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GENERAL EDUCATION COURSES OF DIGITAL ARCHITECTURE AND URBAN COGNITION IN ARCHITECTURE UNIVERSITIES BASED ON KNOWLEDGE GRAPHS

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Abstract: The rapid transformation of architectural practice by digital modeling, urban data, artificial intelligence, geographic information systems, building information modeling, and spatial cognition research has created a new educational challenge for architecture universities: how to cultivate digitally literate, spatially sensitive, and critically reflective students beyond the boundaries of specialized design studios. This paper proposes a knowledge-graph-based framework for the construction of a general education course titled “Digital Architecture and Urban Cognition.” Unlike conventional tool-oriented digital courses, the proposed course treats digital architecture as an interdisciplinary knowledge system connecting architectural form, urban perception, data structures, environmental behavior, cultural context, and ethical judgment. Drawing on learning science, knowledge graph theory, architectural pedagogy, BIM standards, semantic city modeling, and urban cognition studies, the paper develops a curriculum model composed of three interrelated graphs: a domain knowledge graph, a learning-path graph, and an assessment-evidence graph. The study argues that knowledge graphs can help general education courses overcome three persistent problems: fragmented knowledge organization, separation between technical skills and humanistic understanding, and weak visibility of students’ cognitive development. The proposed framework includes curriculum objectives, ontology construction, teaching modules, learning activities, assessment indicators, and implementation strategies. It concludes that knowledge-graph-based general education can support architecture universities in forming a new pedagogical ecology in which students learn not only to use digital tools, but also to understand cities as complex, perceivable, computable, and culturally meaningful environments.
Keywords: Digital architecture; General education; Knowledge graph; Architectural education

1 INTRODUCTION

Architectural education has historically been organized around the design studio, where students learn through drawing, modeling, critique, precedent study, and iterative spatial imagination. This tradition remains indispensable. However, the contemporary built environment is increasingly mediated by digital models, urban sensors, spatial databases, artificial intelligence, simulation platforms, and semantic information systems. Architecture students now encounter buildings not only as physical objects, but also as data-rich entities embedded in networks of mobility, energy, climate, public behavior, regulation, material flows, and cultural memory. Therefore, architecture universities require a broader educational structure that introduces students, including non-specialists or lower-year undergraduates, to digital architectural thinking as a form of general intellectual literacy.

General education in architecture universities should not be reduced to introductory appreciation courses or simplified professional training. Its task is to provide students with conceptual bridges between technology, design, society, and human experience. In this sense, “Digital Architecture and Urban Cognition” can serve as a strategic general education course. It enables students to understand how digital tools reshape architectural representation, how urban environments are perceived and mentally mapped, and how knowledge systems can connect spatial, social, environmental, and technical information.

This paper proposes that knowledge graphs offer a powerful method for organizing such a course. Knowledge graphs have been widely discussed as structured representations of entities, relations, attributes, and inference mechanisms; they allow heterogeneous knowledge to be connected, queried, and extended. Hogan et al. describe knowledge graphs as systems that integrate graph-based data models, semantics, querying, validation, and reasoning, making them suitable for complex domains in which knowledge is distributed across multiple sources and levels of abstraction [1]. In architectural education, this characteristic is particularly valuable because architecture itself is a relational discipline: it links people, space, materials, structure, history, environment, perception, and technology.

The central argument of this paper is that a knowledge-graph-based general education course can transform the teaching of digital architecture from software instruction into cognitive, cultural, and systemic learning. Rather than teaching isolated topics such as BIM, GIS, parametric design, virtual reality, or urban perception as separate units, a knowledge graph can reveal how these topics are related. For example, a “street” may be understood as a spatial element, a mobility corridor, a perceptual path, a public realm, a data object, a regulatory unit, and a cultural scene. A knowledge graph allows these meanings to coexist and become pedagogically visible.

The objective of this paper is threefold. First, it analyzes the educational necessity of general education courses that integrate digital architecture and urban cognition. Second, it proposes a knowledge-graph-based curriculum framework suitable for architecture universities. Third, it discusses implementation strategies, assessment methods, and future research directions.

2 LITERATURE BACKGROUND

2.1 Digital Transformation in Architectural Education

Digital architecture education has often been associated with the acquisition of technical competence: CAD drafting, BIM modeling, parametric design, digital fabrication, environmental simulation, visualization, and computational form generation. These competencies are necessary, but they are insufficient when detached from architectural judgment. Recent research on digital design pedagogy argues that digital tools should be integrated with design thinking, sustainability, and reflective practice rather than treated as neutral instruments [2]. Xiang's study of digital architectural design teaching, for example, emphasizes that digital design education should be connected to sustainability and broader design values, rather than merely software operation [3].

