized within their design cognition. When they asked for areas of further improvement in integration of VR with curriculum, students pointed to aspirations for "enhancing realism and details," "integration advanced features like simulation," and "improved accessibility," reflecting an emergent critical literacy: students were no longer fascinated by novelty but by precision and methodological potential. In this sense, technological engagement matured into reflective practice.

Taken together, the empirical and observational evidence show that VR in Urban Design Studio II served simultaneously as an instrument of inquiry, a medium of communication, and a platform for collaborative process. Immersion fostered situated reasoning; visualization expanded communicative reach; and real-time interaction restructured procedural feedback. Through these interrelated functions, this studio showcases how digital environments can mediate the intellectual, visual, and organizational dimensions of design pedagogy.

The combined outcomes of the two courses confirm that within MUDDE, emerging technologies have become the operative framework through which learning itself occurs. In the Digital Techniques for Urban Design course, students learned to reason parametrically and perceive data as design material. In Urban Design Studio, they learned to inhabit, critique, and iterate spatial propositions through immersion. Across both courses, the digital medium shaped how students think, see, and act, transforming technology from an accessory to pedagogical infrastructure.

Table 3 The Comparative Pedagogical Functions of Two Analyzed Courses

Pedagogical Dimension	Digital Techniques for Urban Design	Urban Design Studio II
Primary Focus	Analytical exploration through parametric and generative modeling, simulation, and computational reasoning	spatial synthesis and experiential evaluation at the scale of the neighborhood
Role of Technology	Pedagogical infrastructure enabling data-driven inquiry, system-based reasoning, and generative experimentation	Pedagogical amplifier supporting spatial understanding, iterative refinement, and collaborative immersion
Dominant Representational Mode	Parametric workflows, coded iterations, AR-based full-scale testing	VR walkthroughs, embodied evaluation, immersive scenario testing
Learning Outcomes	Ability to translate datasets into design logic; strengthened computational literacy; iterative hypothesis testing	Enhanced spatial judgment, human-scale evaluation, reflective decision-making, and clearer communication of design intent

4. Discussion

The analysis of MUDDE curriculum, particularly two focused courses, provides evidence that the role of technology in urban design education has evolved from tool into an operational medium and then an epistemic infrastructure that structures how learning itself occurs. In this sense, technology functions less as an add-on and more as a conceptual operating system. Put another way, it has become a pedagogical matrix that organizes inquiry, shapes urban design workflows, and guides representation at larger urban scale. These dimensions are not discrete; they overlap and reinforce one another, generating a condition where knowledge production and design action are co-dependent. What follows unpacks each of these three aspects, situating them within broader debates in urban design pedagogy.

4.1. Organizing Inquiry

In most traditional design curricula, inquiry was guided by precedent, typology, or design intuition. Our analysis shows that the emergence of advanced digital tools allows redefining this

condition by opening access to large datasets, simulation environments, and algorithmic reasoning that make inquiry itself more exploratory, relational, and speculative. As Batty (2018) note, the datafication of cities has to some degree transformed the nature of urban design problems, requiring students to navigate between qualitative and quantitative domains. Within MUDDE, this shift is evident in how students initiate design exploration through the construction of overlayed datasets, sometimes in parametric ways, rather than through formal sketches. Inquiry thus begins with information organization before moving toward form generation.

In recent years, the accessibility of real-time data and its integration with generative platforms have encouraged a culture of questioning rather than confirmation. Digital tools act as suggestive agents that not only visualize known conditions but also projecting multiple 'what if' scenarios that invite reinterpretation. Moving from representation to simulation, the tools do not depict reality but generate new versions of it. In this context, the abundance of data is both an opportunity and a challenge. As some scholars have argued (Townsend, 2013), more data does not necessarily produce more insight; in fact, it can obscure decision-making if left unfiltered. It was the same within the pedagogical space of MUDDE, where sometimes the abundance of data became an occasion for critical reflection, and on other occasions created confusion. Guided by instructors, students were encouraged to interrogate what kind of knowledge data actually represents, whose priorities it encodes, and what forms of urban futures it privileges.

The reorganization of inquiry through digital technology also changes the scale and temporality of design thinking. Historically, urban design operated at the macro level: slow, infrastructural, and plan based. Computational processing allows students to oscillate between micro and macro scales, testing smaller, adaptive interventions with long-term implications. This resonates with the notion of spatial agency, discussed by Awan et al. (2011), strongly implies a shift away from static master plans towards more ongoing, socially embedded, incremental processes of spatial production. By structuring inquiries around information, simulation, and feedback, MUDDE seeks to cultivate a capacity to move between abstraction and precision, between data and narrative throughout the design thinking process. In this way, technology does not only assist inquiry; it becomes the method of inquiry itself. The studio shifts from being a site of problem-solving to a site of knowledge production, where design emerges through exploration of variables rather than confirmation of hypotheses.

