

BIM-BASED GRAPHIC INSTRUCTION: IMPLICATIONS FOR ITS INTEGRATION INTO ARCHITECTURAL DRAWING EDUCATION

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SUMMARY: *This paper analyses the integration of Building Information Modeling (BIM) into Architectural Drawing education as a graphic and cognitive environment based on the control of the graphic representation of the different information containers that constitute a model. Its main contribution lies in formulating a pedagogical framework for BIM-Based Graphic Instruction grounded in the disciplinary principles of architectural representation, articulated through specific learning outcomes. Based on a Scoping Review following PRISMA-ScR-based criteria, covering journal articles published between 2010 and 2026 in Web of Science and Scopus, the study identifies a shift from tool-centred approaches towards models of curricular integration, collaborative learning, and interoperability. However, it also reveals persistent gaps: the weak definition of learning outcomes, limited assessment evidence, and insufficient attention to the role of graphic thinking within BIM environments. In response to these limitations, the paper selects six studies from the initial literature corpus for detailed analysis, based on criteria aimed at identifying previous research that explicitly provides specific information about the course in which BIM was implemented, together with a defined teaching plan and methodology. These six studies are then contrasted with the competences and learning outcomes of three graphic courses at the School of Architecture of the Technical University of Madrid, where BIM is currently being integrated through innovative and experimental teaching modules integrated into the degree's drawing curriculum. As a result, it proposes a BIM-Based Pedagogical Agenda for Architectural Drawing Instruction, aimed at aligning intended learning outcomes with BIM-mediated learning activities and strategically assessing BIM-Based Architectural Drawing Education through a SWOT analysis. The paper argues that BIM can strengthen spatial reasoning, representational coherence, and collaborative authorship, provided that it is taught critically as an extension — rather than a replacement— of a necessary architectural graphic culture.*

KEYWORDS: *BIM, Architecture Drawing, Pedagogical Methodologies, Buildings, Technologies, Model-Based Representation, Graphic Instruction.*

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1. INTRODUCTION AND BACKGROUND

Architectural Drawing functions as an interface between design intent (conception), technical representation (the conditions of representation), and scientific reasoning (perception, visual thinking and the psychology of Design) (Hewitt, 1984). Just as Eastman foresaw through his Building Description System (BDS), design would consist of interactively defining elements according to their shape and other properties, and arranging them in space, much like one would a balsa-wood model (1975). The adoption of BIM as a design and production paradigm has reorientated architectural practice and education toward information-centred, interdisciplinary, and collaborative workflows. These workflows aim to support the virtual construction of buildings through the integration of heterogeneous datasets within parametric models developed for multiple downstream uses. However, a significant proportion of BIM-based information continues to be materialised as conventional graphic documentation generated directly from models, frequently without explicit consideration of the informational, procedural, or cognitive implications of such translations.

Over the last two decades, the teaching of Drawing in higher technical schools of Architecture has been challenged by the progressive incorporation of digital methodologies and tools that not only transform the technical procedures used to represent architecture, but also the epistemology-based design rationale, which encompasses the four design stages: Planning & Clarification, Conceptual Design, Embodiment Design, and Detail Design (Yin et al., 2015). In this context, the implementation of BIM (Building Information Modelling) has acquired a singular prominence in contrast to CAD (Computer-Aided Design) environments—focused on the production of views and documents from well-known graphic entities. BIM platforms propose a paradigm based on collaborative-virtual construction (Ghosh, 2012) and the management of a model that integrates—according to the definitions of ISO 7817-1:2024 (International Organisation for Standardization, 2024)—geometry and data, from which quantitative and qualitative documentation (predominantly graphical) is derived. This epistemological shift raises a fundamental question for teaching geometry and Architectural Drawing: if drawing is the most powerful pattern of thought (Hewitt, 1984) for architects, what happens when “drawing” derives from the graphical construction and interpretation of a virtual information model? In such a context, the virtual model—mediated through established systems of representation and configured or reconfigured according to the needs of each collaborator—must itself be understood as drawing.

This paper critically examines how BIM-based pedagogies contribute to, transform, or constrain the acquisition of graphic and representational competencies in architectural education. For this purpose a scoping review of a systematic compilation of findings drawn from BIM-related teaching experiences in schools of architecture is carried out. This review is intended to support the implementation of such methodologies in Architectural Drawing courses across other academic contexts. The working hypothesis is that a comparative analysis of these experiences provides a sufficiently robust corpus both to guide—and critically problematise—the integration of the propaedeutic foundations of Architectural Drawing within a BIM environment, and to make visible the limitations inherent in these tools when they are used as mediators of graphic learning. Rather than assuming BIM to be a replacement for drawing, it is approached here as a pedagogical object open to interrogation: an environment that enables certain forms of representation and understanding, while also introducing biases, automatisms, and shifts in meaning. These issues are discussed in this article as central conditions for assessing the pedagogical role of BIM in Architectural Drawing education.

This research is therefore situated within the tension between two complementary, yet non-equivalent, logics. On the one hand, the logic of the critical production of graphic documentation in which the student operates on familiar graphic entities through manual drawing and develops a key competency regarding what is shown, how it is shown, and why. On the other hand, the logic of obtaining graphic documentation through model management, in which documentary coherence rests on a hierarchically organised model, on different levels of development, and on the correct definition of geometric and informational relationships. The transition between these logics is not neutral, as various studies have pointed out (Rahimian & Ibrahim, 2011; Sun et al., 2014; Tung & Chang, 2024): it affects the cognitive sequence of learning, spatial understanding, and the capacity to construct graphic meaning beyond instrumental compliance with a workflow.

1.1 Background

BIM across European Union (EU) Member States remains uneven, reflecting differences in policy maturity, market capacity, and regulatory ecosystems (Charef et al., 2019). While the EU public procurement directive has encouraged BIM uptake in publicly funded projects and ISO-based frameworks have consolidated international guidance for information management (European Parliament, 2014; International Organisation for Standardization, 2015, 2018, 2024), standardisation does not automatically translate into effective practice. ISO-aligned workflows require users to grasp not only tool operations but also the underlying concepts governing information requirements, responsibilities, and the coordination of processes, people, and technologies. Recent formalisation efforts—e.g., ontology-based representations of ISO 19650—aim to make these concepts explicit and computable, supporting tasks such as BIM Execution Plan development and compliance checking (Abanda et al., 2025).

Importantly, this shift from document-centric production to model and information-centric workflows has educational implications: BIM environments can support experiential, project-based learning, yet they may also transform the role of foundational representational competences by automating view generation and embedding geometric constraints within parametric models. Although BIM's benefits have been widely reported in design and construction contexts (Kaner et al., 2008; Patrick & Raja, 2007; Sacks et al., 2005; Salman et al., 2008) and BIM-enabled “learning by doing” has been advocated in architectural and engineering education (Gier, 2007; Hedges & Denzer, 2008; Peterson et al., 2011; Sacks & Barak, 2010), the specific impact of BIM-based pedagogy on propaedeutic knowledge in geometry and Architectural Drawing—such as spatial reasoning, projection systems, and graphic conventions—remains insufficiently synthesised and characterised.

2. RESEARCH OBJECTIVES AND SCOPE

This article presents a Scoping Review of the academic literature on the integration of BIM methodologies and tools into graphic-related courses in Architecture curricula. The review aims to identify and characterise key pedagogical challenges and the teaching approaches adopted for the implementation of BIM in subjects related to architectural representation, geometry, graphic communication, modelling and visualisation. Studies focused exclusively on design studios or construction management are excluded unless they explicitly address graphic competencies.

The scoping review was conducted and reported with reference to the PRISMA extension for Scoping Reviews (PRISMA-ScR, Tricco et al., 2018), applying explicit criteria for database selection (Web of Science and Scopus), publication period (2010-2026), language (English), publication type (peer-reviewed journal articles), and thematic eligibility. Four Research Questions (RQ) guide the analysis: (RQ1) what pedagogical models and learning strategies are used; (RQ2) how BIM integration in graphic education has evolved; (RQ3) what learning outcomes are reported and how they are assessed; and (RQ4) what barriers, challenges, and enabling factors are most frequently identified.

The findings are subsequently contrasted with the general and specific competences of a set of courses taught at the Higher Technical School of Architecture of Madrid, including mandatory course (second course of Geometry and Architectural Drawing) and electives (Experimental Workshop on Infographics and Geometric Modelling, and Architectural Graphic Ideation—Intensification Track). This contrast is framed as a contextual application case to assess the relevance of the review results within a specific teaching setting, without claiming direct generalisability.

The study is organised into three phases: (1) the development of a thematic Synthesis of the Research, partly informed by a PRISMA-ScR-based, to identify relevant studies and analyse the evolution of BIM pedagogy and instructional models in graphic-related courses; (2) the Synthesis of Evidence on BIM teaching methodologies identified through the previous review; and (3) Curricular Transfer to Graphic Education, where this evidence is discussed in relation to the general/specific competences and learning outcomes shared by the aforementioned required and elective courses.

3. METHODOLOGY

The methodology is structured into two interrelated parts that articulate a progression from evidence synthesis to pedagogical translation (Figure 1). The first part is devoted to the Identification of Studies through Databases of BIM-related Educational Experiences. Its purpose is to establish an evidence-based understanding of how BIM

has been incorporated into teaching and learning in Higher Education. This stage enables the development of a Thematic Synthesis of the Research, presented in Section 4, which frames the study around an Overview of BIM Learning Experiences (4.1) and Perceptions across Different Regions and Identification of Barriers in Higher Education (4.2). Furthermore, the study identification process provides the base for the Evidence on BIM Teaching Methodologies presented in Section 5. In this section, the six studies reporting educational experiences are analysed to compare their Instructional Planning and Methodological Orientations (5.1), and identify Gaps, Limitations, and Implications for Future Pedagogical Design (5.2). The section concludes with a synthesis of the main findings, structured around the answers to the research questions (5.3).

The second part transfers the evidence base to architectural graphic education within the Bachelor's Degree in Foundations of Architecture at the School of Architecture of the Technical University of Madrid (UPM). Through a Curricular Mapping for BIM-Based Graphic Instruction, the competences and learning outcomes that would underpin a cross-curricular BIM teaching model across three graphic courses are identified. Developed in Section 6, this Curricular Transfer to Graphic Education is grounded in the Competence and Learning Outcome Mapping (6.1), derived from comparing the Conceptual Curricular Mapping for BIM-Based Graphic Instruction (3.2) with the Instructional Planning and Methodological Orientations (5.1). This mapping supports the Framework of a BIM-Based Pedagogical Agenda for Architectural Drawing Instruction (6.2), which is articulated by aligning intended learning outcomes with BIM-Mediated Learning Activities and by strategically assessing BIM-Based Architectural Drawing Education through a SWOT analysis.

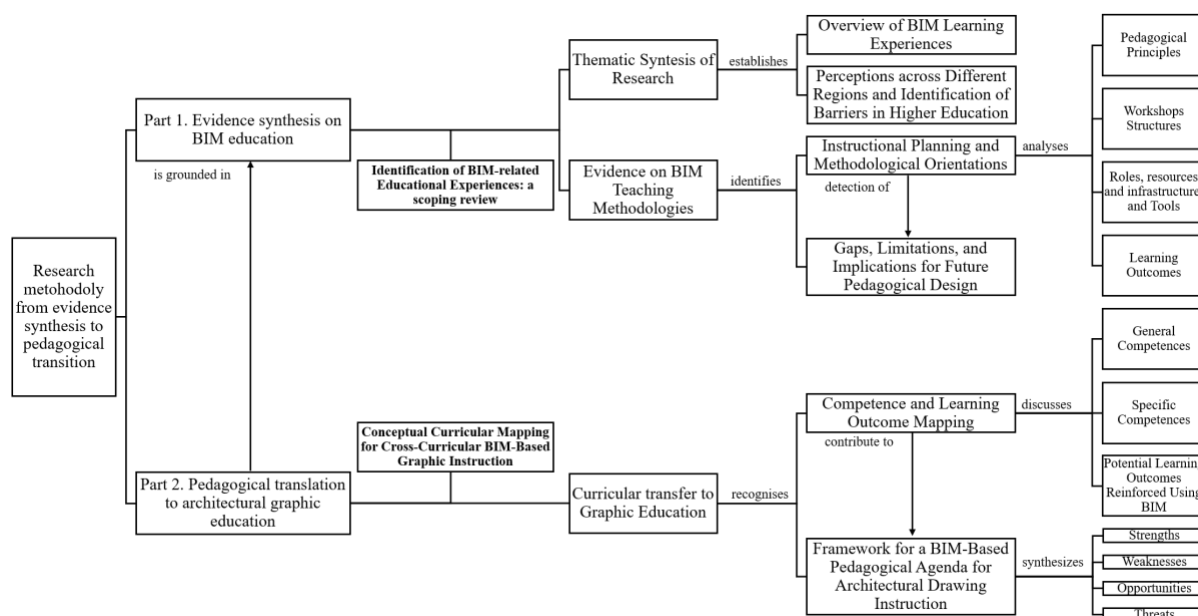


Figure 1: Diagram illustrating the methodological workflow adopted in this study.

3.1 Identification of BIM-related educational experiences: A scoping review

A Scoping Review was conducted to identify studies indexed in Web of Science (WoS) and Scopus that address peer-reviewed journal articles on BIM-related educational experiences in the field of architecture. The aim of the search was to establish a comparative basis for analysing the alignment between educational objectives, methodological approaches and teaching strategies, as well as to inform future teaching plans in Architectural Drawing through the use of BIM as a methodological framework.

As stated previously, the study identification and selection process was documented in accordance with the relevant reporting recommendations of PRISMA-ScR (Tricco et al., 2018). The initial database searches were executed on 21 April 2026 and was subsequently reran on 15 July 2026. The procedure followed the flow diagram presented in Figure 2, which also reports the distribution of results by database and search string.

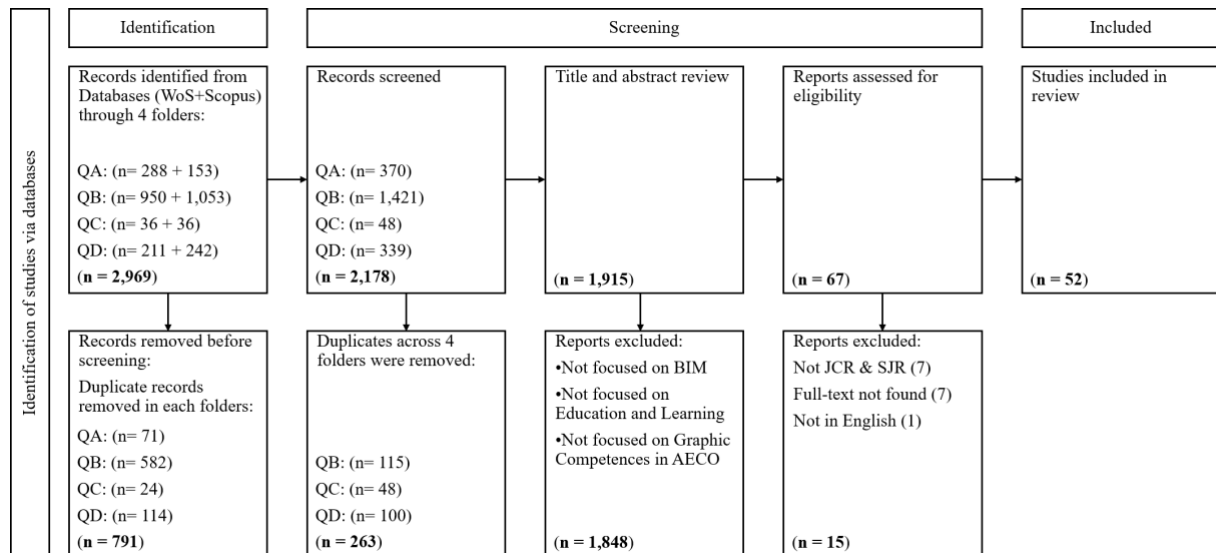


Figure 2: Flow diagram of the study selection process following PRISMA-ScR.

The search strategy was structured around four search strings, presented in Table 1, each designed to address complementary dimensions of the research object. The first string, QA, aimed to identify previous systematic reviews and mapping studies in order to frame the state of the art. The second, QB, focused on retrieving studies dealing with curriculum design and the integration of BIM into architectural education. The third, QC, was intended to narrow the search to the Spanish higher education context, applying the corresponding filters in WoS and Scopus. Finally, the fourth string, QD, targeted studies addressing learning outcomes, competences, or skill development associated with BIM-based teaching methodologies.

Table 1: Search strings used in the bibliographic databases.

	Web of Science	Scopus
QA	(BIM OR "building information model*") AND (architectur* OR "architectural education" OR "architecture education" OR "design studio" OR "architectural design studio") AND ("systematic review" OR "systematic literature review" OR SLR OR "mapping study" OR "systematic mapping" OR PRISMA)	TITLE-ABS-KEY ("building information model*") OR TITLE-ABS-KEY (BIM) AND TITLE-ABS-KEY (architectur*) OR TITLE-ABS-KEY ("architectural education") OR TITLE-ABS-KEY ("architecture education") OR TITLE-ABS-KEY ("design studio") OR TITLE-ABS-KEY (architectural AND design AND studio) AND TITLE-ABS-KEY ("systematic review") OR TITLE-ABS-KEY ("systematic literature review") OR TITLE-ABS-KEY (slr) OR TITLE-ABS-KEY ("mapping study") OR TITLE-ABS-KEY ("systematic mapping") OR TITLE-ABS-KEY (prisma)
QB	(BIM* OR "building information model*")	TITLE-ABS-KEY ("building information model*") OR TITLE-ABS-KEY (BIM*) AND TITLE-ABS-KEY (curricul*) OR TITLE-ABS-KEY ("syllabus") OR TITLE-ABS-KEY ("study plan ") OR TITLE-ABS-KEY ("curricular integration ") OR TITLE-ABS-KEY ("learn*") AND TITLE-ABS-KEY (architectur*) OR TITLE-ABS-KEY ("design studio") OR TITLE-ABS-KEY ("architectur* education")
QC	AND (curricul* OR syllabus OR "study plan" OR "curricular integration" OR "learn*") AND (architectur* OR "design studio" OR "architectur* education")	
QD	(BIM OR "building information model*") AND (skill* OR "learning outcome*" OR "graduate attribute*") AND ("architectural education" OR "design studio" OR architectur*)	TITLE-ABS-KEY (BIM) OR TITLE-ABS-KEY ("building information model*") AND TITLE-ABS-KEY ("skill*") OR TITLE-ABS-KEY ("learning outcome*") OR TITLE-ABS-KEY ("graduate attribute*") AND TITLE-ABS-KEY ("architectural education") OR TITLE-ABS-KEY ("design studio") OR TITLE-ABS-KEY (architectur*)

The keywords were selected to capture studies at the intersection of BIM, architectural education and learning processes. The terms “BIM” and “building information model*” ensured coverage of both the acronym and the full expression, while “architectur*” and concepts such as “architectural education” and “design studio” focused

the search on architecture-based teaching contexts. In QA, terms such as “systematic review”, SLR, “mapping study” and PRISMA were used to identify previous reviews and mapping studies. In the curriculum-related query (QB and QC), terms such as *curricul**, *syllabus*, “study plan” and “curricular integration” targeted BIM incorporation into educational programmes. In QD, *skill**, “learning outcome*” and “graduate attribute*” were included to retrieve studies addressing competences and educational outcomes linked to BIM-based learning.

The selection of these four search strings therefore responded to the need to construct a balanced corpus including both broad overview studies and research focused on specific teaching experiences, curricular integration, institutional context, and competence development. This structure made it possible to approach the topic from a broad perspective while maintaining a clear focus on architectural education and the role of BIM as a methodological and pedagogical tool.

In both databases, searches were conducted through Advanced Search and refined by document type: article and language: English. Records were imported into a RefWorks project using the web available on 21 April 2026 (Clarivate, 2026) with the relevant bibliographic information (authors, date published, DOI, Electronic Source, ID, issue, journal, notes, pages, record type, source database, tags, title, URL, volume, and year.). The eight searches —four strings applied in two databases— produced an initial corpus of 2,969 records, organised in four RefWorks folders: QA, 441; QB, 2,003; QC, 72; and QD, 453.

Deduplication was conducted in two stages using the RefWorks “Find duplicates” function. In both stages, “References that are similar” was selected, “Include empty fields” was enabled, and title, author surname, and publication year were used as matching fields. No additional metadata fields were included in the automated comparison.

First, duplicates were identified separately within each query folder, reducing the corpus from 2,969 to 2,178 records: QA, 441 to 370; QB, 2,003 to 1,421; QC, 72 to 48; and QD, 453 to 339. Second, the same procedure was applied across the “All references” section of the project to identify overlap among query folders. A folder-priority sequence of QA, QB, QC, and QD was applied, resulting in 370 QA records, 1,306 QB records, no QC records, and 239 QD records, for a final corpus of 1,915 references.