More recent studies also point to the value of hybrid digital tools in architectural education, especially where they support iterative design thinking, collaboration, and integration between analog and digital modes [4]. This is significant for general education because students entering architecture universities often possess uneven digital backgrounds. Some are skilled in software but weak in conceptual understanding; others have strong humanistic interests but limited computational confidence. A general education course must therefore cultivate digital literacy as a mode of inquiry, not only as operational proficiency.

2.2 Urban Cognition and Spatial Understanding

Urban cognition concerns how people perceive, remember, navigate, interpret, and emotionally experience urban environments. Kevin Lynch's classic theory of city imageability remains foundational: he identified paths, edges, districts, nodes, and landmarks as elements through which people form mental images of the city [5]. Contemporary computational approaches have extended these ideas by connecting urban perception with GIS, network analysis, and large-scale spatial data. Filomena et al., for instance, proposed a computational approach to *The Image of the City*, showing how concepts from Lynch's theory can be related to network science and GIS-based analysis [6].

For architectural general education, urban cognition provides a humanistic counterweight to technological determinism. Students learn that cities are not merely digital models or geometric datasets; they are experienced by bodies, remembered through images, navigated through cues, and interpreted through social and cultural meanings. A course on digital architecture must therefore ask: How does a digital model correspond to lived space? What forms of urban experience are captured by data, and what forms are excluded? How can computational representation support, rather than replace, embodied understanding?

2.3 Knowledge Graphs and Semantic Representation

Knowledge graphs are well suited to interdisciplinary curriculum design because they represent knowledge as connected entities and relations. In technical terms, many knowledge graph systems draw on Semantic Web standards such as RDF, OWL, and SPARQL. The World Wide Web Consortium describes RDF as a standard model for data interchange that supports data merging even when schemas differ [7]. OWL is designed to represent complex knowledge about things, groups, and relations, and to support consistency checking and inference [8]. SPARQL enables querying across graph-structured data [9].

These standards are not merely technical references; they also suggest a pedagogical philosophy. A course knowledge graph can model how concepts relate: "BIM" connects to "building lifecycle," "IFC," "interoperability," "construction coordination," and "facility management." "Urban cognition" connects to "mental map," "landmark," "path," "legibility," and "navigation." "Digital twin" connects to "sensor data," "simulation," "feedback," "governance," and "ethics." Through such relations, students can see architecture as an interconnected knowledge field rather than a set of disconnected lectures.

2.4 BIM, IFC, City GML, and Urban-Scale Digital Knowledge

Digital architecture increasingly depends on standardized information models. Industry Foundation Classes, or IFC, provide an open, vendor-neutral standard for describing built-environment data, including buildings and civil infrastructure; building SMART identifies IFC 4.3 as the latest official version and notes its ISO standardization as ISO 16739-1:2024 [10]. At the urban scale, City GML defines a conceptual model and exchange format for virtual 3D city models, supporting representation, storage, and exchange of semantic urban information [11].

These standards matter for education because they demonstrate that digital architecture is not only about visual modeling. It is also about semantic modeling: what a wall, window, road, tree, plaza, district, or landmark "means" within a structured information system. This semantic orientation aligns naturally with knowledge graphs. It also helps students understand the transition from drawing-based representation to data-based representation.

3 RESEARCH PROBLEM AND COURSE POSITIONING

Architecture universities face a pedagogical dilemma. On one hand, they must respond to rapid technological change by offering courses in BIM, AI, computational design, digital fabrication, and urban analytics. On the other hand, if these courses are introduced only as professional electives or technical workshops, students may fail to understand their broader cultural, cognitive, and social significance. General education offers a way to solve this dilemma by introducing digital architectural knowledge at an integrative level.

The proposed course, “Digital Architecture and Urban Cognition,” is positioned as a general education course for architecture universities. It may be taken by architecture, urban planning, landscape architecture, design, civil engineering, environmental studies, digital media, or humanities students. The course does not aim to train software specialists. Instead, it aims to cultivate five forms of literacy:

1. Spatial literacy: the ability to read, describe, and interpret architectural and urban space.
2. Digital literacy: the ability to understand how digital tools and data models represent space.
3. Cognitive literacy: the ability to analyze how people perceive, navigate, and remember urban environments.
4. Semantic literacy: the ability to recognize relationships among concepts, entities, attributes, and systems.
5. Ethical literacy: the ability to evaluate the social consequences and limitations of digital urban technologies.