4.2. Shaping Design Workflows

The second aspect of the argument concerns the reconfiguration of design workflows. Urban design has traditionally followed a sequential logic of analysis, concept, development, representation, where often each stage informed the next. Our experiment using emerging tools in urban design shows these platforms could dissolve this linearity, allowing students to move fluidly across phases. In the MUDDE studio, for example, analysis is not something that precedes design but co-evolves with it through generative feedback. This is another evidence that computation could potentially transform design into an iterative ecology, where ideas are tested, simulated, and reconfigured continuously (also see Whyte, 2002 and Oxman, 2017).

The implications of this shift are methodological as well as cultural. First, the pace of design has accelerated. Tools such as machine learning and AI-assisted generation, parametric scripting, or immersive testing allow students to iterate faster than traditional analog processes would permit. Speed, however, is not merely a question of efficiency; it changes the rhythm of thought. When design and evaluation occur almost simultaneously, reflection becomes embedded within action. Going beyond Schön's (1983) reflection-in-action, now the reflection occurs within the feedback loops of software, simulation, and visualization.

Second, our analysis shows that using emerging digital tools in urban analysis and design, which often involves handling multiple parameters, allows workflows to become more non-hierarchical. In conventional pedagogy, design decisions often follow a top-down sequence: analysis by experts, interpretation by designers, and critique by instructors. In contrast, the integration of VR and AR

platforms in MUDDE flattened this structure in a way that instructors and students could inhabit the same model, make adjustments, and test implications in real time. The result may not just be greater collaboration but potentially a redistribution of authorship; a co-design process closer to what Healey (1997) described as collaborative rationality.

This non-linear, collaborative workflow also enables a new kind of temporal awareness. Students can test short-term scenarios (e.g., adaptive reuse, flood mitigation, shadow analysis, mobility interventions) alongside long-term urban transformations. Such simultaneity is central to contemporary discourses of resilience and adaptation (Mostafavi & Doherty, 2010). In this sense, digital workflows bring ecological thinking into the heart of the design process. They enable the continuous calibration of environmental, social, and economic parameters, embedding adaptability within the procedural logic of studio practice.

Yet, this acceleration and fluidity also introduce challenges. The immediacy of digital iteration risks turning design into optimization, privileging what is computationally efficient over what is contextually meaningful. The culture of urban design education must remain critical of technological determinism. Within MUDDE, reflective critique sessions deliberately punctuated the speed of workflow, creating more space for discussion, hesitation, revisions and ethical judgment.

4.3. Guiding Modes of Representation

The analysis of cases studied in this paper shows how representation in MUDDE is not treated as a terminal act of visualization but as an active mode of inquiry. Technologies such as VR and AR alter the epistemology of seeing, vis-à-vis students no longer look at the city but move through it. This immersive condition redefines how design knowledge is communicated, both within the studio and to external audiences. As Al-Kodmany (2002) shows, immersive environments democratize spatial comprehension by translating complex spatial data into embodied experience.

Within the MUDDE studios, as studied cases show, representation became a medium for dialogue rather than a vehicle of persuasion. When students showcased their projects in virtual reality, critiques became spatial dialogues: discussions about light, proportion, scale, connectivity, or accessibility were situated within the very environments being discussed. This aspect of representation could potentially be linked to Lefebvre's (1991) concept of the production of space, in which space is not an object to depict but a condition to be enacted. Representation, therefore, becomes pedagogically productive as it teaches by allowing both designer and audience to inhabit the consequences of design decisions. At the same time, the shift toward immersive representation reconnects technology with the socio-political dimension of urban design. By making space more accessible and legible to non-experts, these modes of representation support inclusive engagement. They allow multiple stakeholders, juries, or even publics to participate in shaping urban imaginaries, transforming representation from an end-stage deliverable into a tool of shared authorship.

However, immersive representation also raises questions of realism and ethics. The persuasive power of visual fidelity can conceal uncertainty or bias. The danger of technological spectacle is that it may displace critical debate with affective immediacy. The pedagogy attempts could mitigate this risk by framing representation as an argument, not an image, in a way that students can discuss what their simulations exclude as much as what they reveal. In this way, representation becomes not just an outcome but a pedagogical act of reflexivity, guiding how designers construct, perceive, and communicate urban knowledge.