All candidate duplicates were reviewed individually by the author before removal. Similar but non-identical records were confirmed by comparing their abstracts. The most complete record was retained, with abstract availability and completeness used to distinguish between candidate records. No preference was given to Web of Science or Scopus.

The titles and abstracts of the remaining records were then reviewed. Three exclusion criteria were applied sequentially according to the established workflow:

- studies not focused on BIM;
- studies not focused on education, teaching, or learning;
- studies not focused on Graphic Competences in AECO (Architecture, Engineering, Construction & Operations).

Following the screening process, 1,848 records were excluded, and 67 reports were assessed for eligibility. Eligibility was evaluated according to three criteria: quality, completeness, and language.

- **Quality.** Journal quality was assessed using the SCImago Journal Rank (SJR) and Journal Citation Reports (JCR), together with the relevance of each journal’s subject area and category to the research topic. This criterion was introduced at the eligibility stage after several journals were found not to be indexed in either database. Consequently, seven reports published in journals not indexed in SJR or JCR were excluded, leaving 60 reports.
- **Completeness.** Of the 60 remaining reports, seven could not be accessed in full text and were therefore excluded. This resulted in 53 full-text reports available for further assessment.
- **Language.** One of the 53 accessible reports, initially classified as being written in English based on its metadata, was found upon full-text examination to be written in another language. It was therefore excluded.

Overall, 15 reports were excluded during the eligibility assessment. The excluded articles and the specific reasons for their exclusion are detailed in Appendix A (Table A.2). The final corpus therefore comprised 52 studies that met all eligibility criteria and were included in the review.

Once the final corpus had been established and the relevance of the selected publications determined, a first general reading was performed to classify the studies thematically. The categories were defined inductively based on this initial reading of the corpus. This process led to the identification of 11 analytical categories, presented in Table 2, which structure the subsequent literature analysis.

Table 2: Thematic categories for corpus classification.

Code	Thematic category	Operational definition
C01	Reviews, mappings and bibliometric studies on BIM education	Systematic reviews, literature reviews, bibliometric studies, scientometric analyses, SWOT analyses, and global approaches to the field of BIM education.
C02	Curricular and institutional integration of BIM	Strategies, models, and levels of BIM integration in curricula, educational programmes, academic cycles, and institutions.
C03	Teaching experiences, courses, and pedagogical methodologies	Classroom case studies, BIM courses, teaching modules, project/problem-based learning, educational resources, and teaching methods.
C04	BIM in the architectural design studio	Specific use of BIM in design studios, capstone projects, architectural design processes, creativity, design critique, and project development.
C05	Interdisciplinary collaboration, coordination, and teamwork	Use of BIM as a collaborative environment across AEC disciplines, team coordination, academic competitions, and interdisciplinary learning.
C06	Perceptions, awareness, barriers, and academic adoption	Surveys, attitudes, preferences, barriers, awareness of BIM, motivation, intention to use, and adoption models in educational contexts.
C07	Professional competences and university-industry alignment	Employability, BIM competences, industry needs, professional identity, and knowledge transfer between academia and professional practice.
C08	BIM, sustainability, Green BIM and high-performance design	Application of BIM to sustainability, Green BIM, energy analysis, data-driven design, and high-performance design.
C09	BIM and immersive technologies in education	Integration of BIM with virtual, augmented or mixed reality, immersive environments, simulation and experiential learning.
C10	BIM, computational design, and parametrisation	Parametric design, computational design thinking, parametric modelling, algorithms, Dynamo, Grasshopper and computational reasoning.
C11	HBIM, Heritage, and adaptive reuse	Applications of Heritage BIM, heritage documentation, adaptive reuse, and education related to built heritage.

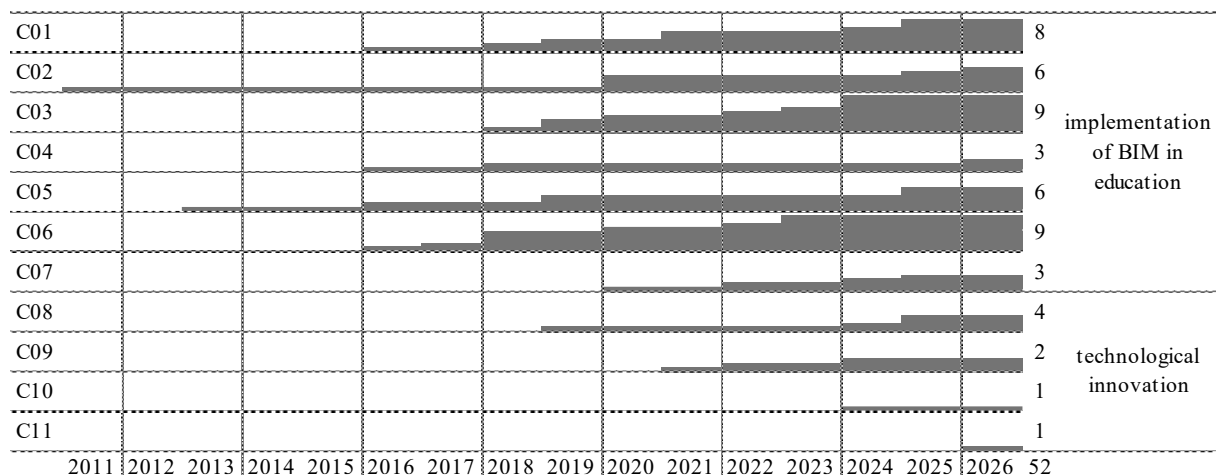


Figure 3: Total number of publications for each thematic category.

The results show a clear predominance of topics related to the implementation of BIM in education (C01–C07), accounting for nearly 80% of the publications, compared to topics related to technological innovation (C08–C11). This suggests that research interest has focused primarily on the incorporation of BIM into Higher Education. Of particular note are C03 (teaching experiences and pedagogical methodologies) and C06 (perceptions and academic

adoption), both due to the volume of publications and their parallel evolution over time (Figure 3). However, no new studies have been identified in C03 since 2024 or in C06 since 2023. Although these data do not allow us to conclude that both lines of research have been exhausted, they do indicate a lack of recent research in two key areas for the educational consolidation of BIM.

The categories presented in Table 2 provide a structured framework for identifying the thematic areas most directly aligned with the research objectives (C01–C07). To determine the level of analytical depth applied to the selected sources, four levels of relevance were established and mapped onto the thematic categories: contextual (C01 and C02), priority (C03, C05, and C06), secondary (C04 and C07), and emerging (C08–C11). Within each thematic category, publications were prioritized for in-depth analysis based on journal quality and impact indicators (Clarivate Analytics, 2026; Scopus, 2026), together with citation counts, as reported in Table 3. This procedure provides a systematic and transparent basis for determining the relative analytical emphasis assigned to the different research themes and their associated publications. Records classified as priority sources are analysed in depth in Section 5, while the other categories provide the necessary context for the research.

In line with the above, the articles selected for in-depth review are those with the greatest impact and/or representativeness within each thematic category (Table 3).

Table 3: Literature reviewed.

Thematic categories and titles of the studies included in the review			cit.	ranking
C01	Abdirad & Dossick (2016)	BIM curriculum design in architecture, engineering, and construction education: A systematic review	144	SJR (Q2) /JCR (N/A)
	Khan et al. (2021)	Integration of BIM and Immersive Technologies for AEC: A Scientometric-SWOT Analysis and Critical Content Review	92	SJR (Q1) / JCR (Q2)
	Besné et al. (2021)	A Systematic Review of Current Strategies and Methods for BIM Implementation in the Academic Field	35	SJR (Q2) /JCR (N/A)
	Chihib et al. (2019)	Bibliometric Maps of BIM and BIM in Universities: A Comparative Analysis	12	SJR (Q2) / JCR (Q3)
	Rocha et al. (2025)	BIM associated with virtual and augmented reality resources in an educational context: a systematic literature review	6	SJR (Q1) / JCR (Q1)
	Shin & Kang (2025)	From Tool-Based Training to Integrated Studios: A Review of BIM Education in Architecture	3	SJR (Q1) / JCR (Q2)
	Puolitaival & Kestle (2018)	Teaching and learning in AEC education-the building information modelling factor	8	SJR (Q2) / JCR (N/A)
	Sucipto & Akhyar (2024)	Implementing Building Information Modeling in Architectural, Engineering and Construction Education: A Systematic Literature Review	1	SJR (Q4) / -
C02	Wong et al. (2011)	Building Information Modelling for Tertiary Construction Education in Hong Kong	49	SJR (Q1) / JCR (N/A)
	Fadjar et al. (2020)	Building information modelling (BIM) adoption model for architectural education	26	SJR (Q1) / -
	Correa et al. (2025)	BIM integration in higher education: a global assessment	8	SJR (Q1) / JCR (Q1)
	Mlinkauskienė et al. (2020)	BIM integration possibilities in different study cycles of architecture study programme	3	SJR (Q2) / JCR (N/A)
	Leite & Brooks (2020)	Integrating an Architectural Engineering Undergraduate Programmewith Building Information Modeling	4	SJR (Q1) / JCR (Q3)
	Aranda-Mena et al. (2026)	Evolutionary patterns in building information modelling uptake across architecture, engineering and construction degrees: a longitudinal study	0	SJR (N/A) / JCR (N/A)
C03	Obi et al. (2024)	Enhancing BIM competencies of built environment undergraduates students using a problem-based learning and network analysis approach	26	SJR (Q1) / JCR (Q2)
	Zhang et al. (2018)	Project based learning with implementation planning for student engagement in BIM classes	23	SJR (Q2) / JCR (Q3)
	Hu (2019)	BIM-Enabled Pedagogy Approach: Using BIM as an Instructional Tool in Technology Courses	22	SJR (Q2) / JCR (Q2)
	Meterelliöz & Özener (2022)	Bim-Enabled Learning for Building Systems and Technology	5	SJR (Q2) / JCR (Q2)

Thematic categories and titles of the studies included in the review			cit.	ranking
	Zieliński (2020)	New technologies to support students in a BIM design course	4	SJR (Q2) / JCR (N/A)
	Markiewicz-Zahorski (2019)	Teaching building construction design using BIM: The benefits and difficulties	4	SJR (Q1) / -
	Bai & Chai (2024)	A Perspective on Micro-Courses and Building Information Modeling for Enhanced Teaching and Learning	1	SJR (Q3) / JCR (Q4)
	Makhmalbaf (2023)	Evaluating effects of an open educational resource on improving performance of students in BIM courses	3	SJR (N/A) / -
	ElShamy et al. (2024)	Building information modeling course for senior architecture and civil undergraduates GUC	0	SJR (Q2) / JCR (Q2)
C04	Jung & Kim (2016)	Virtual Plan-Design-Build for Capstone Projects in the School of Architecture: CM & BIM Studios in Five-Year B.Arch. Program	10	SJR (Q1) / JCR (N/A)
	Abdelhameed (2018)	BIM in architecture curriculum: a case study	8	SJR (Q1) / JCR (Q1)
	Filzmoser et al. (2017)	Integrated Design Studios: Education to Overcome Silo-thinking and Enable Full BIM-exploitation in AEC	0	SJR (N/A) / -
C05	Bozoglu (2016)	Collaboration and Coordination Learning Modules for Bim Education	40	SJR (Q2) / JCR (N/A)
	Mathews (2013)	BIM collaboration in student architectural technologist learning	18	SJR (Q4) / JCR (N/A)
	Ao et al. (2025)	Empowering architecture, engineering and construction students through building information modeling competitions: a deep dive into behavioral motivation	10	SJR (Q1) / JCR (Q1)
	Basson & Smallwood (2025)	Fostering criticality in architecture, construction management, and quantity surveying undergraduate students through digital interdisciplinary collaboration	1	SJR (Q1) / JCR (Q2)
	Rostam (2019)	Education Needs to Support Architecture, Engineering, and Construction Collaboration Using Building Information Modeling	1	SJR (N/A) / JCR (Q3)
	Herrera et al. (2019)	Impact on team performance of interaction with BIM	0	SJR (Q1) / -
C06	Babatunde et al. (2018)	Analysis of the drivers and benefits of BIM incorporation into quantity surveying profession: Academia and students' perspectives	36	SJR (Q2) / JCR (Q3)
	Shelbourn et al. (2017)	Students' perceptions of BIM education in the higher education sector: A UK and US perspective	35	SJR (Q3) / JCR (Q3)
	Corrado et al. (2023)	BIM and IFC: Awareness and Self-assessed knowledge from the perspective of Cambodian university students	13	SJR (Q1) / JCR (Q1)
	Rosli et al. (2016)	To BIM or not to BIM: A pilot study on University of Malaya's architectural students' software preference	10	SJR (Q3) / -
	Deniz, 2018	Emerging Cad and Bim Trends in the Aec Education: an Analysis from Students' Perspective	9	SJR (Q2) / JCR (N/A)
	Maina (2018)	Barriers to effective use of CAD and BIM in architecture education in Nigeria	15	- / JCR (Q4)
	Isanović et al. (2020)	Students' perceptions of BIM learning scenario in architectural education	7	SJR (Q2) / JCR (N/A)
	Hossain & Bin Zaman (2022)	Introducing BIM in Outcome Based Curriculum in undergraduate programme of architecture : Based on students perception and lecture-lab combination	6	SJR (Q1) / -
	(Meterelliyo, 2023)	The Awareness and Knowledge Levels of Building Information Modeling Among Architecture Students: A Survey-Based Study	2	SJR (N/A) / -
C07	Shahrudin et al. (2022)	Performance-based identity in a BIM environment: an architect's perceptions and experiences	9	SJR (Q2) / JCR (Q1)
	Sotelino et al. (2020)	Teaching BIM and Its Impact on Young Professionals	19	SJR (Q2) / JCR (N/A)
	Matniyazov et al. (2025)	The Role of Digital Tools and Bim in Shaping Future Education in Architecture and Construction Management	0	SJR (Q2) / JCR (Q4)

Thematic categories and titles of the studies included in the review			cit.	ranking
C08	Nguyen & Adhikari (2025)	Bridging the Gap: Enhancing BIM Education for Sustainable Design Through Integrated Curriculum and Student Perception Analysis	6	SJR (Q1) / JCR (Q2)
	Benner & McArthur (2019)	Data-Driven Design as a Vehicle for BIM and Sustainability Education	17	SJR (Q1) / JCR (N/A)
	Ahmed (2025)	Constructing an implementation plan for integrating green BIM into undergraduate architecture programs	4	SJR (Q1) / JCR (Q1)
	Shahverdi et al. (2024)	Developing a Pedagogical Framework for an Integrated and BIM-Based High-Performance Design Studio: Experimental Case Study	3	SJR (Q1) / JCR (Q3)
C09	Hajirasouli et al. (2024)	BIM-enabled virtual reality (VR)-based pedagogical framework in architectural design studios	36	SJR (Q1) / JCR (Q2)
	Elgewely et al. (2021)	Immersive construction detailing education: building information modeling (BIM)-based virtual reality (VR)	30	SJR (Q3) / JCR (Q3)
C10	Alassaf (2025)	Computational Precedent-Based Instruction (CPBI): Integrating Precedents and BIM-Based Parametric Modeling in Architectural Design Studio	4	SJR (Q1) / JCR (Q2)
C11	Baik (2026)	From Heritage Documentation to Adaptive Reuse: Assessing HBIM as a Pedagogical Tool in Architectural Education	0	SJR (N/A) / JCR (N/A)

3.2 Conceptual curricular mapping for cross-curricular BIM-based graphic instruction

At the School of Architecture (ETSAM) of the Technical University of Madrid (UPM), BIM training is currently mainly incorporated at postgraduate level, through the UPM postgraduate degree Building Information Modelling Project, Construction & Facility Management. However, previous experiences reported in the literature suggest that BIM can support the integration of graphic, technical, and collaborative learning processes (Ahmed, 2025; Aranda-Mena et al., 2026; Basson & Smallwood, 2025; Benner & McArthur, 2019; Correa et al., 2025; Obi et al., 2024; Rostam, 2019; Shelbourn et al., 2017; Sotelino et al., 2020). Therefore, its progressive incorporation into the Bachelor's Degree may constitute a suitable strategy for strengthening the alignment between architectural graphic education and current professional practices.

Within this context, the author has been implementing BIM-based Educational Innovation Experiences in three graphic courses (Ramos-Martin, 2024; Ramos-Martín et al., 2025; Ramos-Martín & Landínez-González-Valcárcel, 2026): two electives—Experimental Workshop in Infographics and Geometric Modelling (EWIGM), offered in the first cycle, and Intensification in Architectural Graphic Ideation (IAGI), offered in the second cycle—and one mandatory course, the second part of Geometry and Architectural Drawing (GAD 2). Although these experiences have so far been addressed independently, they constitute an initial framework from which a cross-curricular BIM teaching model may be developed.

Consequently, a conceptual curricular mapping becomes essential to identify the shared competences and learning outcomes across the graphic courses currently integrating BIM, and the following section describes the procedure adopted for this identification. This mapping provides the curricular basis for a BIM-Based Pedagogical Agenda for Architectural Drawing Instruction (Figure 4), aligning modelling, documentation management and alphanumeric information management with the pedagogical aims of the discipline.

Furthermore, this framework enables the teacher responsible for these courses to structure a qualitative research process aimed at deriving BIM-supported learning theory for Architectural Drawing Instruction through the iterative collection and analysis of data obtained from teaching experience, in line with the grounded theory approach of Glaser and Strauss (1967). Consequently, the BIM-Based Pedagogical Agenda should be understood as a sensitising framework rather than a predetermined explanatory model, providing an initial point of orientation while allowing theoretical categories to emerge inductively from teaching practice.

To carry out the curricular mapping of the transversal competences and learning outcomes of the aforementioned courses, it is first necessary to identify the regulatory framework that defines the competencies of architects at the European level. Architecture education in each European Union Member State is aligned with the principles of progressive harmonisation of the European Higher Education Area (EHEA), initiated in 1999 (EHEA, 2026), with digital education identified as one of its key areas of development. In parallel, the European Directives 2005/36/EC and 2013/55/EU (European Parliament, 2005, 2013) establish, in Article 46, the training requirements for architects

by defining eleven essential skills. At least seven of these skills are directly related to design and the arts, highlighting the importance of the general arrangement and composition of the different parts of a building.

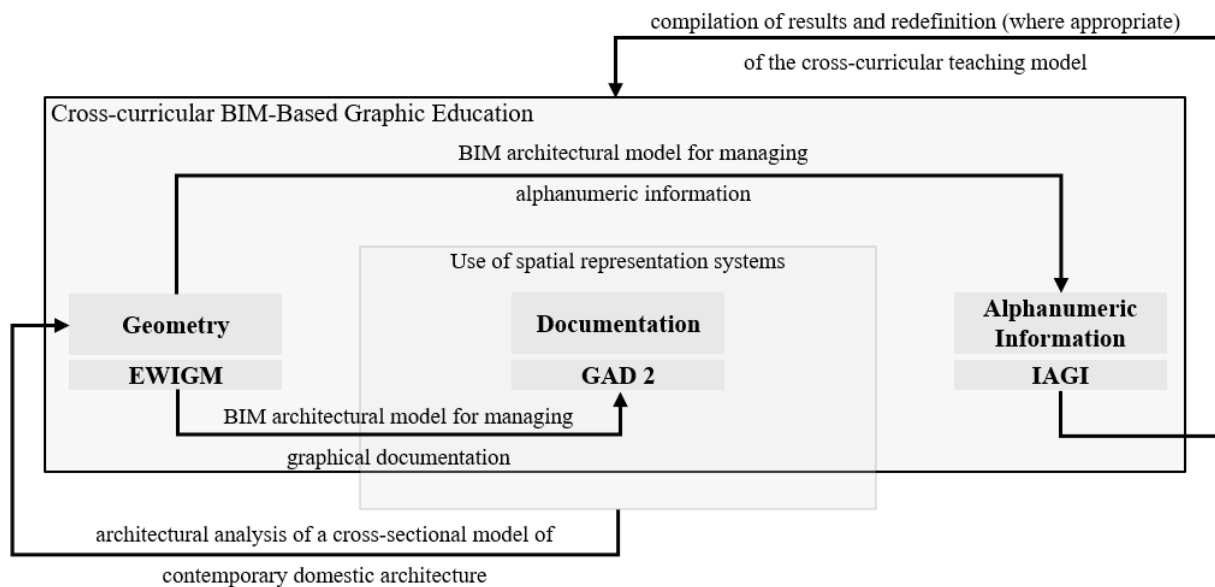


Figure 4: Diagram illustrating the cross-curricular BIM-Based Graphic Instruction.

Table 4: Shared General (G) and Specific Competences (S) according to the classification established in the White Paper on Bachelor's Degree in Architecture prepared by the National Agency for Quality Assessment and Accreditation (WP) and in the report submitted to the UPM for curriculum review (UPM).