The course therefore occupies a middle ground between professional architectural education and broad liberal education. It introduces architectural knowledge to non-specialists while helping architecture students step back from studio production and reflect on the knowledge structures underlying their work.

4 METHODOLOGICAL FRAMEWORK

This paper adopts a conceptual curriculum research method supported by design-based reasoning. It does not report a completed empirical experiment; rather, it proposes a framework that can guide course design, pilot teaching, and future empirical evaluation. The framework is informed by three bodies of theory.

First, learning science emphasizes that effective learning environments should be learner-centered, knowledge-centered, assessment-centered, and community-centered. The National Research Council’s *How People Learn* argues that deep learning requires attention to prior knowledge, conceptual organization, metacognition, and meaningful assessment [12]. This is directly relevant to general education, where students enter with diverse backgrounds.

Second, the revised Bloom’s taxonomy provides a hierarchy of cognitive processes, including remembering, understanding, applying, analyzing, evaluating, and creating [13]. In this course, knowledge graphs are used to move students from remembering isolated terms to analyzing relationships and creating interpretive digital-spatial representations.

Third, knowledge graph theory provides the structural logic for curriculum organization. The course is not planned as a linear sequence of topics, but as a graph of concepts, tools, cases, activities, and evidence. This allows the course to support multiple learning paths while maintaining conceptual coherence.

5 KNOWLEDGE-GRAPH-BASED COURSE MODEL

The proposed curriculum model consists of three interrelated graphs: the domain knowledge graph, the learning-path graph, and the assessment-evidence graph.

5.1 Domain Knowledge Graph

The domain knowledge graph represents the intellectual content of the course. Its core entities include “architecture,” “city,” “digital model,” “data,” “perception,” “cognition,” “urban behavior,” “semantic standard,” “simulation,” “ethics,” and “design decision.” Each entity is linked through relations such as “represents,” “influences,” “is perceived through,” “is measured by,” “is modeled as,” “is governed by,” and “is evaluated through.”

For example:

- “Landmark” — supports — “urban orientation.”
- “BIM model” — represents — “building component.”
- “IFC” — standardizes — “building information exchange.”
- “City GML” — represents — “semantic 3D city model.”
- “Urban path” — shapes — “mental map.”
- “Sensor data” — informs — “digital twin.”
- “Digital twin” — raises — “privacy and governance issues.”

This structure makes conceptual relationships explicit. Students can see that a landmark is not only a visual object, but also a cognitive anchor, a cultural symbol, a GIS feature, a possible 3D model entity, and a design consideration.

5.2 Learning-Path Graph

The learning-path graph organizes the sequence of learning. Unlike a fixed syllabus that assumes all students learn in the same order, the learning-path graph identifies prerequisite relations, parallel modules, and optional extensions. For example, “basic spatial observation” precedes “urban cognitive mapping,” while “data structure” precedes “knowledge graph construction.” “BIM concepts” and “City GML concepts” can be studied in parallel, then integrated in a module on “building-city semantic connection.”

The learning-path graph supports differentiated teaching. Students with weak digital backgrounds may follow a path emphasizing visual examples and conceptual exercises before technical mapping. Students with strong computational backgrounds may extend their work into graph querying, network analysis, or simple ontology design.

5.3 Assessment-Evidence Graph

The assessment-evidence graph connects learning outcomes with student artifacts. Traditional general education assessment often relies on essays, exams, or attendance. In this course, assessment evidence includes concept maps, field observation notes, urban cognitive sketches, semantic diagrams, model annotations, group presentations, reflective journals, and final projects.

For instance, the learning outcome “analyze the relationship between urban form and cognitive experience” may be evidenced by a student’s annotated map of a campus district, a short essay on legibility, and a graph showing relations among paths, nodes, landmarks, and user groups. The outcome “explain the role of semantic standards in digital architecture” may be evidenced by a diagram comparing geometric models and semantic models.

6 COURSE OBJECTIVES

The course objectives are organized into four levels.

At the knowledge level, students should understand basic concepts of digital architecture, urban cognition, BIM, GIS, City GML, knowledge graphs, digital twins, and spatial data ethics.

At the method level, students should be able to conduct spatial observation, draw cognitive maps, identify urban image elements, construct simple concept graphs, and interpret digital representations of buildings and cities.