Across these three aspects, MUDDE demonstrates a paradigmatic shift from instrumental teaching to epistemic mediation. Technology allows organizing inquiry by reframing what can be known, shapes workflows by redefining how design unfolds, and guides representation by transforming how knowledge is shared. Together, these dynamics suggest that the technological turn in urban design education could not be interpreted as a departure from ecological or socio-political priorities. It is suggested to interpret them as their necessary extension, providing the

infrastructure through which complexity, inclusion, and adaptability can be enacted in design pedagogy.

It is important to note that the three analytical dimensions—organizing inquiry, shaping workflows, and guiding representation—were conceptually established in advance based on the emerging theoretical literature on digital design cognition, but subsequently refined through patterns observed in the empirical data. The course observations, student reflections, and survey results helped nuance and validate these dimensions, confirming their relevance within the MUDDE context. At the same time, several limitations should be acknowledged. The study focuses on a single academic institution and examines only two courses in depth, which may limit the broader generalizability of the findings. The sample size for survey data is relatively small, and some insights rely on self-reported reflections that may carry inherent bias. These contextual boundaries do not diminish the value of the results but indicate the need for future research spanning multiple institutions, larger cohorts, and longitudinal evaluation of digital pedagogical practices.

5. Conclusion

The analysis of two courses within the MUDDE program reveals that digital technologies have moved beyond the status of auxiliary instruments and now function as a conceptual infrastructure for urban design pedagogy. By examining how VR, AR, and AI allow organizing the inquiry, shaping workflows, and guiding modes of representation, this study has highlighted a shift from a model of urban design education centered on technical proficiency to one oriented around thematic mediation. The consequence is not only a change in the kinds of skills students acquire but also a reconfiguration of how knowledge in urban design is generated, tested, and shared.

At the level of inquiry, the integration of immersive and data-rich tools broadens the horizon of what can be asked within the studio. Students no longer rely just on traditional forms of site analysis or deductive problem solving; instead, they operate within an environment where data, simulation, and embodiment continually reshape the very questions under investigation. In workflow, the adoption of digital infrastructures disrupts the linear trajectory that has long structured design education. The iterative loops observed in studied cases here illustrate a pedagogical culture in which analysis, generation, and evaluation are inseparably intertwined. Representation, in turn, becomes less about producing polished outputs and more about constructing shared environments of negotiation between students and instructors, but also between designers and stakeholders.

These transformations carry both promise and risk. On the one side, digital mediation enhances cognitive reach, accelerates iteration, and enables more transparent engagement. On the flip side, it risks privileging what is most easily simulated, potentially narrowing rather than expanding critical judgment. A reliance on algorithmic suggestion may dilute the role of intuition, just as the allure of immersive representation may reduce critique to spectacle if not carefully framed. The challenge for pedagogy, therefore, lies in cultivating discernment: preparing students to navigate abundance, to balance tacit and computational modes of reasoning, and to deploy technologies as instruments of inquiry rather than ends in themselves.

What emerges from the studied case is a model of urban design education that reconciles disciplinarity and interdisciplinarity through technology. By serving as a shared platform across diverse student backgrounds, digital tools foster collaborative experimentation and collective authorship. The synergies among VR, AR, and AI could form a cognitive ecosystem that equips graduates to grapple with the layered complexity of urban transformation. In this sense, technology becomes not simply a theme, means of representation, or tools for efficiency but a medium for epistemological experimentation; one through which the future of urban design pedagogy may be reimagined.

Looking ahead, the triadic framework proposed in this study including organizing inquiry, shaping workflows, and guiding representation, offers a transferable structure for rethinking urban design curricula beyond the MUDDE program. The framework can support curriculum development

in other institutions seeking to integrate immersive and computational tools. It also provides a basis for cross-institutional comparison, enabling educators and researchers to examine how different programs embed technological mediation within their studios and workshops. Future research could extend this work by applying the framework to diverse courses, incorporating larger sample sizes, and conducting longitudinal studies that assess how digital pedagogies evolve over time. Such directions would broaden the applicability of the model and situate digital mediation as a shared, adaptable foundation for contemporary urban design education.

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CRediT Authorship Contribution Statement

Maryam Shafiei: Writing – review & editing, Writing – original draft, Methodology, Investigation, Analysis, Data curation, Conceptualization, Data visualization. M. Nabyl Chenaf: Writing – review & editing, Writing – original draft, Methodology, Investigation, Analysis, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Ethics Committee Approval

For this survey, American University in Dubai does not an ethical report.

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