C	WP	UPM	Description	
G	G1	CG 4	Analytical and synthesis skills	I
	G5	CG 20	Use of ICT and computing skills related to the field	
	G3	CG 26	Oral and written communication in the native language	
	G8	CG 5	Decision-making	
	G9	CG 13	Teamwork	P
	G10	CG 12	Ability to work in an interdisciplinary team	
	G14	CG 11	Critical thinking	
	G15	CG 14	Ethical commitment	
	G23	CG 15	Environmental awareness	S
	G26	CG 6	Imagination	O
	G27	CG 1	Spatial vision	
	G30	CG 3	Aesthetic sensitivity	
	G32	CG 10	Historical awareness	
S	A1	CE 34	Ability to conceive, practice, and develop basic and execution projects, sketches, and preliminary designs	A
	A2			
	A7	CE 1	Ability to apply graphic procedures to the representation of spaces and objects	
	B4	CE 4	Adequate and applied knowledge of architecture and urban planning related to form analysis and theory and the laws of visual perception	K
	B5	CE 3	Adequate and applied knowledge of architecture and urban planning related to spatial representation systems	
	B6	CE 6	Adequate and applied knowledge of architecture and urban planning related to graphic surveying techniques in all phases, from sketching to scientific restitution	
	B7	CE 5	Adequate and applied knowledge of architecture and urban planning related to metric and projective geometry	

instrumental (I), systemic (S), personal (P), other transversal competencies (O), abilities (A), and knowledge (K)

In Spain, RD 581/2017 and RD 233/2020 transpose these Directives into national law for the recognition of professional qualifications (Spanish Government, 2017, 2020). Within the EHEA framework, national legislative texts regulating official higher education studies (Spanish Government, 2007, 2010b) establish the structure of official degree programmes, recognising Information Technology and Graphic Expression as core subjects within the field of Engineering and Architecture.

Specifically, Ministerial Order EDU/2075/2010 (Spanish Government, 2010a) developed the requirements for the verification of official university degrees qualifying for the practice of the profession of Architect and identified competences distinguish Masters' and Degrees' competences. Most of them are quite similar to the essential skills reflected in European Directives (See Appendix A, table A.3). This Ministerial Order also recognises Drawing, in addition to the Basic Sciences, as a propaedeutic module, specifying that students must acquire the ability to apply graphic procedures to the representation of spaces and objects; to conceive and represent the visual attributes of objects; and to master proportion and drawing techniques, including computer-based methods. These are essentially studio-based courses.

Table 5: Shared Learning Outcomes.

Subject	LO	Learning Outcomes
EWIGM +	119	Practise representational drawing critically and reflectively.
IAGI +	120	Initiate analytical processes of form.
GAD 2		
IAGI +	69	Understand and apply the operations, resources, and codes of architectural graphic language as instruments of thought and communication.
GAD 2	70	Apply fundamental geometric and metric procedures to control architectural form and its scaled representation.
	71	Use representation systems coherently, controlling their interrelationships and the arrangement of drawings within the graphic field.
	76	Be able to establish a set of basic relationships among the various thematic aspects of architecture and assign them to specific codes according to the graphic resources used.
	77	Recognise architecture as an essentially synthetic phenomenon, capable of being understood by separating its components through appropriate graphic expression.
	78	Demonstrate command of the basic concepts of urban representation as a specific application of long-range scales and of the graphic resources appropriate to the relationships between architecture and the city.
	125	Demonstrate the ability to analyse graphically the relationships among architecture, the city, territory, and nature.
EWIGM +	11	The student will be able to locate and compile reliable documentation (written, graphic, photographic, and infographic) on a specific topic, building, historical period, or architect.
IAGI	106	Analyse, based on the documentation found or provided, relevant aspects of a building or of the work of a specific architect.
	110	Understand and apply the relationships among the different dimensions of architecture and their symbolic role.
	115	Develop graphic skills and abilities to undertake creative graphic processes.
	116	Be prepared to initiate graphic developments linked to thinking-in-action processes.
	117	Demonstrate the ability to initiate graphic-project processes.
	118	Exercise and strengthen perceptual capacity.
	121	Attain basic levels of creativity and formal intuition.
	124	Understand formal creation as a process.
	129	Understand the mode of generation, the geometric, graphic, and constructive properties of the forms of interest to the architect, as well as the relevant guidelines that enable their control.
EWIGM +	68	Identify, analyse, and solve problems of spatial configuration in ways that enable understanding and resolving the geometric structure of architectural forms.
GAD 2		

General and specific competences for all Spanish Schools of Architecture are established through the White Paper for the Bachelor's Degree in Architecture prepared by the National Agency for Quality Assessment and Accreditation (Agencia Nacional de Evaluación de la Calidad y Acreditación, 2005). General competences are classified according to their characteristics, into instrumental (I), systemic (S), personal (P), and other transversal competencies (O). Likewise, specific competences—which derive from an analysis of the professional

competencies and responsibilities associated with the Architecture degree—are further divided into skills (group A) and knowledge (group B). The common General and Specific Competences are presented in Table 4.

Within this framework, each university, in the exercise of its autonomy, prepares a verification report for the curriculum leading to the official Bachelor's Degree and establishes the general and specific competences of the programme, further specifying those defined in the corresponding Ministerial Order (Universidad Politécnica de Madrid, 2022). These competences are developed through the different courses that make up the curriculum. Each course contributes to their acquisition through the learning outcomes established for the subject, which must be clearly identified in the corresponding course syllabi (Escuela Técnica Superior de Arquitectura de Madrid, 2018, 2022b, 2022a).

To identify the competencies and learning outcomes shared by the three courses in which BIM is currently being implemented, the information contained in their respective course catalogues was cross-checked. This comparison establishes shared General Competences (CG), Specific Competences (CE), and Learning Outcomes (LO), providing the curricular conditions required to explore the transferability of BIM-based teaching methodologies. The shared Learning Outcomes are listed in Table 5.

As shown in Table 4, the General Competencies most frequently associated with the courses currently implementing BIM are primarily personal and transversal competences, followed by instrumental competences and, to a lesser extent, systemic competences. This distribution may be related to the collaborative and project-based pedagogical approaches adopted in the two elective courses included in the proposed cross-curricular teaching model, which place particular emphasis on teamwork, critical thinking, and decision-making.

Regarding Specific Competences, a greater presence of knowledge-based competencies (Group B) can be observed than skill-based competencies (Group A). The predominance of knowledge-based competencies indicates that BIM implementation is associated not only with procedural abilities, but also with expected conceptual and disciplinary learning outcomes, which may facilitate connections between different topics.

4. THEMATIC SYNTHESIS OF RESEARCH

Before turning to the analysis of specific teaching experiences, it is pertinent to consider studies that undertake broader systematic reviews and integrate a wider documentary corpus—including conference proceedings, books, and other contributions—since such an approach situates the discussion within a more solid conceptual and historical framework. From this point of view, BIM can initially be defined as a methodology whose origins are commonly traced back to Charles Eastman's pioneering work in the 1970s and which later became consolidated as a computer technology for a comprehensive, consistent, and coherent representation of buildings (Eastman, 1975, 1999; Eastman et al., 2008; Reddy, 2012; Sacks et al., 2011). Moreover, the broader literature has shown that its scope extends beyond digital modelling itself, as it has also been deployed as a learning and support tool in activities related to field staff training, occupational health and safety, machinery operation, and logistics planning (Becerik-Gerber & Kensek, 2010; Eastman et al., 2008; Fox & Hietanen, 2007).

4.1 Overview of BIM learning experiences

Given the well-documented professional benefits of BIM in terms of productivity, an important question remains: how, under what conditions, and with what limitations does the integration of BIM methodologies contribute to architectural education through graphic language? To address this issue, it is necessary to examine the evidence provided by the various systematic reviews analysed in the present study.

One of the most recent contributions, by Shin & Kang (2025), identifies a clear shift in BIM implementation strategies within architectural education, moving from tool-based training toward curriculum integration. The authors propose four levels of BIM integration: (1) tool-based, (2) process-based, (3) design-thinking integration, and (4) curriculum-level integration. The first two levels focus primarily on technical competencies and procedural learning, whereas Levels 3 and 4 represent a deeper form of integration, increasingly orientated toward data-driven design through digital technologies.

Effective curriculum integration depends on the consolidation of BIM as a cognitive design tool. Consequently, BIM integration should not be limited to teaching students how to operate a technological platform; rather, disciplinary content should employ BIM technologies as learning devices capable of integrating knowledge.

Achieving this goal requires a clear pedagogical framework. (Puolitaival & Kestle, 2018) framed this discussion through an analysis of learning theories to identify the so-called “BIM factor” in the education of Architecture, Engineering, and Construction (AEC). Their study aimed to support curriculum design and connect future research with learning theories, pedagogical approaches, and instructional methods. The results reveal a recurring weakness: learning theories—cognitivism, constructivism, social constructivism, and behaviourism—are generally present only implicitly and are rarely discussed critically or in depth. In contrast, learner-centred approaches dominate the literature, particularly collaborative learning, active learning, and problem-based learning.

Beyond whether pedagogical approaches are treated explicitly or implicitly, a more fundamental issue for effective educational integration concerns learning outcomes. The possibilities for collaborative and interdisciplinary knowledge construction offered by BIM methodologies sometimes appear to displace a more basic pedagogical question: what exactly are we teaching through BIM? Abdirad and Dossick (2016) highlighted this weakness by observing that only a limited number of studies provided detailed descriptions of the educational strategies implemented, while even fewer evaluated their impact on learning outcomes.

It is also important to note that the misunderstanding BIM as “just software” remains common (Shin & Kang, 2025). Although Revit continues to be the dominant platform in many educational contexts (Khan et al., 2021; Shin & Kang, 2025; Tanko & Mbugua, 2022), recent research points to a growing emphasis on Open BIM and interoperability as core competencies. Shin and Kang (2026) highlight the increasing importance of standards, data exchange, cloud collaboration, and coordination workflows, shifting the focus from mastery of a single proprietary application to the management of information within complex digital ecosystems. This evolution reinforces the distinction between Means and Ends already noted by Besné et al. (2021), who argue that BIM should not modify the content or objectives of the curriculum, but rather the methodology through which disciplinary knowledge is taught. BIM thus becomes an enabling representational and organisational infrastructure, not knowledge itself.

This distinction is particularly relevant because the literature frequently treats BIM competencies, BIM literacy, or BIM skills as educational outcomes without critically differentiating them from architectural, constructive, structural, or graphic knowledge. The identification of BIM as a professional knowledge platform by Correa et al. (2025) highlights its considerable potential as an integrative environment through which multiple forms of disciplinary knowledge can be connected and coordinated, an aspect that is particularly significant in architectural education. However, BIM itself should not be confused with the knowledge that it represents, organises, or facilitates.

The Integration of this knowledge through BIM requires the establishment of a common language. Besné et al. (2021) call for shared protocols and guidance to ensure coherent academic implementation, improve coordination and assessment practices, and facilitate the transfer of best practices among institutions. Particularly significant is their insistence that, although BIM integration should be transversal across the entire curriculum, departments of Graphic Expression should lead this process and actively promote collaboration with other disciplinary areas. This position is especially relevant because it shifts the centre of gravity away from software training and toward issues of representation, communication, spatial reasoning, and the graphic culture of architecture itself.

The evidence reviewed suggests that studies point to a transition from tool-centred instruction toward approaches that emphasise curriculum-level integration, collaboration, and interoperability (Besné et al., 2021; Puolitaival & Kestle, 2018; Shin & Kang, 2025). However, within this body of research (Abdirad & Dossick, 2016; Chihib et al., 2019; Khan et al., 2021; Rocha et al., 2025; Sucipto & Akhyar, 2024) and studies focusing on curricular and institutional integration of BIM (Aranda-Mena et al., 2026; Correa et al., 2025; Fadjar et al., 2020; Leite & Brooks, 2020; Mlinkauskienė et al., 2020; Wong et al., 2011), limited sustained attention has been paid to the graphic language embedded in BIM environments. By graphic language, this study refers not only to visual output, but also to the representational grammar through which BIM tools organise architectural information: conventions, hierarchies, view dependencies, templates, automatisms, model-view relations, and graphic styles. This omission is significant because such systems do not simply document architectural knowledge; they actively mediate how architectural information is selected, structured, visualised, and interpreted.

Revit, one of the most widely used BIM platforms in architectural education, offers a useful example of this issue. The question is not whether specific drawings—such as oblique projections or sectional axonometries based on multiple cutting planes—can be produced by means of workarounds, scripting, external tools, or post-production.

Rather, the question is whether such modes of representation are embedded in the ordinary graphic logic through which the software teaches students to move from model to drawing. From this perspective, BIM environments do not simply expand or restrict representation; they organise a hierarchy of graphic affordances, making some operations immediate and others exceptional. Unless they are critically mediated as hybrid instruments of graphic language, as Pérez-Gómez and Pelletier (2000, p. 382) propose, they may silently reshape the “patterns of thought” through which Architectural Drawing is conceived, to use Hewitt’s terms.

This gap matters because teaching drawing is not only about procedures; it is also about cultivating criteria for reading and producing graphic meaning. For that reason, a disciplinary debate should be made explicit: it is not enough to teach students how to “extract” drawings from a model; it is essential to discuss what kind of representation BIM produces, what biases it embeds, what is gained and what is lost relative to deliberate graphic construction, and how this displacement should be evaluated within the architect education.

4.2 Perceptions across different regions and identification of barriers in higher education

Several empirical studies conducted in universities across different national and disciplinary contexts do not provide specific methodological proposals for integrating BIM into geometry or Architectural Drawing courses. Nevertheless, they are useful for identifying broader patterns in students’ and instructors’ perceptions and recurrent barriers to curricular implementation. Across the studies reviewed, a consistent message emerges: BIM-related learning in higher education is widely perceived as valuable, yet its implementation remains uneven, fragmented, and often reduced to software training rather than understood as a process-orientated, information-based, and collaborative paradigm. This tension is explicit in Shelbourn’s UK/USA focus-group study, which warns against “BIM washing” and stresses that BIM is process-driven and does not depend on any single software package (Shelbourn et al., 2017). Thus, while the literature shows strong conceptual agreement on what BIM should mean pedagogically, it offers weaker evidence on how to operationalise it within specific curricular niches.

Nguyen and Adhikari (2025) frame BIM-for-sustainability education as a “perception–practice gap”: students recognise the potential of BIM but lack the confidence and competence to apply it in real contexts. Their findings support experiential, integrated, and project-based learning rather than isolated theoretical instruction. This suggests that BIM education should include model coordination, constructability review, information checking and early identification of design conflicts, where appropriate to the level of progression of students. Such activities are relevant to architectural representation because they connect drawing and modelling with decision-making, coordination, and preconstruction reasoning.

Shelbourn et al. (2017) also shows that collaboration cannot be assumed to emerge simply from group work. The students identified collaborative curricula, space, teamwork, industry relevance, technological skills, and the role of the lecturer as key dimensions of inclusive BIM education. In particular, inadequate learning spaces and poorly organised collaborative modules limited participation and coordination. Therefore, collaborative BIM learning must be explicitly scaffolded through defined roles, scheduled coordination, shared modelling tasks, assessment criteria, and lecturer facilitation.

Although Babatunde et al. (2018) focus on Quantity Surveying rather than architecture and are not qualitative in the strict sense, their study is analytically useful because it identifies institutional conditions that also affect BIM education in built-environment programmes. These include trained staff, software availability and affordability, IT infrastructure, and an enabling institutional environment. Their contribution should therefore be read as complementary evidence on the institutional prerequisites for scalable BIM pedagogy.

In general, the reviewed literature indicates that the main barriers to BIM integration in higher education are not only technical but also conceptual, curricular, and institutional. For geometry and Architectural Drawing courses, the challenge is not simply to introduce BIM tools but to embed them within a pedagogical sequence that links geometric modelling, representation, information standards, collaboration, and decision-making.

The consolidated barriers can be summarised as follows:

- **Conceptual reductionism:** BIM is treated as software proficiency rather than as a process for information management, coordination, and collaboration (Shelbourn et al., 2017).

- **Curricular fragmentation and disciplinary silos:** BIM is often taught in isolated modules, limiting the students' understanding of collaborative and role-based workflows (Nguyen & Adhikari, 2025; Shelbourn et al., 2017).
- **Perception–practice gap:** students recognise the value of BIM but lack opportunities to apply it in authentic project-based contexts (Nguyen & Adhikari, 2025).
- **Insufficient scaffolding of collaboration:** collaborative learning requires structured tasks, explicit roles, scheduled coordination, assessment criteria, and lecturer support (Shelbourn et al., 2017).
- **Institutional constraints:** trained staff, software access, IT infrastructure, suitable learning spaces, and programme-level strategy are necessary for meaningful BIM implementation (Babatunde et al., 2018; Shelbourn et al., 2017).

These barriers suggest that BIM integration in architectural education requires a shift from drawing as a graphic output to modelling as a coordinated informational, spatial, and collaborative process.

5. EVIDENCE ON BIM TEACHING METHODOLOGIES

Based on the scoping review carried out, the explicitly identified methodologies are analysed (Bozoglu, 2016; Deniz, 2018; Hu, 2019; Mathews, 2013; Meterelliyöz & Özener, 2022; Obi et al., 2024), with a focus on (1) pedagogical principles, (2) workshop structures, (3) roles, resources and infrastructure, and tools, (4) learning outcomes, and (5) identified gaps and limitations.

Although Mathews and Bozoglu belong to thematic category C05 and Deniz to thematic category C06, they provide valuable information regarding teaching plans and learning outcomes which, from a broader perspective, should be considered as relevant evidence for the analysis of BIM teaching methodologies.

From the corpus corresponding to thematic category C03, the following studies have been excluded from the detailed analysis because they share several limiting features: they are predominantly tool-orientated, focus mainly on operational or introductory BIM training, provide limited evidence of curricular integration, and do not sufficiently articulate their pedagogical approaches with the specific representational, design, and technical competencies required in architectural education. In addition, their learning outcomes are either weakly contextualised, inferred from limited evidence, or not sufficiently connected to the progressive development of architectural expertise. The excluded studies are the following:

- **Markiewicz-Zahorski (2019).** It offers limited analytical depth, relying mainly on observation and an BIM-driven isolated experience rather than clear curricular integration, although it highlights BIM-to-drawing difficulties, tentative student roles, and point-cloud-based surveying exercise;
- **Zieliński (2020).** It examines a short instructional BIM course centred on operational training in ArchiCAD, highlighting how e-learning materials and tutorials support classroom activity;
- **Makhmalbaf (2023).** It presents strong empirical value by using a robust statistical assessment to show that the OER (Open Educational Resource) significantly improves BIM student performance; although the contribution remains tool-based (Autodesk Revit), it usefully demonstrates the potential of structured OER to support autonomous, repeatable learning and to achieve broader global impact;
- **Bai & Chai (2024).** It provides a theoretical framing of BIM as a constructivist learning environment, but remains weak as evidence for architectural graphic education, since the micro-courses are generic and not tied to specific architectural contents or representational competencies, while learning outcomes are inferred mainly from insufficiently contextualised survey data;
- **ElShamy et al. (2024).** It describes a collaborative BIM course and its intended learning outcomes, but does not provide evidence of educational impact, does not provide a robust pedagogical framework, and does not discuss the relationship of BIM with architecture education.

These studies offer relevant insights into BIM teaching, although their value depends on their alignment with architectural competencies and learning outcomes. No explicit references to Geometry or Architectural Drawing courses were identified in the peer-reviewed corpus, suggesting that BIM's role in these foundational areas remains underexplored.

5.1 Instructional planning and methodological orientations

The identification of evidence through the analysis of instructional planning and methodological orientations is based on the identification of three fundamental aspects (Biggs, 1996): (1) learning objectives, understood through the learning outcomes (5.1.1); (2) the proposed activities, which are aligned with pedagogical principles (5.1.2) and are organised into workshop structures (5.1.3), within which roles, resources and infrastructure, and tools (5.1.4) are defined for their implementation; and (3) the assessment plan, which, in general, is not sufficiently explicit in the references reviewed.

5.1.1 Learning outcomes

The conceptual results frame BIM as a system of processes, relationships, and information structures rather than merely as software (Table 6). Bozoglu focuses on BIM concepts, processes, standards, deliverables, and model uses; Hu connects materials and assemblies with design thinking; and Meterelliyöz & Özener stress systemic understanding through parametric abstraction and object-orientated logic. Obi et al. address BIM concepts and benefits in multidisciplinary contexts and are the only authors to align outcomes explicitly with a recognised framework (Underwood et al., 2015).