At the integration level, students should connect human perception with digital modeling. They should be able to explain how a physical urban environment becomes a mental image, a drawing, a 3D model, a database object, or a graph node.

At the value level, students should critically evaluate the social implications of digital urban technologies, including surveillance, accessibility, algorithmic bias, heritage representation, environmental responsibility, and public participation.

7 PROPOSED TEACHING MODULES

The course may be organized into eight modules over a sixteen-week semester.

Module 1: Architecture, City, and Digital Transformation

This module introduces the historical shift from hand drawing to CAD, BIM, parametric modeling, simulation, urban platforms, and digital twins. The key teaching point is that each representational system changes what designers notice and what decisions they can make.

Module 2: Spatial Perception and Urban Cognition

Students study how people perceive, navigate, and remember urban space. Lynch’s five elements are introduced as a bridge between classic urban theory and contemporary computational analysis. Students complete a short field exercise by drawing a cognitive map of a campus, street, or neighborhood.

Module 3: From Drawing to Data

This module explains the difference between visual representation and semantic representation. A wall in a drawing is a line or surface; a wall in a semantic model has material, fire rating, load-bearing status, cost, thermal performance, and maintenance implications.

Module 4: BIM and Building Knowledge

Students are introduced to BIM as an information-centered approach to building representation. The module emphasizes interoperability, lifecycle thinking, and IFC as a shared data standard rather than teaching a specific commercial software package.

Module 5: City Information Models and Urban Data

This module extends the discussion from building to city. Students learn the concept of semantic 3D city models and examine how City GML represents urban objects such as buildings, roads, terrain, vegetation, water bodies, and city furniture.

Module 6: Knowledge Graphs for Architecture and Cities

Students learn the basic structure of a knowledge graph: entities, relations, attributes, triples, classes, and instances. They construct a small graph linking urban elements, cognitive functions, digital representations, and social meanings.

Module 7: Digital Ethics and Urban Governance

This module addresses the risks of digital urbanism. Topics include data privacy, platform governance, surveillance, algorithmic exclusion, unequal access to digital tools, and the need to preserve embodied, local, and cultural knowledge.

Module 8: Integrative Project

Student groups select a site and produce a “digital-urban cognition graph.” The final project includes a field observation, cognitive map, semantic concept graph, short analytical essay, and presentation. The project does not require advanced programming; rather, it requires conceptual integration.

8 TEACHING STRATEGIES

The course should combine lectures, seminars, fieldwork, workshops, and project-based learning. A purely lecture-based format would contradict the relational nature of the subject. The following strategies are recommended.

First, case-based teaching should be used to connect abstract concepts with real built environments. A campus, transit station, commercial street, historic district, or public square can become a living laboratory.

Second, dual representation exercises should be emphasized. Students may first sketch a place by hand, then translate the same place into a table of entities and relations, and finally into a graph. This process helps them understand the difference between visual, textual, and semantic representation.

Third, collaborative graph construction should be used as a classroom activity. Students collectively build a graph on a board or digital platform, debating whether "landmark" should be linked to "visual salience," "cultural memory," "navigation," or "tourism." Such debates are pedagogically valuable because they reveal that knowledge organization is interpretive, not automatic.

Fourth, reflective writing should accompany technical exercises. After constructing a graph, students should write a short reflection on what the graph clarifies and what it fails to capture. This prevents digital representation from being mistaken for total understanding.

Fifth, progressive complexity should guide teaching. Students begin with simple concept maps, move to entity-relation diagrams, and only later encounter formal knowledge graph ideas such as RDF, ontology, or querying.

9 ASSESSMENT DESIGN

Assessment should align with the course's general education character. It should evaluate conceptual understanding, integrative thinking, ethical reflection, and communication, not only technical output.

A possible assessment structure is (Table 1):

Table 1 Evaluation Table for Knowledge Graph Learning Effectiveness

Assessment Component	Weight	Purpose
Weekly concept notes	15%	Check understanding of key terms and relations
Field observation and cognitive map	20%	Connect urban experience with spatial perception
Mini knowledge graph exercise	20%	Evaluate semantic organization ability
Group integrative project	30%	Assess interdisciplinary synthesis
Reflective essay	15%	Evaluate critical and ethical judgment

Rubrics should include criteria such as conceptual accuracy, relational richness, clarity of representation, evidence from observation, integration of digital and humanistic perspectives, and ethical awareness.

The assessment-evidence graph can also be used by instructors to identify learning gaps. For example, if many students correctly identify landmarks but cannot connect them to social meaning or data representation, the instructor can adjust teaching in later weeks.