The procedural and technical results dominate the reviewed studies. Deniz emphasises drawing, modelling, plan production, error correction, and advanced Revit functions. Bozoglu broadens technical learning to structural, MEP, and energy analysis, phase planning, quantity take-off, cost estimation, sustainability assessment, and code validation. Obi et al. link BIM tools to cost and schedule management. Thus, Deniz prioritises software mastery, while Bozoglu and Obi et al. connect technical skills to coordination and management.

Outcomes related to Architectural Drawing redefine representation as the construction and interrogation of an integrated building model. Mathews most clearly identifies this shift from a “drawing” to a “building” mentality, linked to shared model construction and “macro-scale” thinking (2013, p. 202). Meterelliyöz & Özener move similarly from drafting to parametric modelling and complex system representation, while Hu integrates technical knowledge into design thinking.

Higher-order outcomes include critical thinking, cognitive transformation, and collaboration. Meterelliyöz & Özener refer to “cognitive alteration” and decision-making through interactive modelling (2022, p. 10); Hu includes critical thinking, self-efficacy, and motivation for further BIM learning; and Obi et al. emphasise analytical, communicative, and collaborative abilities. In general, studies distinguish knowledge, skills and competences with varying precision: Obi et al. use an external framework, while several of Mathews’s outcomes are inferred from student discourse rather than formally stated learning outcomes (2013, p. 202).

5.1.2 Pedagogical principles

The reviewed studies broadly converge around active learning methodologies for teaching through BIM, while differing in their pedagogical foundations and degrees of explicitness (see Table 7). Mathews (2013, p. 204) provides the clearest constructivist framework, linking BIM learning to knowledge construction through studio-based problem solving, authentic contexts, iterative decision-making, and professional scaffolding. In the same vein, Bozoglu (2016, p. 115) adopts an explicitly experiential approach, grounded in Kolb’s notion of “learning by doing” and developed through laboratories, workshops, case studies, and real-context problem solving. Deniz (2018) also relies on practical modelling tasks, individual support, and collaborative projects; however, at the introductory level, teaching remains more strongly software-centred, which limits the development of Project Based Learning. A different emphasis can be found in Obi et al. (2024), whose work is more clearly aligned with Problem-Based Learning, stressing real-world problem scenarios, collaboration, student autonomy, and communication skills.

Hu (2019) and Meterelliyöz & Özener (2022) developed a more explicitly BIM-based pedagogical orientation. Hu proposes BIM-Enabled Pedagogy as a process-orientated learning environment that integrates modelling, materials, systems, industry workflows, and design-studio logics, contrasting it with Drafting-based Modelling Pedagogy (DMP). Meterelliyöz & Özener, in turn, provide the most specific cognitive contribution through a dual-channel framework that links object-orientated ontological modelling, parametrisation, and the understanding of systemic relationships among building components.

These studies suggest that BIM can expand the cognitive value of Architectural Drawing when modelling is conceived as a professional knowledge platform rather than merely as graphic production or technical software proficiency. The main differences lie in the degree to which each study makes its pedagogical framework explicit and connects BIM-based activities to cognitive outcomes. Mathews, Hu, and Meterelliyöz & Özener offer the most developed formulations; Bozoglu and Deniz provide valuable experiential models with varying degrees of conceptual articulation; and Obi et al. demonstrate the potential of PBL for collaborative and self-directed learning.

Table 6: Learning Outcomes in selected articles.

Mathews (2013)	- Improved visibility of issues/clashes and earlier detection of errors (repeated student claims). - Shift from the mentality of “drawing” to “building” (conceptual reframing of representation). - Macro-scale thinking and altered “way one would think.” - Enhanced collaboration and communication, including group discussion before decisions propagate into the shared model. - Decision-making through dialogue: students explicitly tie decisions to talking with peers and group discussion.
Bozoglu (2016)	- Understanding BIM concepts, project process, model offerings, standards, and deliverables - Developing skills in design authoring, structural analysis, MEP engineering analysis, and energy analysis using BIM tools - Gaining experience in phase planning, quantity take-off, cost estimation, sustainability evaluation, and code validation.
Deniz (2018)	The expected learning outcomes of the freshman-level CAD/BIM course include: - Practice drawing/modelling with software - Become familiar with the user-interface of AutoCAD and Revit - Create building plans and architectural systems - Detect and correct individual mistakes when creating plans - Develop a basic knowledge on both software programmes to be capable of using them in forthcoming courses and in professional life The expected learning outcomes of the junior-level BIM course include: - Apply the advanced features of Revit including Architecture, CM, Structure, and MEP functions - Create specialty building plans and systems - Collaborate in Revit - Use Revit specialty modules in the forthcoming courses and in professional life
Hu (2019)	- Understanding of construction materials and assemblies - Ability to integrate technical knowledge into design thinking - Critical thinking and self-efficacy - Motivation for continued BIM learning
Meterelliyöz & Özener (2022)	- Effective use of time for learning and comprehending course topics through parametric modelling and visual communication using BIM models and components - Comprehensive representations of complex building systems, subsystems, and their relationships using explanatory BIM models - Cognitive alteration of thinking about building systems and assemblies through parametric abstraction and object-orientated understanding - Observable cognitive mechanisms of decision making through interactive BIM modelling - Change in the design process from conventional drafting to parametric modelling, which is more complex, multi-dimensional and scale-transitive - Evaluation of multiple design alternatives through iterative model modification and propagation of parametric seed models
Obi et al. (2024)	- BIM Academic forum learning outcomes framework (Underwood et al., 2015) - Demonstrate an understanding of the concept of BIM and highlight commonly used tools - Understand the benefits of BIM for construction professionals in a multidisciplinary construction project environment - Apply BIM tools for effective cost and schedule management - Demonstrate improved analytical, communication, and collaborative skills relevant to working in a BIM project environment

5.1.3 Workshop structures

The reviewed studies show the implementation of BIM in diverse higher-education contexts (Table 8), including undergraduate and graduate courses, introductory and specialised modules, compulsory and elective formats, and durations from 4-week intensives to full-semester or 12-week courses (Mathews, 2013, p. 191; Bozoglu, 2016, pp.

153–155; Deniz, 2018, pp. 143–144; Hu, 2019, p. 1; Meterelliyöz & Özener, 2022, p. 2; Obi et al., 2024, pp. 219–222). This indicates that BIM is introduced at multiple curricular stages rather than at a single educational level.

Studies organise BIM through modular, technological, project-based, parametric, workflow-orientated, or problem-based approaches. These include competency and assessment matrices focused on collaboration and coordination (Bozoglu, 2016, pp. 157, 160), integration with materials, assemblies, and construction processes (Hu, 2019, p. 3), live-project learning (Mathews, 2013, pp. 195–198), phased parametric sequences linked to building technology (Meterelliyöz & Özener, 2022, p. 6), CAD–BIM and master-model workflows (Deniz, 2018, p. 144), and scenario-based collaborative learning (Obi et al., 2024, p. 225).

5.1.4 Roles, resources and infrastructure, and tools

The reviewed studies distinguish two main role models: BIM as simulated collaborative professional practice and BIM as software-centred training. Bozoglu and Hu align with the former through multidisciplinary organisation, distributed support, and industry participation, while Deniz adopts a more procedural model, positioning students as novice software users. Mathews complicates this contrast by showing the continued value of analogue graphic mediation within BIM collaboration. Meterelliyöz & Özener and Obi et al. emphasise self-organisation, peer support, and collaborative learning.

The scope of the classroom also depends on the infrastructure. Bozoglu describes a resource-intensive setting of licences, labs, vendor support, repositories, and specialised spaces, while Hu combines face-to-face teaching, workshops, and online training. These models increase professional authenticity, but raise issues of scalability, equity, and institutional dependence. Deniz uses more replicable sequential resources, though with less scope for exploration and critique. Mathews (2013), Meterelliyöz & Özener (2022), and Obi et al. (2024) rely on lighter infrastructures—servers, blogs, shared storage, social networks, and virtual platforms—which support coordination but may transfer organisational work to students.

The technological ecosystem remains dominated by proprietary platforms, especially Autodesk Revit. Bozoglu uses the broadest toolset, but with limited attention to interoperability or open standards; Deniz closely equates BIM with AutoCAD and Revit; and Hu, Mathews, and Meterelliyöz & Özener also centre Revit. Obi et al. do not specify software, though this does not imply an open-standard approach. This platform dependence risks reducing Architectural Drawing to parametric modelling and data management, weakening its critical, ambiguous, and projective functions. Mathews remains the clearest exception by documenting the coexistence of digital and analogue media.

In general, the studies show a shift towards collaborative, professional and information-rich BIM education, yet constrained by demanding infrastructures, proprietary ecosystems, and limited attention to the graphic and critical dimensions of Architectural Drawing. Table 9 expands on the roles, resources, infrastructure, and tools identified in the reviewed articles.

Table 7: Pedagogical Principles in selected articles.

Author	Dominant principle	Associated principles
Mathews (2013)	Constructivism	Designing constructivist learning environments (Jonassen, 1999); student-centred learning (Pearlman, 2010); authentic learning; problem-solving learning environments (Jonassen, 2011) and iterative design; professional scaffolding; and collaborative learning and higher-order cognition (Anderson & Krathwohl, 2001; Engelhart et al., 1956).
Bozoglu (2016)	Experiential learning	Learning by doing (Kolb, 1984); authentic tasks; workshops; and problem-solving strategies.
Deniz (2018)	Experiential learning (implicit)	Practical knowledge; one-to-one support; and collaborative working practices
Hu (2019)	BIM-Enabled Pedagogy	Learning as process; design thinking (Hedges & Denzer, 2008); self-motivated learning; and industry insights.
Meterelliyöz & Özener (2022)	Dual-channel framework	Parametric thinking; object-orientated ontology; problem-based learning; social learning; and iterative feedback
Obi et al. (2024)	Problem-Based Learning	Analytical, communications, and collaboration skills; autonomous learning; and authentic practices.



Table 8: Workshop structures in selected articles.

Research	Institution (I), Course (C), Level of Students (LoS), and Duration (D)	Organisation
Mathews (2013)	I Dublin Institute of Technology (DIT)	4-staged trajectory: (1) problem solvers; (2) formulating collaborative skills; (3) active collaboration; and (4) collaboration through the BIM model
	C Architectural Technology	
	LoS Undergraduate students	
	D 12 weeks	
Bozoglu (2016)	I Department of Civil, Architectural, and Environmental Engineering at Illinois Institute of Technology (IIT)	-Modular approximation: Collaboration (design) and Coordination (construction) modules - Micro-structure: Knowledge sets, skill sets, methods, practices, tools, and assessment
	C - EG 430 - Introduction to BIM - CAE 573 - Construction Management with BIM	
	LoS - Senior level elective in the Engineering Graphics Program - Graduate level elective in the Construction Engineering and Management Program	
	D 12 weeks	
Deniz (2018)	I Milwaukee School of Engineering (MSOE)	- Modelization in CAD (from week 1 to 5), and BIM (from week 6 to 12) - Three-part structure: (1) create BIM models; (2) add Revit specialty (CM/Structure/MEP); and (3) practice the building design by a collaborative term project
	C Architectural Engineering (AE), Civil Engineering (CE), and Construction Management (CM): - AE 1312 Introduction to BIM I - AE 3311 Building Information Modelling II	
	LoS - Undergraduate (freshman) - Undergraduate (junior) (3-year time lag between these two courses)	
	D -11 weeks -10 weeks	
Hu (2019)	I School of Architecture, Planning, and Preservation at the University of Maryland	Three integrated categories: (1) major building materials (wood, concrete, and steel); (2) main building assemblies (wall, roof, and other enclosure systems); and (3) integrated design thinking (construction methods and modern technology)
	C Building Materials and Construction Methods (BMCM)	
	LoS Different levels (mainly sophomore, 59.4%)	
	D One full academic semester	
Meterelliyöz & Özener (2022)	I Department of Architecture at Istanbul Technical University	Modular approximation: 12 modules covering BIM topics
	C Architecture curriculum (comprehensive approach) focused on Building Technology	
	LoS Undergraduate students	
	D 12 weeks	
Obi et al. (2024)	I Built Environment (BE) at a University in the United Kingdom	The BIM introductory module divides into cohort 1 (HNC and HND) and cohort 2 (BSc undergraduate students)
	C - Higher National Certificate (HNC) - Higher National Diploma (HND) - BSc undergraduate students (level four)	
	LoS - Graduate (cohort 1) - Undergraduate (cohort 2)	
	D 4 weeks	

5.2 Gaps, limitations, and implications for future pedagogical design

The reviewed literature documents valuable early BIM-integration experiences, but often uses evaluative designs too weak to support strong causal claims. In Bozoglu (2016), “Module Assessment” resembles instructor classification rather than educational evaluation, lacking validated instruments or comparisons. Hu (2019) faces similar limits due to non-equivalent cohorts. Meterelliyöz & Özener (2022) report “significant advantages” but do not specify rubrics or reliability between authors. Obi et al. (2024, p. 222) claim “accelerated learning” without a control group or baseline, while Mathews (2013) refers to higher-order learning without clearly operationalising competencies.

A further limitation is the weak theorisation of graphic thinking as a basis for BIM literacy. Bozoglu (2016) and Deniz (2018) do not explain how prior representational competences mediate BIM modelling, and Hu (2019) does not clarify whether improvements derive from a deeper understanding or from digital affordances. Mathews (2013) is more explicit, identifying the tension between BIM as early formal fixation and as informed decision-making, thus pointing to representational sequencing rather than mere technological adoption.

This weak cognitive framework explains the instrumental treatment of BIM in several studies. Although Bozoglu (2016, p. 153) states that “BIM is a human activity”, the curriculum privileges tools and professional training; Deniz (2018) similarly reduces BIM to platform competence. Hu (2019) connects BIM with studio logics, but does not fully define didactic principles preventing modelling from becoming procedural closure rather than open-ended inquiry.

Access, scalability, and material conditions are also not adequately addressed. Bozoglu (2016) and Hu (2019) describe systems that require significant resources—licenses, laboratories, support, workshops, and professional involvement—without assessing their transferability. Obi et al. (2024) do not specify the technological conditions, while Meterelliyöz and Özener (2022) acknowledge the initial difficulties without providing a sustained reflection on inequality in access or cognitive load.

In general, BIM can become meaningful in early architectural education only through stronger assessment designs, explicit pedagogical frameworks, and the reintegration of Architectural Drawing as the cognitive and disciplinary basis of model-based learning. The identified gaps concern BIM literacy, graphic and exploratory thinking, progressive and hybrid learning, interoperability, collaboration, implementation conditions, equitable access, and the balance between professional and disciplinary aims. These issues, together with other recommendations arising from the research, will be addressed in the conclusions section.

Table 9: Roles (Students, S; Groups, G; Teachers/Instructors/Researchers, TIR; and Others, O), Resources and Infrastructure (RI), and Tools (T) in selected articles.

Mathews (2013)	G	Groups of 6 students developing a proposal
	TIR	A single teacher and researcher observing the group collaborative design meetings with the practicing architect; observing the students working in the studio environment; keeping a reflective writing journal, setting up an online blog for the students to voice their thoughts and experiences; assessing the students' formative work from the project brief; and conducting individual interviews with the students at the end of the project
	RI	IPD (Integrated Project Delivery); studio infrastructure: open-plan studio with work tables, and PCs mounted and networked within studio; information resources: library and web access via networked computers; digital collaboration infrastructure: shared drive space on institutional network (server-based model sharing); and reflective and communicative resources: student blog with open-ended prompts; author reflective journal.
	T	Autodesk Revit Conventional media: pencil/pen sketches on transparency (“butter paper”), overlays; “hard copies drawn from CAD formats”; projector display of BIM model to architect.
Bozoglu (2016)	G	Individuals and groups of multidisciplinary cohorts spanning civil/structural/MEP/architectural engineering, architecture, construction management, IT management—used to simulate integrated delivery contexts.
	R	TIR Facilitation and guidance, particularly in workshop
		O Industry partners to improve BIM education
	RI	Collaboration workshops with industry partners, I-rooms for integrated design, and in-lab workstations Lectures, hands-on practices, case studies, self-learning tutorials, vendor training, and guest speakers
	T	Autodesk Revit, Navisworks, Bentley BIM, Graphisoft ArchiCAD, Trimble Vico, Synchro Professional, Green Building Studio, Sefaira Architecture, Sefaira HVAC, Tekla X-Steel, Vico Report Editor, Revit Structural Analysis, Revit Systems (MEP), Revit Analyze, Solibri Model Checker, Trimble Showcase, Revit Credit Manager, EcoDomus
Deniz (2018)	S	Positioned as novice software users rather than reflective designers or system thinkers, particularly at the freshman level.
	G	Freshman-Level Course: No formal group organisation
	R	Junior-Level BIM Course: Structured collaborative teams TIR Providing appropriate techniques to support the CAD–BIM transition; introducing BIM theoretical foundations before Revit practice; strategically scheduling BIM courses, particularly before internships; separating Revit Architecture instruction from specialised BIM areas —CM, Structure, and MEP—; and reinforcing the

		professional relevance and applications of BIM/Revit in the AEC industry to sustain student interest and engagement.
	O	Inviting industry experts as guest lecturers to share real-world BIM challenges and solutions
	RI	Software manuals and step-by-step textbooks, with limited open-ended modelling tasks (Stine, 2015a, 2015b)
	T	Autodesk AutoCAD and Revit
Hu (2019)	S	Active learners were expected to navigate complexity, ambiguity, and self-regulated learning pathways
	G	Control Group (Fall 2016 semester)
	R	Experimental Group (Fall 2017 semester)
	TIR	Designer of the immersive BIM environment; mediator between industry practice and academic content.
	O	Teaching Assistants: Technical facilitators providing hands-on support
		- Lynda.com online tutorials (72 hours available)
	RI	- Workshops (24 hours total) - Industry guest lectures and site visits
	T	Autodesk Revit
	S	Entry-level architecture students with no previous BIM experience.
	G	Control Group Study (12 members), and 3 Intervention Group Case Studies (13-15 students)
Meterelliyöz & Özener (2022)	R	TIR Provides direct instruction on building technology concepts and BIM fundamentals in the initial stages. Later, they transition to a facilitator role, providing just-in-time support and organising collective assessment sessions.
	O	Student Social Network emerges organically as students share parametric models, solve software-related problems, and collectively evaluate design alternatives. Facilitates knowledge exchange and dissemination.
		- Just-in-Time Instruction: The instructors offered targeted training sessions to help students overcome the initial learning curve of the BIM software interface and modelling procedures.
		- Parametric Seed Models: The instructors provided pre-built parametric BIM models that students could use as a starting point to develop their own building component designs.
	RI	- Online Training Resources: The students reported that the suggested online tutorials and training materials were effective in helping them solve specific software-related problems and expand their understanding of BIM capabilities.
		- Collaborative Learning Environment: The study facilitated the formation of an informal social network among students, where they could share parametric models, discuss design ideas, and collectively solve problems.
	T	Autodesk Revit
		Cloud sharing: Dropbox used to store and share models and parametric families.
	S	Engage in collaborative group work to examine problem scenarios, identify BIM tools, best/poor practices, process challenges, and benefits, and recommend possible solutions.
	R	G Students are divided into small groups of 7 members, with each group required to maintain a communication platform and update their findings weekly on the virtual teaching and learning platform.
Obi et al. (2024)	TIR	Facilitates learning by guiding group discussions and monitoring student engagement.
	RI	Virtual learning platform and module discussion page for documentation and information exchange.
	T	Not specified

5.3 Synthesis through the answers to the research questions

The review provides consistent evidence on BIM pedagogical approaches, historical evolution, and implementation conditions (Abdirad & Dossick, 2016; Besné et al., 2021; Puolitaival & Kestle, 2018; Shin & Kang, 2026). Evidence on learning outcomes is less robust because assessments often rely on perceptions, project outputs, or nonvalidated instruments (Bozoglu, 2016; Deniz, 2018; Hu, 2019). Therefore, the findings reflect recurrent patterns rather than universal or causal effects.

RQ1: What pedagogical models and learning strategies are used?

BIM education is predominantly based on learner-centred, active, collaborative, and experiential pedagogies, particularly project- and problem-based learning, studio instruction, and learning by doing (Mathews, 2013; Bozoglu, 2016; Hu, 2019; Puolitaival & Kestle, 2018; Meterelliyöz & Özener, 2022; Obi et al., 2024). These approaches use authentic or simulated professional tasks, shared-model development, interdisciplinary teamwork, modular activities, and iterative modelling to promote a progression from direct instruction to autonomous decision-making and peer collaboration. Accordingly, teachers act primarily as facilitators who provide mediation and just-in-time support (Mathews, 2013; Bozoglu, 2016; Meterelliyöz & Özener, 2022). Although theoretical

foundations are often implicit, some studies propose explicit frameworks, including BIM-Enabled Pedagogy, object-oriented and parametric learning, project-based learning, and modular collaboration and coordination (Bozoglu, 2016; Hu, 2019; Puolitaival & Kestle, 2018; Meterelliyöz & Özener, 2022; Obi et al., 2024). Overall, the literature supports active, collaborative, and authentic learning, but provides less clarity about how specific activities generate disciplinary outcomes. For graphic education, the most promising strategies treat the BIM model as an environment for inquiry, representation, coordination, and decision-making rather than merely as a final product (Mathews, 2013; Hu, 2019; Meterelliyöz & Özener, 2022).

RQ2: How has BIM integration in graphic education evolved?

The literature identifies a gradual shift from isolated, software-centred BIM instruction towards process-based, collaborative, and curriculum-level integration (Abdirad & Dossick, 2016; Besné et al., 2021; Shin & Kang, 2026). While early approaches emphasised software proficiency, digital modelling, and plan production (Deniz, 2018), more developed models incorporate information management, parametric relationships, multidisciplinary coordination, interoperability, sustainability, and integration across courses (Bozoglu, 2016; Hu, 2019; Khan et al., 2021; Meterelliyöz & Özener, 2022). This evolution reflects a progression from teaching BIM as a tool to using it as a process-oriented, cognitive, and curricular environment (Shin & Kang, 2026). However, the transition remains uneven: proprietary platforms, particularly Revit, still dominate, whereas Open BIM, IFC, and standards-based information exchange receive less systematic attention (Ahn & Kim, 2016; Khan et al., 2021; Tanko & Mbugua, 2022). In graphic education, BIM increasingly reframes drawing as the interpretation and management of coordinated information models, linking modelling, documentation, parametric definition, and coordination (Mathews, 2013; Hu, 2019; Meterelliyöz & Özener, 2022). Nevertheless, its specific implications for Architectural Drawing, including graphic hierarchies, view dependency, model-to-drawing relationships, and representational conventions, remain insufficiently examined.

RQ3: What learning outcomes are reported, and how are they assessed?

The reported learning outcomes fall into four domains: conceptual, procedural, collaborative, and higher-order learning. Conceptually, students understand BIM as an integrated system of information, objects, parameters, relationships, and standards rather than merely as software (Hu, 2019; Shelbourn et al., 2017; Meterelliyöz & Özener, 2022). Procedural outcomes include modelling, documentation, coordination, clash detection, quantity extraction, scheduling, and discipline-specific workflows (Mathews, 2013; Bozoglu, 2016; Deniz, 2018; Hu, 2019; Meterelliyöz & Özener, 2022). Collaborative outcomes encompass teamwork, communication, role coordination, shared decision-making, and interdisciplinary participation (Mathews, 2013; Bozoglu, 2016; Shelbourn et al., 2017; Obi et al., 2024). Higher-order outcomes include spatial and systemic reasoning, critical and parametric thinking, self-efficacy, and iterative decision-making, supporting a transition from drawing-centred to model-centred representation (Mathews, 2013; Deniz, 2018; Hu, 2019; Meterelliyöz & Özener, 2022).

For Architectural Drawing, BIM particularly supports spatial configuration, geometric and metric control, coordination between views, model-based documentation, and the analysis of relationships within complex building systems (Mathews, 2013; Hu, 2019; Meterelliyöz & Özener, 2022). However, outcomes related to visual perception, aesthetic judgement, projective geometry, surveying, historical awareness, and exploratory graphic thinking remain rarely defined or assessed.

Assessment is the least developed area, as studies commonly rely on questionnaires, interviews, observations, instructor judgements, project outputs, and cohort comparisons (Abdirad & Dossick, 2016; Deniz, 2018; Hu, 2019; Meterelliyöz & Özener, 2022). Validated instruments, explicit rubrics, baseline measures, control groups, longitudinal follow-up, and criteria aligned with disciplinary outcomes remain uncommon (Abdirad & Dossick, 2016; Besné et al., 2021). Consequently, the literature indicates BIM's educational potential but does not provide strong causal evidence of superior learning in Architectural Drawing. Future assessment should examine observable evidence such as cross-view coherence, geometric accuracy, representational hierarchy, model-to-document consistency, graphic economy, information density, and students' justification of representational decisions.

RQ4: What barriers, challenges, and enabling factors are most frequently identified?

The literature identifies five interconnected barriers to BIM education: conceptual, curricular, pedagogical, technological, and institutional (Ahn & Kim, 2016; Shelbourn et al., 2017; Babatunde et al., 2018; Besné et al.,

2021; Sucipto & Akhyar, 2024). Conceptually, BIM is often reduced to software training rather than understood as an information-management, collaborative, and learning environment (Shelbourn et al., 2017; Hu, 2019; Shin & Kang, 2026). Curricularly, it is frequently confined to isolated modules with limited integration across design, representation, construction, structures, and environmental subjects (Abdirad & Dossick, 2016; Besné et al., 2021; Meterelliyöz & Özener, 2022). Pedagogical limitations include poorly defined learning outcomes, insufficient assessment criteria, weakly scaffolded collaboration, and the uncritical reproduction of professional workflows (Abdirad & Dossick, 2016; Shelbourn et al., 2017; Puolitaival & Kestle, 2018).

Technological barriers include proprietary-platform dependency, limited interoperability, complex interfaces, steep learning curves, and unequal access to software and hardware (Ahn & Kim, 2016; Babatunde et al., 2018; Khan et al., 2021; Tanko & Mbugua, 2022). Institutionally, implementation is constrained by limited staff expertise, teaching time, infrastructure, technical support, and programme-level coordination (Shelbourn et al., 2017; Babatunde et al., 2018; Besné et al., 2021; Sucipto & Akhyar, 2024). In graphic education, BIM also privileges coordinated orthographic documentation, while non-standard, exploratory, and disciplinary representations may require indirect workflows or complementary tools. Consequently, students may mistake software conventions for the limits of architectural representation.

Effective integration therefore requires clear pedagogical frameworks, alignment among outcomes, activities, and assessment, progressive curricular sequencing, authentic project-based learning, structured collaboration, trained staff, adequate infrastructure, reusable learning resources, and standards-based interoperability (Abdirad & Dossick, 2016; Ahn & Kim, 2016; Bozoglu, 2016; Hu, 2019; Meterelliyöz & Özener, 2022; Shin & Kang, 2026). Most importantly, BIM should serve disciplinary learning rather than become the learning objective itself. Its pedagogical value derives from aligning model-mediated activities and collaboration with disciplinary outcomes and appropriate assessment, thereby supporting spatial reasoning, representational coherence, information management, and collaborative authorship (Abdirad & Dossick, 2016; Hu, 2019; Meterelliyöz & Özener, 2022). BIM-Based Graphic Instruction should thus be understood as a critical extension and reorganisation of architectural graphic education, not as its replacement by software competence or model production.

6. CURRICULAR TRANSFER TO GRAPHIC EDUCATION

This discussion of the results is organised into two parts. First, Competence and Learning Outcome Mapping compares evidence on BIM teaching methodologies with the curricular mapping developed for BIM-Based Graphic Instruction, identifying the competencies and learning outcomes required in three graphic subjects of the Architecture degree at the Technical University of Madrid and assessing how previous teaching experiences contribute to them. Second, the Framework for a BIM-Based Pedagogical Agenda for Architectural Drawing Instruction defines the complete set of learning outcomes and discusses a range of teaching considerations related to the learning activities that may be supported through BIM, and summarises the findings through a SWOT analysis of the weaknesses, threats, strengths, and opportunities derived from the competency mapping.

6.1 Competence and learning outcome mapping

Given the collaborative nature of BIM-based methodologies, it is useful to reclassify competences not only according to their content but also according to the processes through which learning is developed. From this perspective, the individual-cognitive and collaborative-communicative dimensions are understood as complementary processes through which students achieve cultural-critical development, namely the appropriation and critical understanding of professional and disciplinary practices (Figure 5).

This reclassification is grounded in Vygotsky's sociocultural constructivist theory (Vygotsky, 1978, p. 69), which conceives learning as mediated by social interaction, cultural tools, and language. While Vygotsky refers to language in a broad sense, in the BIM context, this mediating function may be interpreted through the graphic language. BIM models thus transcend their role as digital representations and operate as mediating artefacts that support exploration, communication, reflection, and the co-construction of meaning.

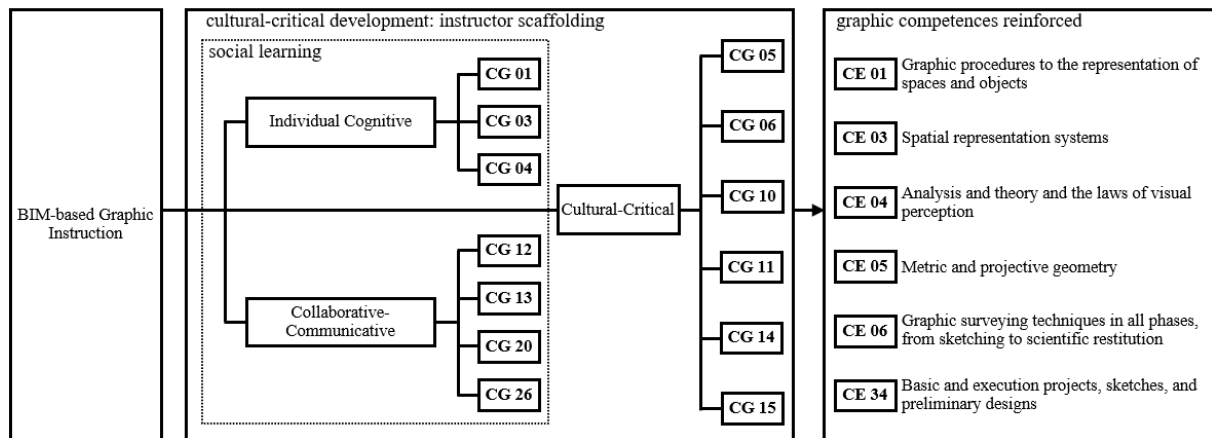


Figure 5: Diagram illustrating the reclassification of competences according to BIM-Based Graphic Instruction.

6.1.1 General competences

Individual Cognitive Competencies. Among the six proposals, BIM strengthens cognition most when used as a graphic knowledge environment, not just software training. Learning improves through 3D modelling, navigation, sectioning, and system coordination, which help students develop spatial vision (CG 01). Analytical and synthesis skills (CG 04) are reinforced, while aesthetic sensitivity (CG 03) remains weaker because visualisation is mainly used for technical coordination rather than formal critique.

Regarding one of the competencies least frequently addressed in the studies—aesthetic sensitivity—it is worth considering the interoperability of BIM models with 3D rendering software. The selection of materials, including their scale and optical properties, together with the possibility of developing preliminary landscape proposals for proper architectural contextualisation and integration, represents a significant potential for using models as mediators between different forms of analysis.

Similarly, in relation to analytical and synthesis skills, it is necessary to specify which of these skills are grounded in principles of graphic action. The mere extraction of alphanumeric information from a model does not constitute an analytical process capable of strengthening competencies essentially related to Architectural Drawing.

Collaborative-Communicative Competencies. Social learning is strongly reinforced through BIM, especially in teamwork (CG 13), interdisciplinary collaboration, and ICT skills. Shared models, repositories, roles, and coordinated outputs simulate professional workflows, while communication appears mainly as support for reports, presentations, and collaborative exchange (CG 26).

From an Architectural Drawing perspective, the key issue is whether collaboration occurs through co-authorship of the BIM model. In Mathews, Bozoglu, Deniz, and Meterelliöz & Özener, teamwork and digital competence are tied to shared graphic production. In Obi et al., collaboration is strong but less consistently anchored in model-based representation.

In general, BIM pedagogy presents Architectural Drawing as a socially distributed digital practice (CG 20), in which communication, coordination, and technical literacy converge in the model as the main medium of architectural work. It is therefore especially important that information-exchange frameworks are firmly established and that students share common criteria and a graphic language that enables them to advance collectively in their work. Similarly, the ability to work in an interdisciplinary team (CG 12) is strengthened through the definition of open exchange standards, particularly through IFC files (Corrado et al., 2023). However, the analysed proposals generally do not address this issue explicitly.

Cultural-Critical Competencies. The strongest competencies are critical thinking (CG11) and decision-making (CG 05), fostered through alternative comparison, modelling choices, clash assessment, and technical evaluation. In contrast, environmental (CG 15), historical (CG 10), and ethical (CG 14) awareness remain weak, which may explain why imagination (CG 06) appears only moderately, mainly as a controlled variation rather than an open-ended invention.

There is a contradiction in the fact that the analysed proposals emphasise critical thinking and decision-making, while these competences are not explicitly grounded in the historical and environmental awareness needed to support an adequate ethical commitment among those expected to make critical decisions and imagine culturally coherent solutions.

In this sense, the teaching experiences examined appear to focus primarily on the optimisation of technical resources, while overlooking the possibility of structuring content that strengthens students' graphic culture or addresses environmental issues that may only be implicitly present in the definition of the PBL activities (Nguyen & Adhikari, 2025).

6.1.2 Specific competences

In a BIM-Based Graphic Instruction paradigm, BIM can be understood as a pedagogical mediator that enables the construction of knowledge through which students progressively build their own knowledge. Its main contribution lies not only in producing documentation but also in fostering an understanding of drawing as a model, insofar as graphic information is derived from a structured informational model. Thus, it can reinforce the ability to apply graphic procedures to the representation of spaces and objects (CE 01), although this transfer is neither automatic nor complete, given that BIM expands certain representational possibilities but also conditions them through the software's internal logic. Therefore, it should be taught as a powerful but limited tool that—as mentioned earlier—requires critical exploration and integration with other tools when necessary.

This mediation requires adequate knowledge of spatial representation systems (CE 03), since the ability to generate different types of view does not imply that they are supported with equal precision or freedom. Orthographic documentation can be enhanced through model coordination, but operations such as vanishing-point sections, oblique axonometrics, or other non-native representations may require indirect procedures or external platforms. These restrictions should be understood as limitations of the tool, not of the architectural representation. Similarly, BIM only fully contributes to the analysis of form and visual perception (CE 04) and to the precise control of metric and projective geometry (CE 05) when modelling tasks are explicitly linked by instructors to these disciplines—aspects rarely addressed directly in the reviewed experiences.

This need for mediation is even more evident in graphic surveying techniques, ranging from sketching to scientific reconstruction (CE 06). Bozoglu offers the clearest transfer through the modelling of existing conditions and scan-to-model workflows; Mathews provides a more indirect connection through the interpretation of sketches; and this line of inquiry can be expanded with HBIM approaches such as Baik (2026) or with teaching experiences linked to point clouds such as Markiewicz-Zahorski (2019). However, a significant portion of the studies are based on pre-existing information; therefore, capture-to-model processes could be explicitly incorporated to avoid taking the model for granted as a starting point.

Under these conditions, BIM-Based Graphic Instruction can support the conception, practice, and development of basic and construction projects, sketches, and preliminary designs (CE 34). Mathews more clearly links sketches, shared models, and technical documentation; Bozoglu and Meterelliöz & Özener reinforce project development through structured modelling, coordination, and systems integration; while Deniz and Hu focus more on guided documentation and constructive modelling. BIM can be effective for project development and documentation, provided it is guided by criteria of selection, synthesis, and graphic economy. Otherwise, the automatic generation of views, drawings, and tables can shift architectural judgement toward the mere accumulation of information.

6.1.3 Potential learning outcomes reinforced using BIM

In general, the teaching proposals analysed do not explicitly define their Learning Outcomes (LO). When LO are stated, they are generally orientated towards collaborative dynamics and participation in task-based activities developed within BIM environments. Despite this lack of explicit formulation, the LO mapped in Section 3.2 for each proposal allows for comparative analysis. Therefore, a general synthesis was produced for each LO, identifying its degree of contribution to the specific competencies that are common to the graphic courses included in the study.

Based on this analysis, an expert appraisal was conducted to estimate the degree to which each LO contributes to the competencies considered in the study. This appraisal should be understood as an interpretative synthesis of the evidence identified in the analysed teaching proposals, rather than as a systematic or objectively derived measurement. No inter-rater reliability assessment was conducted. An overall score was assigned to each LO as

part of this expert appraisal. This score derives from the assessment of its contribution to each specific competence, using a Likert-type scale from 0 to 5: 0, no contribution; 1, minor contribution; 2, moderate contribution; 3, high contribution; 4, very high contribution; and 5, maximum contribution. The results are shown in Table 10, where the scores are colour coded from red, corresponding to 0, to green, corresponding to 5. The assessment is based on the extent to which the available evidence explicitly addresses the aspects encompassed by each learning outcome. The general criteria and reasoning supporting the determination of the degree of contribution are explained in Section 6.1.1. A detailed justification of each Specific Competence is provided in Appendix A of the supplementary material, including the corresponding numerical rating according to the 0-5 Likert-type scale for each LO.

The results of this expert appraisal indicate that BIM-Based experiences contribute most clearly to the learning outcomes above the overall average: LO124, LO68, LO119, LO120, LO69, LO129, LO71, LO70, LO76, LO77, LO115, LO116, and LO117. These outcomes suggest a marked contribution to competencies related to spatial reasoning, geometric and metric control, graphic codification, model-based documentation, coordination, and design decision-making. Thus, BIM appears to be particularly relevant when used as an active environment for analysing, developing, and transforming architectural form through a graphic interface.

Table 10: Heatmap showing the contribution of potential Learning Outcomes to Specific Competences.

		Specific Competences: 01 03 04 05 06 34					
LO 119	Practise representational drawing critically and reflectively.						
LO 120	Initiate analytical processes of form.						
LO 69	Understand and apply the operations, resources, and codes of architectural graphic language as instruments of thought and communication.						
LO 70	Apply fundamental geometric and metric procedures to control architectural form and its scaled representation.						
LO 71	Use representation systems coherently, controlling their interrelationships and the arrangement of drawings within the graphic field.						
LO 76	Be able to establish a set of basic relationships among the various thematic aspects of architecture and assign them to specific codes according to the graphic resources used.						
LO 77	Recognise architecture as an essentially synthetic phenomenon, capable of being understood by separating its components through appropriate graphic expression.						
LO 78	Demonstrate command of the basic concepts of urban representation as a specific application of long-range scales and of the graphic resources appropriate to the relationships between architecture and the city.						
LO 125	Demonstrate the ability to analyse graphically the relationships among architecture, the city, territory, and nature.						
LO 11	The student will be able to locate and compile reliable documentation (written, graphic, photographic, and infographic) on a specific topic, building, historical period, or architect.						
LO 106	Analyse, based on the documentation found or provided, relevant aspects of a building or of the work of a specific architect.						
LO 110	Understand and apply the relationships among the different dimensions of architecture and their symbolic role.						
LO 115	Develop graphic skills and abilities to undertake creative graphic processes.						
LO 116	Be prepared to initiate graphic developments linked to thinking-in-action processes.						
LO 117	Demonstrate the ability to initiate graphic-project processes.						
LO 118	Exercise and strengthen perceptual capacity.						
LO 121	Attain basic levels of creativity and formal intuition.						
LO 124	Understand formal creation as a process.						
LO 129	Understand the mode of generation, the geometric, graphic, and constructive properties of the forms of interest to the architect, as well as the relevant guidelines that enable their control.						
LO 68	Identify, analyse, and solve problems of spatial configuration in ways that enable understanding and resolving the geometric structure of architectural forms.						

For the remaining learning outcomes, the review does not provide sufficient evidence of a clear contribution. This should be interpreted with caution, since the absence of explicit evidence does not necessarily imply lack of relevance, but rather that these dimensions were not clearly demonstrated in the analysed BIM-based experiences. Section 6.2.1 provides a detailed account of these graphic learning outcomes and reflects on their alignment with BIM-mediated learning activities.

6.2 Framework for a BIM-based pedagogical agenda for architectural drawing instruction

In accordance with the previously described in Biggs's theory of constructive alignment (Biggs, 1996), the Framework for a BIM-Based Pedagogical Agenda for Architectural Drawing Instruction is also conceived around three interdependent components: intended learning outcomes, teaching and learning activities, and assessment tasks.

From this perspective, Learning Outcomes constitute a fundamental component of the framework, as they guide both the organisation of didactic content and the selection of learning activities and assessment plan. Their role is particularly relevant in a BIM-based pedagogical proposal, since they make it possible to relate graphic competences to a coherent educational structure.

However, the definition of specific learning activities and assessment strategies is largely dependent on the conditions of each teaching context. Pre-existing course structures, student group size, the level of digital competence among teaching staff, the availability of technological resources, and the degree of curricular integration of BIM are all variables that may significantly affect the implementation of the proposal. Consequently, it is difficult to define a closed repertoire of activities that can be applied systematically without first relying on empirical evidence regarding their impact in different educational settings.