10 EXPECTED EDUCATIONAL CONTRIBUTIONS

The proposed course can contribute to architectural education in several ways.

First, it expands digital education from tool training to knowledge formation. Students learn that digital architecture is not simply the use of software, but a transformation in how architectural knowledge is structured, exchanged, and interpreted.

Second, it strengthens the relationship between architectural education and urban human experience. By integrating urban cognition, students are reminded that digital models must ultimately respond to human perception, memory, behavior, and emotion.

Third, it offers a general education model suitable for interdisciplinary classrooms. Engineering students may focus on data structures; design students may focus on spatial experience; humanities students may focus on memory, culture, and ethics. The knowledge graph provides a shared structure for dialogue.

Fourth, it supports curriculum transparency. When the course itself is represented as a knowledge graph, students can see why topics are included and how they relate. This reduces the common problem of fragmented general education courses in which weekly topics appear unrelated.

Fifth, it creates a basis for future learning analytics. If student artifacts are mapped to learning outcomes, instructors can identify which concepts are central, which relations are weak, and which learning paths produce deeper integration.

11 CHALLENGES AND LIMITATIONS

Despite its promise, the proposed model faces several challenges.

The first challenge is teacher preparation. Many architecture instructors are comfortable with design critique but less familiar with knowledge graph concepts. Conversely, computer science instructors may understand graphs but lack architectural and urban sensitivity. Team teaching may therefore be necessary.

The second challenge is technical overload. A general education course must avoid becoming an advanced semantic web or database course. RDF, OWL, SPARQL, BIM, and City GML should be introduced conceptually, with optional technical extensions for advanced students.

The third challenge is assessment complexity. Evaluating graphs is more difficult than grading conventional essays or exams. Rubrics must balance correctness with interpretive openness. In architecture, there may be multiple valid ways to relate concepts.

The fourth challenge is data ethics. When students use urban data, photographs, maps, or behavioral observations, the course must establish clear ethical guidelines. Public-space observation should avoid intrusive personal data collection.

The fifth challenge is institutional positioning. Some universities may classify the course as digital technology, while others may classify it as urban studies, design theory, or general education. Its interdisciplinary nature is a strength, but it may complicate administrative approval.

12 FUTURE RESEARCH DIRECTIONS

Future research should move from conceptual framework to empirical validation. Several directions are recommended.

First, pilot courses should be implemented in different types of architecture universities, including research universities, design schools, and applied technology institutions. Comparative studies can examine how students from different majors respond to the course.

Second, pre-course and post-course concept maps can be analyzed to measure changes in relational understanding. If students' graphs become more accurate, more connected, and more interdisciplinary, this may indicate cognitive development.

Third, learning analytics can be developed from the assessment-evidence graph. Instructors may examine which concepts become central in student work and which remain peripheral.

Fourth, digital platforms can be created to support collaborative graph construction. Such platforms should be simple enough for general education students but flexible enough to support advanced semantic modeling.

Fifth, the relationship between knowledge graph learning and design studio performance deserves investigation. It is possible that students who understand architectural knowledge relationally may produce more integrated design work in later studios.

13 CONCLUSION

This paper has proposed a knowledge-graph-based framework for a general education course titled "Digital Architecture and Urban Cognition" in architecture universities. The main argument is that digital architectural education should not be limited to software training or technical specialization. In the context of general education, digital architecture should be taught as an interdisciplinary knowledge system linking spatial form, urban perception, semantic data, cultural meaning, environmental responsibility, and ethical judgment.

Knowledge graphs provide a suitable pedagogical structure because they make relationships visible. They can connect BIM with building knowledge, City GML with urban semantics, Lynchian urban cognition with computational analysis, and digital modeling with human experience. By organizing the course through a domain knowledge graph, learning-path graph, and assessment-evidence graph, instructors can create a curriculum that is coherent, flexible, and reflective.

The proposed course helps students understand that the city is simultaneously built, perceived, represented, computed, and governed. A street is not only a line in a plan; it is a path in memory, an edge in a network, a public space, a data object, and a cultural experience. A building is not only a form; it is a semantic system of components, performances, histories, and users. A digital model is not only a visual simulation; it is a selective interpretation of reality.

For architecture universities, such a course can become a bridge between professional education and general education, between technology and humanities, and between design practice and research thinking. Its broader significance lies in cultivating students who can use digital tools critically, understand urban environments relationally, and participate responsibly in the future transformation of architecture and cities.

COMPETING INTERESTS

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