Consequently, and as previously stated, this proposal places learning outcomes at the centre of the framework, understanding them as elements capable of articulating a structure that can be adapted to diverse academic contexts. Therefore, the following section examines these learning outcomes in detail and proposes final considerations on their alignment with BIM-mediated learning activities (6.1), which are grounded in the author's own teaching practice and connected to the reviewed literature and other studies. In addition, a SWOT analysis is included to synthesise the implications derived from the use of BIM in Architectural Drawing education (6.2). This final analysis provides a strategic support tool for enhancing the educational potential of the proposal while minimising the risks associated with its implementation.

Although the proposed framework provides a structured basis for integrating BIM into Architectural Drawing education, its curricular implementation is necessarily context-dependent. Differences in programme structure, course duration, institutional resources, faculty expertise, student profiles, and accreditation requirements may affect how the framework is applied. It should therefore be understood as an adaptable pedagogical model rather than as a universally prescriptive curriculum.

6.2.1 Aligning intended learning outcomes with BIM-mediated learning activities

The following section presents the full set of learning outcomes mapped in Section 3.2 and discusses a series of teaching considerations regarding the learning activities that may be mediated through BIM. These considerations are informed by the author's teaching practice and should therefore be understood as context-sensitive pedagogical reflections rather than as universally generalisable prescriptions.

To provide an explicit assessment component and reinforce the constructive alignment between learning outcomes, learning activities, and assessment, an outline rubric has also been developed and included in Appendix A as supplementary material. The rubric is structured around broad learning outcome clusters so that its assessment dimensions and performance criteria can be contextualised across different subjects. This degree of flexibility is necessary because the selection of specific assessment strategies depends on factors such as course structure, class size, staff digital competence, technological availability, and the level of BIM integration within the curriculum.

Practise representational drawing critically and reflectively (LO 119). Teaching approaches that incorporate the use of spatial representation systems into their planning, regardless of whether they rely on CAD tools or not, can contribute more effectively to fostering reflection and critical thinking. In practical terms, achieving this learning objective involves helping students understand that model-based drawing requires: (1) reviewing

information requirements, (2) reviewing the structure and organisation of the model, (3) reviewing the geometry and the documentation derived from it, (4) reviewing alphanumeric information, and (5) reviewing interdisciplinary coordination.

Initiate analytical processes of form (LO 120). It should be noted that the use of BIM can introduce biases into architectural conception when diverse methodologies are not made explicit to analyse, explore, and generate forms. This implies recognising that the formal configuration of a building does not necessarily have to derive exclusively from the additive assembly of constructive elements (*tectonic*), but it can also be conceived through conceptual information models based on the development of spatial elements (*stereotomic*). In the case of Revit, one of the most widely used tools, this approach would correspond to the use of conceptual masses, which can subsequently be defined in constructive terms.

Understand and apply the operations, resources, and codes of architectural graphic language as instruments of thought and communication (LO 69). Students must understand that graphic documentation is not merely the result of sectioning or projecting a model. In BIM, graphic encoding is governed by information containers and their hierarchy, while the cross-sections through which they are represented do not always adequately reflect the architecture itself. Therefore, to achieve the intended learning outcome, it is necessary to be aware of both dimensions—the hierarchical logic of graphical coding and the use, when appropriate, of local representation mechanisms—along with a deep understanding of what is being represented and, when necessary, the ability to supplement the documentation with two-dimensional annotations that make the drawing legible and effective from a communicative standpoint.

Apply fundamental geometric and metric procedures to control architectural form and its scaled representation (LO 70). Geometric and metric procedures for formal control operate on the information model. Accordingly, an increase in the *Level of Information Need* does not necessarily imply greater representational detail, as the former concerns information requirements while the latter concerns visual display. This disconnect means that model definition cannot be assumed to correspond directly to the scale of representation. Unless this distinction is made explicit in teaching, students may overdefine their models, incurring an avoidable workload that diverts effort towards premature detailing without improving either representational quality or the intended learning outcomes.

Use representation systems coherently, controlling their interrelationships and the arrangement of drawings within the graphic field (LO 71). As noted previously, most commercial BIM tools currently in use do not support the production of oblique projections. This limitation is particularly significant, given that oblique projection remains one of the most widely used systems of architectural representation due to its capacity to show one face of an object in true size. However, such projections can still be obtained from these models by incorporating additional tools into the workflow. In this regard, the corresponding learning outcome should be understood as relating both to the necessary hybridisation of tools and to the fostering of an investigative disposition in students, orientated towards exploring graphical solutions to the current limitations of software.

Be able to establish a set of basic relationships among the various thematic aspects of architecture and assign them to specific codes according to the graphic resources used (LO 76). The thematic aspects most clearly reinforced using BIM methodologies are those related to the construction of architecture. However, more complex spatial readings are not sufficiently articulated in the proposals analysed. Graphically representing not only the container but also the contained space enables thematic analyses related to function, form, or hierarchy. This requires control over the spatial elements —*IfcSpace* within the IFC hierarchy— together with their representation and the alphanumeric information associated with them. Incorporating this perspective into the learning outcomes is therefore both useful and consistent with a tradition of Architectural Drawing that should also be channelled through BIM.

Recognise architecture as an essentially synthetic phenomenon, capable of being understood by separating its components through appropriate graphic expression (LO 77). As with the previous learning outcome, this one is explicitly addressed in the teaching proposals analysed. However, appropriate representation with BIM tools requires an understanding of object taxonomy and hierarchy within the model. Yet this logic may prove limiting when representation is intended to support other forms of analysis. For this reason, it is useful to adopt representation rules based on model data, so that objects are displayed not only according to their taxonomy, but

also according to the alphanumeric information they contain. This makes it possible to move beyond readings based solely on constructive function and to support more complex and diverse interpretations.

Demonstrate command of the basic concepts of urban representation as a specific application of long-range scales and of the graphic resources appropriate to the relationships between architecture and the city (LO 78). Addressing multiple scales of representation requires moving beyond the isolated building model and integrating several models within a shared working environment. However, the operational scope of these proposals remains restricted to the site of a specific design solution, whereas the urban scale refers to analytical frameworks that exceed the exclusive use of BIM software —except for the incorporation of two-dimensional planimetric information to contextualise the building. The interaction between these information models and others intended for urban analysis through Geographic Information Systems (GIS) should therefore be made explicit, even if it cannot be fully developed within a single teaching proposal. This multiscale reading broadens the understanding of students and fosters a more systemic approach to managing the information contained in geometric entities.

Demonstrate the ability to analyse graphically the relationships among architecture, the city, territory, and nature (LO 125). Graphic analyses mediated by BIM tools, as envisaged by this learning outcome, require attention to issues that extend beyond the isolated building model. In this respect, the collaborative potential of these tools is particularly relevant, since BIM workflows are based on model coordination and the exchange of information associated with it. For this reason, proposing collaborative dynamics in which several models are integrated within a single file or coordination environment enables students to acquire basic technical notions of these processes while also grounding graphic analyses of architecture in relation to its context.

Locate and compile reliable documentation on a specific topic, building, historical period, or architect (LO 11). From the perspective of Architectural Drawing, the learning objective derived from graphic research through drawing constitutes a distinguishing feature in the training of future architects, as opposed to the instrumental logic of graphic production characteristic of BIM. This approach is grounded in the view of technology as a “third culture” and of drawing as a specific mode of non-verbal (visual) thought (French, 1994, p. 289) imbued with intrinsic values—in accordance with Cross’s premises (1982) in *Designerly Ways of Knowing*—and in the recognition of architectural research as a field where graphic media actively participate in the construction of disciplinary knowledge. Achieving this outcome requires guiding students in identifying systems of spatial representation, graphic operations, and resources present in the graphic work of leading architects, so that they can critically recognise the limitations of current tools and explore their own processes of pattern synthesis.

Analyse, based on the documentation found or provided, relevant aspects of a building or of the work of a specific architect (LO 106). Except for a few cases, such as Mathews (2013), the teaching proposals analysed do not make explicit the “graphic models” used for BIM literacy. Selecting pedagogically appropriate models broadens students’ architectural knowledge beyond the *extrinsic* and turns these models into a field of experimentation. Once the logic of the project is understood (read), students can intervene coherently in the architectural proposal (write), developing both technological skills and critical capacity to interpret and produce architecture that embodies new messages (Cross, 1982, p. 8).

Understand and apply the relationships among the different dimensions of architecture and their symbolic role (LO 110). Moving beyond the concrete or iconic dimensions of architecture—in Piaget’s and Bruner’s terms—involves recognising the formal or symbolic roles embedded in the graphic and informational model through which students’ education is structured. This requires engaging not only with the constructive elements that define architecture, but also with space, its hierarchy, function, and thematic analyses—such as those already identified in LO 76—all necessarily connected to the tradition of Architectural Drawing.

Develop graphic skills and abilities to undertake creative graphic processes (LO 115). Some of the studies analysed clearly distinguish between *graphic skill* development and *creative graphic processes*, drawing, among other references, on Jonassen’s (2011) conceptual framework to define an iterative design process model. Based on this distinction and in line with Cross’s differentiation, the graphic skills students can acquire through BIM can be understood as *extrinsic* learning values that should meet three educational criteria: (1) worthwhile knowledge—the collected body of practical knowledge based on sensibility, invention, validation, and implementation (Archer, 1979)—, (2) meta-learning, and (3) the cultivation of intrinsic values rather than merely instrumental

training. Consequently, *creative graphic processes* should likewise be regarded as *intrinsic* values within BIM-based architectural education. Their development requires students to propose, argue for, and collectively defend—in line with LO 106—solutions supported by the workflows these tools enable, understanding them as platforms for graphical, design-orientated, and collaborative dynamics articulated through a shared graphic model.

Be prepared to initiate graphic developments linked to thinking-in-action processes (LO 116). BIM-based pedagogy can support this learning outcome when the graphic-information model is understood as a live environment for action, modification, and immediate feedback. However, this cannot be achieved through the mere reproduction of architectural forms. Students must be able to intervene in, reinterpret, and creatively transform models, using them to test design intentions through thinking-in-action. The aim is therefore not to train students in every analytical or visualisation tool, but to help them understand when and why a shared model may interact with tools for parametrisation, material and lighting verification, environmental performance analysis or spatial assessment through virtual mock-ups and Virtual Reality.

Demonstrate the ability to initiate graphic–project processes (LO 117). The proposals differ here according to how far they move from isolated modelling tasks (Deniz, 2018; Hu, 2019) to a projective sequence of representational development (Bozoglu, 2016; Mathews, 2013; Meterelliyöz & Özener, 2022; Obi et al., 2024). However, with few exceptions, graphic–project processes are not explicitly articulated, and the ability to initiate them is not clearly evidenced, except in cases where hybrid developments are described in which hand drawing plays a significant role (Mathews, 2013). This learning objective, mediated by the use of BIM tools, entails the need for a clear conceptualisation of the modelling processes that enable the coherent creation of a model capable of accurately responding to the proposed architecture. As previously introduced in LO 120, the interpretation of the stereotomic and/or tectonic characteristics of a given architectural proposal—or parts thereof—requires either a prior understanding of its geometry (conceptual masses) for its subsequent translation into different constructive elements, or the juxtaposition and assembly of known building components (floors, walls, roofs, openings, etc.).

Exercise and strengthen perceptual capacity (LO 118). Most of the proposals support perceptual development only indirectly, through 3D visualisation, clash detection, and multi-view coordination. Nevertheless, the key aspects that would make it possible to evaluate how the use of graphic models in BIM exercises and enhances spatial perceptual capacity are not explicitly addressed. In this regard, the work of Uttal et al. (2013) is especially relevant. Based on a meta-analysis of 217 studies, the authors demonstrate that spatial skills are both trainable and transferable, and identify several factors associated with their improvement, including experience in interactive visual environments such as video games, given their contribution to spatial attention and working memory. This evidence is particularly relevant to BIM, since these tools may likewise be understood as three-dimensional virtual environments in which a building is constructed, explored, and interpreted. As such, they require processes of navigation, orientation, mental rotation, and spatial recognition that are comparable to those activated in video games. Similarly, Martín-Dorta et al. (2008) report significant improvements in engineering students following a short training programme based on 3D CAD modelling, with gains assessed through the Mental Rotation Test (Albaret & Aubert, 1996) and the Differential Aptitude Test: Space Relations (Bennett et al., 2006).

Attain basic levels of creativity and formal intuition (LO 121). The analysed teaching proposals do not sufficiently foreground the architectural attributes of the models employed to develop BIM-based skills and knowledge; though, the careful selection of a model with strong architectural relevance—whose formal and constructive values are explicitly highlighted by instructors following prior analysis—can foster the transmission of intrinsic disciplinary principles to students. Through controlled and reproducible geometric transformations enabled by digital tools, students can engage with and understand the ordering principles of the reference architecture (axis, symmetry, hierarchy, rhythm, datum, and transformation, as defined by Ching, thereby linking instrumental proficiency in BIM with deeper architectural learning outcomes.

Understand formal creation as a process (LO 124). This learning outcome is best supported when BIM is approached as a progressive sequence of graphical and geometrical decisions rather than as a finished object. From the perspective of Architectural Drawing, students are expected to understand the Level of Information Need — LOIN— mainly in terms of the graphic definition of the model, in line with ISO 7817-1:2024, while recognising that BIM belongs to broader information frameworks, such as those described in the ISO 19650 series. The focus is therefore not on alphanumerical data management, but on defining an appropriate level of graphic information according to the purpose, stage, and expected use of the model. In this sense, each stage of graphic modelling must be understood as part of an integrated sequence of models supporting project definition —PIM, Project Information

Model— or the representation of existing assets —AIM, Asset Information Model—, and providing a graphic basis for further assessments, including sustainability-related evaluations within the applicable regulatory framework (European Committee for Standardization, 2021).

Understand the mode of generation, the geometric, graphic, and constructive properties of the forms of interest to the architect, as well as the relevant guidelines that enable their control (LO 129). Achieving this learning outcome requires the establishment of explicit links between the generation of the architectural form and the rigorous control of its defining elements. From a BIM-based pedagogical perspective, it is essential to articulate the workflows that enable the integration of geometries generated through visual programming or imported from external software into the digital environment. In this regard, training in the definition and management of such workflows has a particularly strong potential.

Identify, analyse, and solve problems of spatial configuration in ways that enable understanding and resolving the geometric structure of architectural forms (LO 68). This learning outcome constitutes one of the most salient points of convergence across the analysed proposals, which consistently frame BIM as an effective instrument for the detection, visualisation, and resolution of spatial conflicts, with graphical modelling emerging as the process that most directly underpins this competence; nevertheless, the explicit articulation of mechanisms for the identification, analysis, and resolution of such issues remains necessary. In certain cases, such as Bozoglu (2016), conflict resolution is supported by using specialised software capable of identifying interferences across disciplines—including architecture, structures, and building services—an approach that becomes particularly relevant when model scale or multidisciplinary integration requires systematic assessment of clashes. However, from the point of view of architectural representation, the graphic detection of such conflicts remains critical, requiring the systematic confrontation of model-derived documentation—plans, sections, and elevations—with the underlying geometric model. Only through this process can students develop the graphic discernment required not only to resolve spatial problems within a virtual environment, but to translate them rigorously and coherently into the technical documentation derived from the model.

6.2.2 Strategic assessment of BIM-based architectural drawing education: A SWOT analysis

This section presents a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis based on the preceding discussion. The analysis distinguishes between (a) what BIM truly enhances as a means of architectural representation and (b) what remains limited by the logic of the software, underdeveloped from a pedagogical standpoint, or dependent on hybrid workflows.

The line of reasoning is consistent with the validated pedagogical patterns found in the reviewed literature. SWOT Analysis is summarized at Table 13.

Table 13: SWOT Analysis.

Helpful / Positive	Related LO	Harmful / Negative	Related LO
S1. BIM consolidates drawing-as-model as an integrated representational environment. Plans, sections, elevations, schedules, and 3D views derive from a coordinated model, reinforcing representational coherence and supporting spatial vision and architectural synthesis.	LO 71, LO 69, LO 77, LO 118, LO 68	W1. BIM does not support all graphic procedures with equal freedom. Standard orthographic systems are well supported, but non-standard sections, oblique projections, and other less native operations often require indirect workflows or complementary tools.	LO 71, LO 69, LO 129, LO 115, LO 11
S2. BIM strengthens applied metric control, spatial reasoning, and graphic verification. Levels, dimensions, parameters, constraints, and coordinated views support operational geometric control and the detection of inconsistencies through model-based checking.	LO 70, LO 68, LO 129, LO 118, LO 124	W2. Formal theory, visual perception, and aesthetic sensitivity remain weakly addressed. Visualisation is typically mobilised for modelling and coordination rather than for the explicit teaching of form theory, perceptual order, or aesthetic judgement.	LO 118, LO 120, LO 121, LO 110, LO 11
S3. BIM strongly supports teamwork, interdisciplinary coordination, and ICT competence. Shared models, repositories, role-based workflows, and coordinated outputs reinforce socially distributed drawing practices	LO 115, LO 125, LO 76, LO 69, LO 119	W3. Geometric knowledge and drawing-related learning outcomes remain insufficiently conceptualised and articulated. BIM reinforces applied metric control, but projective logic and geometric theory frequently remain implicit, while learning outcomes are often inferred from	LO 68, LO 70, LO 69, LO 71,

Helpful / Positive	Related LO	Harmful / Negative	Related LO
when collaboration is grounded in co-authorship of the model.		activities rather than explicitly linked to representational evidence.	LO 129, LO 124
S4. BIM can support reflective review and project development when used critically. When the model is treated as a reviewable and adjustable environment, rather than a mere documentation device, it supports reflective drawing, project development, decision-making, and model-based critique.	LO 119, LO 116, LO 117, LO 124, LO 106	W4. Surveying, restitution, and pre-model operations are underdeveloped. Most pedagogical experiences start from pre-given information, leaving capture-to-model, verification, and scientific restitution weakly integrated.	LO 11, LO 106, LO 70, LO 68, LO 124
O1. Hybridisation with complementary media can expand the representational scope. Rendering tools, GIS, diagrammatic environments, visual programming, scan-to-model technologies, and hand drawing can compensate for BIM's native representational restrictions.	LO 71, LO 78, LO 125, LO 129, LO 115, LO 116	T1. Software-driven and instrumental learning may undermine architectural judgement and critical awareness. Dependence on BIM defaults can reduce drawing to compliance with the platform, distancing students from the historical, analytical, symbolic, and cultural dimensions of Architectural Drawing. As a result, decision-making may become merely technical and disconnected from environmental and ethical responsibilities.	LO 119, LO 69, LO 11, LO 106, LO 110, LO 124
O2. BIM can support a richer graphic culture if the model becomes an object of interpretation, not only production. Treating models as instruments for reading, analysing, and transforming architecture can reconnect BIM literacy with disciplinary graphic culture rather than limiting it to technical proficiency.	LO 106, LO 11, LO 69, LO 77, LO 110, LO 121	T2. The abundance of generated documentation may undermine the synthesis and graphic economy. Rapid production of drawings, views, and schedules can be mistaken for representational quality, shifting attention from purposeful selection, hierarchy, and graphic synthesis towards the mere accumulation of information.	LO 77, LO 69, LO 71, LO 76, LO 119
O3. Explicit outcome-based assessment could substantially improve BIM pedagogy. If curricula evaluate cross-view coherence, view logic, geometric control, thematic coding, and graphic economy, BIM can move beyond software training toward assessable drawing knowledge.	LO 69, LO 70, LO 71, LO 76, LO 77, LO 68, LO 119	T3. Early BIM adoption may suppress exploratory and ambiguous graphic thinking. Without conceptual massing, option management, or hybrid sketch-based workflows, BIM may prematurely stabilise design thinking and reduce imaginative openness.	LO 120, LO 115, LO 116, LO 117, LO 121, LO 124
O4. Interoperability and open exchange standards can deepen collaborative literacy. Explicit teaching of IFC-based exchange, model federation, and shared representational criteria can strengthen interdisciplinary co-authorship and multiscale graphic analysis.	LO 125, LO 78, LO 76, LO 115, LO 119, LO 124	T4. Interoperability may remain implicit, leaving conceptually shallow collaboration. Students may learn to collaborate within a single platform without understanding the broader technical, organisational, and representational implications of robust model exchange across different tools and professional workflows.	LO 125, LO 78, LO 76, LO 115, LO 119, LO 69

7. CONCLUSIONS

The preceding analysis suggests that BIM-based Graphic Instruction should not be understood as the replacement of Architectural Drawing by software, but as the reframing of Drawing as a model-based, interface-mediated, and critically managed representational practice. As both a methodological and cognitive framework, BIM can link design thinking, graphic reasoning, and digital production more effectively than software-centred instruction, provided that its capacities and limitations are made explicit. It should therefore be introduced not as a self-sufficient medium or a late professional add-on, but as a staged pedagogical vehicle for learning architectural representation. Although BIM supports spatial reasoning, metric control, representational coherence, documentation management, and collaborative production, areas such as projective geometry, formal theory,

surveying, visual perception, aesthetic judgement, and critical graphic intention still require explicit curricular support. Students must therefore learn not only how to model, but also how models generate drawings, what they represent inadequately, and where disciplinary judgement remains essential.

The following recommendations provide general guidance for the pedagogically grounded integration of BIM into Architectural Drawing education:

- **Establish an explicit pedagogical framework.** Introduce BIM as a support for foundational graphic learning, grounded in defined learning theories, didactic principles, educational aims, and learning outcomes, before treating it as technical or professional training.
- **Maintain the centrality of architectural graphic thinking.** IM should reinforce drawing conventions, geometry, projection, spatial reasoning, visual judgement, formal analysis, graphic synthesis, and architectural representation.
- **Teach architectural drawing concepts through model-based operations.** Address projection, section, hierarchy, visibility, annotation, and documentation as interconnected operations, emphasising geometric control, cross-view coherence, and justified graphic decisions.
- **Make BIM's internal logic explicit.** Students should understand view generation, object hierarchies, parameters, and graphic coding rather than merely learning sequences of software commands.
- **Develop BIM literacy beyond software proficiency.** BIM literacy should encompass information management, modelling criteria, representation, coordination, communication, interoperability, and decision-making. It should not be equated solely with mastery of a particular platform.
- **Focus learning on graphic operations and disciplinary judgement.** Prioritise modelling, sectioning, annotation, view management, comparison, iteration, and critique, ensuring that productivity does not replace clarity, synthesis, or representational intention.
- **Preserve exploratory and open-ended forms of representation.** Use conceptual masses, reversible modelling, alternatives, and option-based workflows to support experimentation, comparison, and critical judgement.
- **Introduce BIM through progressive sequencing.** Sequence learning from analogue drawing, sketching, geometry, CAD, and diagrammatic practices toward increasingly complex model-based workflows.
- **Integrate pedagogically relevant hybrid workflows.** Combine hand drawing, CAD, rendering, GIS, scan-to-model, visual programming, selective 2D interventions, and BIM when they support specific learning objectives.
- **Address curricular blind spots deliberately.** Ensure that BIM teaching does not neglect geometry, perception, formal analysis, surveying, sketch-based exploration, or the interpretation of architectural form.
- **Teach interoperability and open standards.** Incorporate IFC, Open BIM, model exchange, and cross-platform coordination to develop critical awareness of compatibility, information transfer, and data loss.
- **Structure collaborative learning around shared authorship.** Organise collaborative modelling through defined roles, repositories, worksets, communication systems, and coordination protocols, assessing both individual and collective contributions.
- **Align assessment with learning outcomes and observable evidence.** Use explicit criteria and rubrics to evaluate processes and results, including geometric control, cross-view coherence, representational hierarchy, coordination, and the justification of graphic decisions.

- **Specify the conditions required for implementation.** Integrate software, hardware, technical support, staff expertise, instructional time, group size, and institutional resources into the pedagogical design.
- **Ensure transferability and equitable access.** BIM teaching models should be adaptable to institutions and student groups with unequal access to equipment, infrastructure, software, training, or technical support. Proposed methods should therefore include scalable alternatives and avoid depending on idealised resource conditions.
- **Reconnect BIM with architectural graphic culture.** Students should interpret, compare, question, and transform meaningful architectural models rather than merely reproduce predefined procedures. This approach positions BIM within the broader history and culture of architectural representation.
- **Balance professional preparation with disciplinary education.** BIM may simulate professional workflows and coordination environments, but it should also strengthen spatial understanding, formal analysis, graphic synthesis, critical project thinking, and representational judgement. Its transfer into education should therefore be framed critically, showing both how BIM extends Architectural Drawing and where it may constrain, simplify, or obscure established forms of graphic reasoning.

These points suggest that BIM becomes pedagogically valuable when framed as a critical representational environment, reorganising the drawing around the model as a space for geometric control, graphic reasoning, documentation management, and collaborative authorship, while clarifying where complementary media, explicit teaching, and disciplinary judgement remain necessary.

The BIM-Based Graphic Instruction framework proposed in this study provides a theoretically grounded basis for connecting BIM activities with Architectural Drawing competences and learning outcomes. However, it should be understood as a starting point for curricular development rather than as a fully validated instructional model. Its educational effectiveness and transferability should be examined through longitudinal classroom implementation, systematic assessment instruments, and comparative studies across different architectural education contexts.

8. LIMITATIONS OF THE STUDY AND FUTURE RESEARCH

This study was limited to a scoping review of journal articles and did not directly include conference proceedings. However, the contributions of the main conferences were indirectly considered through the systematic literature reviews analysed, which incorporated this type of publication.

The pedagogical implications of the use of BIM in Architectural Drawing were identified across three courses at different academic levels within the School of Architecture at UPM. Although these courses had previously been involved in educational innovation initiatives related to BIM, the study does not draw conclusions from the specific interventions conducted in them, nor does it propose a detailed assessment framework. Instead, it provides a foundation for future research aimed at developing instructional and assessment plans.

The proposed BIM-Based Graphic Instruction framework is theoretically grounded in the findings of the systematic review. However, it remains primarily conceptual, since its effectiveness has not yet been evaluated through systematic classroom implementation. The framework should therefore be regarded as a structured basis for curricular development and empirical investigation rather than as a fully validated instructional model.

Future research should include longitudinal classroom implementation to examine how students' graphic, spatial, cognitive, technical, communicative, and collaborative competences develop over time. Such studies would also help determine how BIM-Based Graphic Instruction can be progressively integrated across different courses and levels of architectural education.

“Empirical validation of the framework will require systematic assessment instruments aligned with the proposed competences and learning outcomes. These instruments may include competency-based rubrics, pre-test and post-test designs, analysis of student work, spatial reasoning assessments, BIM model evaluation criteria, classroom observation, and qualitative feedback from students and instructors.”

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APPENDIX A: SUPPLEMENTARY MATERIAL

Section 3.1

Table A.1: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist.

Section	Item	Prisma-scr checklist item	Reported on page
TITLE			
Title	1	Identification of BIM-related Educational Experiences: a scoping review	4
ABSTRACT			
Structured summary	2	BACKGROUND: BIM education has progressively shifted from software-centred training towards curricular integration, collaborative learning, and interoperability. However, its contribution to graphic thinking, representational judgement, and Architectural Drawing education remains insufficiently defined, while learning outcomes and assessment evidence are often weakly articulated. OBJECTIVE: To identify and characterise the pedagogical models, learning strategies, reported learning outcomes, assessment approaches, barriers, challenges, and enabling factors associated with BIM integration in architecture education, and to examine their implications for BIM-Based Architectural Drawing Instruction. ELIGIBILITY CRITERIA: Peer-reviewed journal articles published in English between 2010 and 2026 and addressing BIM-related education, teaching, or learning in AECO were considered. Studies focused exclusively on design studios or construction management were excluded unless they explicitly addressed graphic competencies. Journals not indexed in SJR or JCR and inaccessible or non-English reports were also excluded. SOURCES OF EVIDENCE: Web of Science and Scopus were searched using four complementary search strings. The initial search was conducted on 21 April 2026 and reviewed on 15 July 2026. CHARTING METHODS: The final corpus was classified inductively into 11 thematic categories. Selected teaching experiences were examined in terms of learning outcomes, pedagogical principles, workshop structures, roles, resources, infrastructure, tools, gaps, and limitations. The manuscript does not report the use of a calibrated or piloted charting form, whether charting was undertaken independently or in duplicate, or how disagreements or missing information were managed. RESULTS: The searches identified 2,969 records; after deduplication, screening, eligibility assessment, and exclusions, 52 references were included. The evidence indicates a transition from tool-centred instruction towards curricular integration, active and collaborative learning, and interoperability. Persistent limitations include weakly defined learning outcomes, limited assessment evidence, insufficient attention to graphic thinking, dependence on proprietary platforms, and institutional and infrastructural constraints. CONCLUSIONS: BIM can support spatial reasoning, geometric and metric control, representational coherence, documentation management, and collaborative authorship when taught as a critical graphic and cognitive environment rather than as software training. Its integration into Architectural Drawing should preserve disciplinary judgement, explicitly address its representational limitations, and combine model-based learning with complementary graphic media and outcome-aligned assessment.	3-4, 3, 4-5, 8-9
INTRODUCTION			
Rationale	3	Existing BIM education research largely addresses curriculum design, technology adoption, and professional competencies, with limited attention to graphic thinking, spatial reasoning, and architectural representation. The evidence is also heterogeneous in educational contexts, teaching methods, technologies, and assessment approaches.	16
A scoping review is therefore appropriate because the study aims to map this diverse evidence,			



Section	Item	Prisma-scr checklist item	Reported on page
		clarify key concepts and pedagogical approaches, and identify research gaps rather than evaluate the effectiveness of a single intervention. This approach supports the development of an evidence-informed framework for BIM-Based Graphic Instruction.	
Objectives	4	Using the Population–Concept–Context framework, the review considers students, educators, and programmes in Architecture and related AEEO higher education as the population; BIM-based pedagogies, curricular integration, learning outcomes, assessment practices, graphic competencies, and implementation conditions as the concepts; and university-level architecture and related AEEO courses as the context. The review seeks to map the pedagogical models used, the evolution of BIM integration, the learning outcomes and their assessment, and the barriers and enabling factors reported, before examining the transferability of this evidence to Architectural Drawing education.	3, 17
METHODS			
Protocol and registration	5	A separate protocol was not published or prospectively registered for this scoping review; therefore, no protocol URL or registration number is available. The review objectives, eligibility criteria, databases, search strategy, and selection procedures were established before the database searches and are reported in Section 3.1 and Appendix A. PRISMA-ScR was used as a reporting guideline rather than as a registered protocol. This review is not an update of an earlier review.	4-9
Eligibility criteria	6	The review included peer-reviewed journal articles and conference papers published between 2010 and 2026, in English, and available in full text. This period captures the development of BIM-based educational practices, while the language restriction reflects the review team's linguistic capacity. Peer-reviewed publications were prioritised to ensure minimum standards of academic quality; editorials, abstracts, dissertations, reports, and non-peer-reviewed sources were excluded to maintain consistency and relevance.	3, 6
Information sources	7	Web of Science Core Collection and Scopus were searched for English-language, peer-reviewed journal articles published from 1 January 2010 to 15 July 2026. The initial search was executed on 21 April 2026 and updated on 15 July 2026, the date of the most recent search. No other databases or grey-literature sources were systematically searched, and authors were not contacted to identify additional or inaccessible evidence. See Section 3.1 and Table 1.	4-9
Search	8	QA (WoS): (BIM OR "building information model*") AND (architectur* OR "architectural education" OR "architecture education" OR "design studio" OR "architectural design studio") AND ("systematic review" OR "systematic literature review" OR SLR OR "mapping study" OR "systematic mapping" OR PRISMA) QB/QC (WoS): (BIM* OR "building information model*") AND (curricul* OR syllabus OR "study plan" OR "curricular integration" OR "learn*") AND (architectur* OR "design studio" OR "architectur* education") QD (WoS): (BIM OR "building information model*") AND (skill* OR "learning outcome*" OR "graduate attribute*") AND ("architectural education" OR "design studio" OR architectur*)	5
Selection of sources of evidence	9	Records retrieved from Web of Science and Scopus were imported into RefWorks and deduplicated in two stages, first within each search-string folder and subsequently across the complete project. Candidate duplicates were identified using title, author surname, and publication year and were individually verified by the author before removal. Similar records were compared using their abstracts and metadata, and the most complete record was retained.	5-6

Section	Item	Prisma-scr checklist item	Reported on page
		This process reduced the initial 2,969 records to 1,915 unique references. The author then screened all titles and abstracts by sequentially excluding studies that were not focused on BIM, education or learning, or architecture and the broader AECO field. Studies focused exclusively on design studios or construction management were eligible only when they explicitly addressed graphic competencies. After 1,855 records were excluded, 60 reports underwent full-text eligibility assessment. Seven reports could not be retrieved, and one of the 53 retrieved reports was excluded because its full text was not in English. The final corpus comprised 52 sources. Screening and eligibility assessment were performed by one reviewer and were not conducted independently or in duplicate. No formal calibration exercise, third-party adjudication procedure, or separately piloted screening form was used. The complete selection process is reported in Figure 2, and the reports excluded at the full-text stage are listed with reasons in Appendix A, Table A.2.	
Data charting process	10	52 sources were charted and classified into 11 thematic categories: 1, Reviews, mappings and bibliometric studies on BIM education; 2, Curricular and institutional integration of BIM; 3, Teaching experiences, courses, and pedagogical methodologies; 4, BIM in the architectural design studio; 5, Interdisciplinary collaboration, coordination, and teamwork; 6, Perceptions, awareness, barriers, and academic adoption; 7, Professional competences and university-industry alignment; 8, BIM, sustainability, Green BIM and high-performance design; 9, BIM and immersive technologies in education; 10, BIM, computational design, and parametrisation; and 11, HBIM, Heritage, and adaptive reuse. These categories guided the synthesis and its application to Architectural Drawing education.	6-9
Data items	11	Data were sought on the educational context, study objectives, pedagogical approach, BIM technologies used, learning outcomes, assessment methods, reported benefits, barriers, and enabling conditions. Interpretive items included the identification of pedagogical approaches and the synthesis of outcomes reported using different terminology. Terminology was standardised where necessary to support comparison, but missing information was not inferred. The definitions of all variables and the final data-charting form are provided in Appendix B.	Appendix B
Critical appraisal of individual sources of evidence	12	No formal critical appraisal or risk-of-bias assessment was conducted across the complete corpus. A focused narrative examination of the methodological strengths and limitations of the six teaching experiences selected for detailed analysis was conducted by the author; no formal appraisal tool, numerical quality score, duplicate assessment, or calibration exercise was used. The findings informed the interpretation of the evidence, the identification of methodological gaps, and the recommendations presented in Sections 5.2 and 6; they were not used as criteria for exclusion.	22-31
Synthesis of results	13	The synthesis was structured to answer RQ1 through the comparison of pedagogical principles, learning strategies, and workshop structures; RQ2 through the narrative examination of the transition from tool-based training to curricular integration, collaboration, and interoperability; RQ3 through the comparison of learning outcomes and assessment arrangements; and RQ4 through the thematic consolidation of conceptual, curricular, technological, institutional, and infrastructural barriers and enabling conditions.	14-16
RESULTS			
Selection of sources of evidence	14	The searches identified 2,969 records. After removing 1,054 duplicates in two stages, 1,915 records were screened by title and abstract. Of these, 1,855 were excluded because they did not focus on BIM, education, teaching or learning, or architecture and the AECO field. Full-text retrieval was sought for 60 reports, of which 7 were not accessible. The remaining 53 reports were assessed for eligibility, and 1 was excluded because the full text was not in English, despite being indexed as such. Consequently, 52 sources of evidence were included in the scoping review. The	5, 6

Section	Item	Prisma-scr checklist item	Reported on page
		complete process is presented in the PRISMA flow diagram (Figure 2).	
		Flow: 2,969 identified → 1,054 duplicates removed → 1,915 screened → 1,855 excluded → 60 sought for retrieval → 7 unavailable → 53 assessed → 1 non-English report excluded → 52 included.	
Characteristic s of sources of evidence	15	Characteristics of all 52 included sources, including author and year, article title, thematic category, citation count, and SJR/JCR classification, are presented in Table 3. The operational definitions of the 11 thematic categories are provided in Table 2 and their distribution is shown in Figure 3. Additional educational and methodological characteristics of the six teaching experiences selected for detailed analysis, including learning outcomes, pedagogical principles, institution, course, student level, duration, workshop structure, roles, resources, infrastructure, and tools, are presented in Tables 6 to 9.	7-9, 19-21
Critical appraisal within sources of evidence	16	No formal critical appraisal was conducted across the complete corpus. A narrative appraisal of the six teaching experiences selected for detailed analysis identified limitations in study design, assessment instruments, comparison procedures, reliability reporting, and the strength of causal claims. Results are reported by source in Section 5.2, informed the interpretation of the evidence, and were not used for study exclusion.	22-31
Results of individual sources of evidence	17	Partially reported. Source-specific data are presented for the six teaching experiences selected for detailed analysis in Section 5.2. Individual charted data for all 52 included sources are not reported.	22-31
Synthesis of results	18	The 52 included sources were synthesised narratively and organised into 11 thematic categories to address the four research questions. The results describe: (RQ1) the pedagogical models and learning strategies identified, particularly active, experiential, project-based, problem-based, constructivist, and collaborative learning; (RQ2) the evolution from software-centred training towards curricular integration, interoperability, and collaborative workflows; (RQ3) the reported learning outcomes and the limited evidence regarding their assessment; and (RQ4) the main conceptual, curricular, technological, and institutional barriers and enabling conditions. The synthesis is presented through narrative analysis, thematic tables, figures showing the distribution of publications, and comparative tables examining selected teaching experiences in terms of learning outcomes, pedagogical principles, workshop structures, roles, resources, infrastructure, and tools. These findings are subsequently mapped against the competences and learning outcomes of the three Architectural Drawing courses and summarised through a SWOT analysis.	23-26
DISCUSSION			
Summary of evidence	19	Findings showed a shift from software-based training towards active, collaborative, and curriculum-integrated learning. Reported outcomes were conceptual, technical, graphic, cognitive, and collaborative, but assessment evidence remained limited. Implementation faced pedagogical, curricular, technological, and institutional barriers. Since none of the six detailed teaching experiences concerned Architectural Drawing or geometry, their application represents conceptual curricular transfer rather than direct evidence of effectiveness.	8-10, 16-29, 35-36
Limitations	20	The review was limited to English-language journal articles published between 2010 and 2026 and indexed in Web of Science or Scopus; conference proceedings, grey literature, and other databases were not searched directly, and seven potentially eligible reports could not be retrieved. Screening, eligibility assessment, data charting, thematic classification, and synthesis were conducted by a single reviewer without duplicate assessment, formal calibration, or third-party adjudication. No separate protocol was prospectively registered, and no formal critical appraisal	33

Section	Item	Prisma-scr checklist item	Reported on page
		was applied consistently to all 52 included sources. Thematic and bibliometric prioritisation may have favoured older or highly cited publications and involved subjective judgement. The heterogeneity of the evidence precluded statistical synthesis, while the detailed pedagogical analysis was limited to six studies, none situated specifically in an Architectural Drawing or geometry course. Consequently, the curricular transfer and contribution scores should be interpreted as context-specific expert appraisal rather than direct evidence of educational effectiveness.	
Conclusions	21	BIM should be interpreted as a critical graphic and cognitive environment that can extend, but not replace, the disciplinary foundations of Architectural Drawing. The findings support progressive curricular integration, explicit constructive alignment, structured collaboration, hybrid graphic workflows, and assessment focused on spatial reasoning, geometric control, model-view coherence, representational judgement, and collaborative authorship. However, these implications should be treated as directions for curriculum development rather than definitive practice or policy recommendations, because the review did not formally appraise the methodological quality of the complete evidence base. Future research should empirically test the proposed BIM-Based Pedagogical Agenda in Architectural Drawing and geometry courses through explicit learning outcomes, transparent assessment rubrics, validated instruments, and comparative, longitudinal, mixed-methods, or multi-institutional designs. A subsequent focused systematic review may become appropriate once a sufficiently homogeneous body of evaluative studies is available.	32-33
FUNDING			
Funding	22	Funding sources for the individual studies were not extracted or reported. The scoping review received no specific funding, and therefore no funder had any role in its design, conduct, analysis, interpretation, or reporting. No funding contract number was applicable.	-

Table A.2: Complete list of 15 reports assessed for eligibility and exclusion criteria.

Thematic categories and titles of studies included in review	citations	ranking	Full-Text	ENG.
C02 Joannides, M. M., Olbina, S., & Issa, R. R. (2012). Implementation of building information modeling into accredited programs in architecture and construction education. <i>International Journal of Construction Education and Research</i> , 8(2), 83-100.	44	SJR (Q3) / -	No	-
Laovisutthichai, V., Srihiran, K., & Lu, W. (2023). Towards greater integration of building information modeling in the architectural design curriculum: A longitudinal case study. <i>Industry and Higher Education</i> , 37(2), 265-278.	14	SJR (Q2) / JCR (Q2)	No	-
Younis, S. B., & Al-Kazzaz, D. A. (2023). Scenarios of Building Information Modelling-Based Design Education in Architecture Schools. <i>Int. J. Eng. Pedagog.</i> , 13(8), 51-66.	4	SJR (Q2) / JCR (Q2)	No	-
Semenov, A. A. (2024). Introduction of BIM technologies in architectural and civil engineering education. <i>Industry and Higher Education</i> .	0	SJR (N/A) / JCR (N/A)	No	-
Peters, A., & Thon, A. (2026). Digital Transformation at Half Speed: Fit for BIM or Fit for Yesterday? The Gap between Practical BIM Requirements and Curricula in Landscape Architecture Education. <i>Journal of Digital Landscape Architecture</i> , (11), 423-431.	0	SJR (N/A) / -	No	-
C10 Holzer, D. (2015). BIM and parametric design in academia and practice: The changing context of knowledge acquisition and application in the digital age. <i>International journal of architectural computing</i> , 13(1), 65-82.	16	SJR (Q3) / JCR (N/A)	No	-
Indraprastha, A., Agirachman, F. A., & Aditra, R. F. (2026). Abstraction-Reconstruction as a Lens for Computational Design Thinking: A Comparative Study of the Parametric Design Environment and Building Information Modeling-Based Modeling. <i>International Journal of Technology</i> , 17(2), 692-711.	1	SJR (N/A) / JCR (N/A)	No	-
C11 Ivanova, L., Botvinovska, S., Levchenko, O., & Kosarevska, R. (2025). The Application of Heritage Building Information Modelling (HBIM) Technology in Training Specialists for Working with Architectural Heritage. <i>Information Technologies and Learning Tools</i> , 106(2), 35-57	0	- / JCR (Q3)	Yes	No
Ao, Y., Wang, Y., Peng, P., & Zhao, J. (2025). What determines BIM competition results of undergraduate students in the architecture, engineering and construction industry? In <i>Behavioral Science</i> , 12(10), p.360		No	-	-
Aryanti, F. N., Busono, R. R. T., & Siswoyo, S. (2020). Implementation of Building Information Modelling (BIM) Revit to meet the needs of the construction industry. In <i>IOP Conference Series: Materials Science and Engineering</i> (Vol. 830, No. 4, p. 042054). IOP Publishing.		No	-	-
Choi, Y. J. (2019). Analysis of curriculum management and proposal of BIM educational strategy in architecture design. <i>Journal of the Korea Convergence Society</i> , 10(12), 263-270.		No	-	-
Lee, Y. (2016). A Study on the Effect of Education Method for Adolescent's Suicide Prevention Using HMD and Virtual Reality, 19(2), 495-503		No	-	-
Yakshina, A., Vasilovskaya, G., Danilovich, E., & Hoffman, O. (2019). Bim technology in the educational process. In <i>Xxii International Scientific Conference: Construction the Formation of Living Environment</i> (Vol. 97, p. 06025). E3S Web of Conferences		No	-	-
Yi, T., & Yun, S. (2018). BIM (Building Information Modeling) education program in KSA: A case study of BIM program at Prince Sultan University. In <i>E3S Web of Conferences</i> (Vol. 65, p. 04004). EDP Sciences.		No	-	-
Yoon, J. (2017). Creative Teaching Methods of BIM Studio. In <i>Design Convergence Study</i> , 16(1), 217-236,		No	-	-

Section 3.2

Table A.3: Comparison of General Competencies established in European Directives and Spanish Ministerial Order.

European Directives 2005/36/EC and 2013/55/EU	EDU/2075/2010. Degrees' (D)/ Masters' (M) competences
Ability to create architectural designs that satisfy both aesthetic and technical requirements;	Ability to create architectural projects that simultaneously meet aesthetic and technical requirements and the needs of users, while respecting the constraints imposed by budgetary factors and building regulations. M
Adequate knowledge of the history and theories of architecture and the related arts, technologies, and human sciences;	Knowledge of the history and theories of architecture, as well as of the related arts, technologies, and human sciences. D
Knowledge of the fine arts as an influence on the quality of architectural design;	Knowledge of the role of the fine arts as a factor that may influence the quality of architectural design D
Adequate knowledge of urban design, planning and the skills involved in the planning process;	Knowledge of urban planning and the techniques applied in the planning process. D
Understanding of the relationship between people and buildings, and between buildings and their environment, and of the need to relate buildings and the spaces between them to human needs and scale;	Understanding of the relationships between people and buildings, and between buildings and their environment, as well as the need to relate buildings and the spaces between them according to human needs and scale. D
Understanding of the profession of architecture and the role of the architect in society, in particular in preparing briefs that take account of social factors;	Understanding of the profession of architect and its role in society, particularly through the development of projects that take social factors into account. M
Understanding of the methods of investigation and preparation of the brief for a design project;	Knowledge of research methods and the preparation of construction projects. M
Understanding of the structural design, constructional and engineering problems associated with building design;	Understanding of the issues related to structural design, construction, and engineering associated with building projects, as well as the techniques for addressing and resolving them. D
Adequate knowledge of physical problems and technologies and of the function of buildings so as to provide them with internal conditions of comfort and protection against the climate;	Knowledge of physical issues, the different technologies, and the functions of buildings to provide them with appropriate internal conditions of comfort and protection against climatic factors. D
The necessary design skills to meet building users' requirements within the constraints imposed by cost factors and building regulations;	(integrated in the first General Competency)
Adequate knowledge of the industries, organisations, regulations and procedures involved in translating design concepts into buildings and integrating plans into overall planning.	Knowledge of the industries, organisations, regulations, and procedures required to translate projects into buildings and to integrate drawings into the planning process. D

Section 6.1.3

Table A.4: Detailed justification of each Specific Competence and numerical rating on a 0–5 Likert-type scale indicating the contribution of each Learning Outcome to each Specific Competence.

CE 1. Ability to apply graphic procedures to the representation of spaces and objects.

The corpus's main contribution lies in consolidating drawing-as-model: BIM functions as the medium through which spaces, components, and systems are generated, coordinated, and translated into plans, sections, and views. This transfer should not be overstated: not every graphic procedure is feasible, nor can all representational operations be performed with equal freedom within BIM environments. When operations are constrained by the software's internal logic—for example, when sections must be tied to conventional cutting planes rather than more complex or non-standard procedures—a limitation emerges. BIM should therefore be presented not as a self-sufficient medium, but as a powerful yet partial tool whose value depends on exploration and, where necessary, hybridisation with other media.

LO	119	120	69	70	71	76	77	78	125	11	106	110	115	116	117	118	121	124	129	68
	5	4	5	4	4	4	4	3	3	2	3	3	4	4	4	3	3	4	4	5

CE 3. Adequate and applied knowledge of architecture and urban planning related to spatial representation systems.

BIM operates as an integrated system of architectural representation, bringing together plans, sections, elevations, schedules, and 3D views within a coordinated environment. Yet the fact that BIM integrates several representational systems does not mean that it supports all of them, or with the same precision and freedom. If certain projections or conventions—such as oblique axonometries or other systems outside the software's native logic—cannot be constructed directly or require indirect procedures, this should be understood as a limitation of the tool rather than of architectural representation itself. Curricular transfer is therefore robust at the architectural scale and within standardised systems, but it must be framed critically wherever the software restricts diversity or requires platforms.

LO	119	120	69	70	71	76	77	78	125	11	106	110	115	116	117	118	121	124	129	68
	5	4	5	4	5	5	4	4	4	2	3	3	3	3	3	3	3	4	3	4

CE 4. Adequate and applied knowledge of architecture and urban planning related to form analysis and theory and the laws of visual perception.

This competence is addressed only indirectly. BIM visualisation and discussion of massing or systemic coherence may support formal reasoning, yet neither form theory nor visual perception is treated as explicit pedagogical content. In the remaining studies, visualisation serves primarily modelling, coordination, or technological learning. In BIM, the graphic outcome usually depends on the hierarchical and parametric structure of the model, so direct intervention in the resulting image does not allow autonomous control over all aspects of visualisation. This constrains drawing as a field of visual, expressive, or hybrid experimentation. BIM therefore strengthens this competence only when instructors connect modelling tasks to formal categories such as proportion, hierarchy, rhythm, or visual order, and recognise that some expressive operations may require complementary media.

LO	119	120	69	70	71	76	77	78	125	11	106	110	115	116	117	118	121	124	129	68
	3	5	3	2	3	3	3	2	3	3	4	4	3	3	3	5	5	4	4	3

CE 5. Adequate and applied knowledge of architecture and urban planning related to metric and projective geometry.

BIM reinforces metric discipline through dimensions, levels, parameters, and coordinates. Pedagogical experiences rely on orthographic views, constraints, and dimensional control, but geometry appears as an operational requirement of modelling rather than as explicit theoretical content. Yet this does not amount to full geometric control over representation. If camera placement, viewpoints, or projective systems cannot be defined with the precision available in environments more specifically oriented to views and projections, BIM reveals a limitation for refined projective work. BIM clearly strengthens the applied metric dimension of drawing, but it does not in itself guarantee an equivalent command of projective geometry or precise control over certain views. These areas require explicit teaching and, in some cases, complementary tools.

LO	119	120	69	70	71	76	77	78	125	11	106	110	115	116	117	118	121	124	129	68
	3	4	3	5	4	2	3	2	2	1	2	2	3	3	3	3	3	4	5	5

CE 6. Adequate and applied knowledge of architecture and urban planning related to graphic surveying techniques in all phases, from sketching to scientific restitution.

Bozoglu offers the clearest point of transfer through existing-conditions modelling and its relationship to scan-to-model workflows, whereas Mathews suggests only a weaker connection through sketch interpretation and initial model setup. The remaining studies largely begin from pre-given information and focus on modelling and documentation rather than on data capture, measurement, photogrammetry, or scientific restitution. This competence therefore cannot be considered developed through BIM pedagogy unless the curriculum explicitly incorporates capture-to-model processes. The risk is that the model becomes naturalised as a given starting point, obscuring the fact that rigorous representation of existing conditions depends on prior operations of surveying, selection, verification, and graphic interpretation that are not resolved by BIM itself.

LO	119	120	69	70	71	76	77	78	125	11	106	110	115	116	117	118	121	124	129	68
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	1	1	1	1	1	1	1	2	2	2	2	1	1	1	1	0	0	1	1	1
CE 34. Ability to conceive, practice, and develop basic and execution projects, sketches, and preliminary designs.																				
Mathews establishes the clearest link between sketching, the shared model, and technical documentation, thus connecting conception, modelling, and execution. Bozoglu and Meterelliyöz & Özener likewise strengthen project development through structured modelling, coordination, and systems integration, whereas Deniz and Hu are more strongly oriented towards guided documentation and construction-focused modelling than towards open-ended design ideation. The possibility of producing design projects in BIM, however, does not eliminate the biases introduced by the limitations identified above: representation, selection, abstraction, and communication remain partly conditioned by the software's logic. The ease with which models generate documentation may also lead to a proliferation of drawings, views, and schedules whose abundance does not necessarily produce greater clarity. Without critical review, this productivity can shift attention away from synthesis and representational intention towards information accumulation. Thus, while BIM is effective for teaching project development and documentation, its pedagogical use must be accompanied by criteria of selection, synthesis, and graphic economy, so that automated document production does not replace architectural judgement concerning what should be represented, how, and with what degree of relevance.																				
LO	119	120	69	70	71	76	77	78	125	11	106	110	115	116	117	118	121	124	129	68
	4	3	4	3	3	4	4	3	3	2	3	3	5	5	5	2	4	5	4	4

Section 6.2.1

Table A.5: Outline Assessment rubric for each major LO cluster.

Module: 1. Graphic research, documentation, and critical reading	
Pedagogical Focus	Understanding architectural drawing as a form of knowledge, not merely as graphic production
Related Learning	LO 11, LO 106, LO 119
Outcomes	
Pedagogical Rationale	Before modelling, students must learn to read architecture. Graphic, historical, and technical documentation allows them to identify representation systems, graphic operations, and design strategies. The BIM model is introduced as an object of critical analysis, not as an end in itself.
Main Contents	Documentary research; drawing as visual thinking; analysis of reference works; critical reading of architectural models; introduction to BIM as a graphic and informational model
Learning Activities	Search for and selection of reliable documentation; graphic analysis of a building or architect; identification of representation systems; comparison between traditional documentation and BIM models; reflection on the limits of graphic automation
Evidence / Products	Documentary dossier; graphic analysis sheet; map of representation systems; short critical report
Assessment	Quality and reliability of sources; graphic analysis skills; clarity of architectural interpretation; critical depth
Module: 2. Spatial perception, form, and architectural thinking	
Pedagogical Focus	Developing spatial perception and formal understanding through conceptual models
Related Learning	LO 118, LO 120, LO 121, LO 110
Outcomes	
Pedagogical Rationale	Spatial perception is not developed merely by viewing 3D models, but through navigation, mental rotation, analysis of spatial relationships, volumetric interpretation, and formal transformation. Students must distinguish between a tectonic logic, based on constructive assembly, and a stereotomic logic, based on masses, voids, and spatial configurations.
Main Contents	Spatial perception; formal analysis; conceptual massing; tectonic and stereotomic form; axis, symmetry, rhythm, hierarchy, datum, and transformation; symbolic dimension of architecture
Learning Activities	Reconstruction of a work through conceptual masses; orientation and spatial rotation exercises; analysis of solids and voids; controlled geometric transformations; diagrams of hierarchy, rhythm, and organization
Evidence / Products	Conceptual model; analytical diagrams; sequence of formal transformations; reflection on formal intuition
Assessment	Capacity for formal analysis; geometric coherence; understanding of spatial relationships; initial creativity; graphic argumentation
Module: 3. Geometry, measurement, and progressive control of the model	

Pedagogical Focus	Controlling architectural form through appropriate geometric and metric procedures
Related Learning Outcomes	LO 70, LO 124, LO 129, LO 116
Pedagogical Rationale	Learning should prevent students from confusing Level of Information Need with excessive visual detail. The model must be defined according to purpose, scale, stage, and expected use. Geometry is not introduced as a final result, but as a sequence of controlled decisions.
Main Contents	Geometric and metric procedures; scale and representation; LOIN; progressive model definition; basics of parametrization; formal control; imported or externally generated geometry
Learning Activities	Phased modelling; construction of reference geometries; comparison between schematic, intermediate, and developed models; basic parametrization exercises; review of geometry against derived documentation
Evidence / Products	BIM model at different levels of graphic development; logbook of geometric decisions; metric diagrams; comparison between scale, detail, and information
Assessment	Geometric control; suitability of the level of definition; clarity of process; capacity for review; avoidance of unnecessary over-detailing
Module: 4. Architectural graphic language and information coding	
Pedagogical Focus	Understanding graphic documentation as an intentional construction, not a simple automatic extraction from the model
Related Learning Outcomes	LO 69, LO 71, LO 77, LO 119
Pedagogical Rationale	In BIM, representation depends on hierarchies, categories, filters, families, views, and associated data. However, automatic documentation does not always communicate architecture adequately. Therefore, students must master graphic coding and know when to complement the model with 2D resources or external tools.
Main Contents	Architectural graphic language; plans, sections, elevations, and axonometries; object hierarchy; graphic filters; local representation; 2D annotation; limitations of BIM software; BIM–CAD hybridization
Learning Activities	Critical generation of plans, sections, and elevations; configuration of styles and filters; production of axonometries and hybrid representations; graphic resolution of cases where the model does not communicate effectively; exploration of oblique projections using complementary tools
Evidence / Products	Graphic sheets; catalogue of graphic codes; comparative views; corrected and annotated documentation; short report on graphic decisions
Assessment	Communicative clarity; coherent use of codes; suitability of the representation system; ability to overcome software limitations; graphic quality
Module: 5. Space, function, hierarchy, and thematic analysis	
Pedagogical Focus	Representing not only constructive elements, but also architectural space and its relationships
Related Learning Outcomes	LO 76, LO 77, LO 110
Pedagogical Rationale	BIM representation tends to reinforce the constructive reading of the building, but architecture must also be understood as a spatial, functional, symbolic, and hierarchical system. Incorporating spaces, relationships, and data allows analysis to move beyond the built object.
Main Contents	Spatial modelling; functional relationships; spatial hierarchies; thematic analysis; alphanumeric information; data-based filters; representation of contained space
Learning Activities	Creation and classification of spaces; assignment of uses, hierarchies, and attributes; functional maps; diagrams of spatial relationships; thematic visualizations by colour, category, or parameter; analysis of served/servant, public/private, and primary/secondary spaces
Evidence / Products	Enriched spatial model; functional diagrams; hierarchy maps; spatial information tables; interpretive report
Assessment	Capacity for spatial reading; correct assignment of information; coherence between data and representation; depth of thematic analysis
Module: 6. Graphic-project processes, creativity, and BIM collaboration	
Pedagogical Focus	Using the model as a live environment for thinking, intervention, coordination, and transformation

Related Learning LO 115, LO 116, LO 117, LO 68, LO 119

Outcomes

Pedagogical Rationale	The design process should not be reduced to reproducing an existing form. Students must critically intervene in the model, test alternatives, solve conflicts, and defend decisions. The collaborative dimension of BIM makes it possible to introduce coordination, review, and graphic negotiation.
Main Contents	Thinking in action; graphic-project processes; iterative design; interdisciplinary coordination; resolution of spatial conflicts; review of information, geometry, documentation, and coordination
Learning Activities	Teamwork on a shared model; clash detection; peer review; modification of spatial solutions; public defence of alternatives; record of issues and decisions
Evidence / Products	Coordinated model; conflict report; sequence of alternatives; collaborative logbook; argued presentation of decisions
Assessment	Collaborative participation; ability to solve spatial problems; project coherence; traceability of decisions; critical thinking

Module: 7. Architecture, city, territory, and nature

Pedagogical Focus	Expanding representation from the isolated building to urban and territorial scales
Related Learning Outcomes	LO 78, LO 125
Pedagogical Rationale	Architecture cannot be fully understood from the isolated building alone. Relationships with the city, territory, infrastructure, topography, landscape, and environmental systems must be introduced. BIM should open up to multiscale coordination environments and, where appropriate, to GIS-based logics.
Main Contents	Urban representation; integration of models; territorial context; BIM-GIS; cartography; long-range scales; architecture-city-nature relationships; multiscale analysis
Learning Activities	Insertion of the model into an urban context; incorporation of planimetric information; analysis of access, orientation, topography, and visual relationships; context maps; coordination of several models in a shared environment
Evidence / Products	Contextualized model; urban plan; multiscale graphic analysis; thematic maps; report on the architecture-city-territory relationship
Assessment	Multiscale understanding; accuracy of contextualization; quality of urban analysis; graphic integration of diverse information

Module: 8. Synthesis, communication, and final critical defence

Pedagogical Focus	Integrating research, modelling, representation, analysis, and project work into an argued presentation
Related Learning Outcomes	LO 68, LO 69, LO 70, LO 71, LO 76, LO 77, LO 78, LO 106, LO 110, LO 115, LO 116, LO 117, LO 118, LO 119, LO 120, LO 121, LO 124, LO 125, LO 129
Pedagogical Rationale	The end of the course must demonstrate that students not only master tools, but also understand how the graphic-informational model serves to research, think, represent, analyse, coordinate, and communicate architecture. The oral defence allows the maturity of the process to be critically assessed.
Main Contents	Graphic synthesis; presentation of the process; critical defence; peer assessment; relationship between model, documentation, and architectural discourse
Learning Activities	Preparation of the final presentation; comprehensive review of the model; oral presentation; collective critique; self-assessment; final portfolio submission
Evidence / Products	Final BIM model; graphic documentation; spatial and urban analysis; reflective report; coordination record; oral presentation
Assessment	Overall coherence; graphic quality; critical depth; integration of scales; conceptual and technical mastery; argumentative ability

APPENDIX B: DEFINITIONS

1. Core concepts

Architectural Drawing. A disciplinary medium through which architecture is conceived, examined, represented, and communicated. It functions both as a representational product and as an instrument of design cognition.

Provenance: synthesis informed by Mark Alan Hewitt.

BDS. Building Description System. A computer-based system for storing and manipulating building information as a spatial composition of parts, incorporating graphical input, interactive editing, drawing production, and attribute-based data sorting.

*Provenance: introduced by Charles Eastman and colleagues in the 1974 research report *An Outline of the Building Description System*.*

BIM-Based Architectural Drawing Education. The integration of BIM into architectural drawing education while retaining disciplinary objectives such as spatial reasoning, geometrical control, graphic hierarchy, synthesis, and representational judgement.

BIM-Based Graphic Instruction. A pedagogical approach that employs BIM as a graphical, informational, and cognitive environment for teaching architectural representation.

Building Product Model. A formal digital representation of a building as an organised set of objects, attributes, and relationships.

Provenance: associated with the early computational building-modelling research of Charles Eastman.

Drawing-as-Model. The understanding of drawing as a relational system through which architectural form, space, and information can be organised and transformed.

Pattern of Thought. A recurrent cognitive structure through which architectural ideas are formed and developed in relation to representational practices.

Provenance: attributed to Mark Alan Hewitt's research on representational forms, modes of conception, and cognitive patterns.

Graphic Language. A system of conventions, codes, projections, hierarchies, and compositional rules through which spatial and architectural information is constructed and communicated.

Graphic Language in BIM. The representational grammar through which BIM organises and displays architectural information by means of categorised information containers.

Graphic Code. A conventional visual device, such as line weight, colour, pattern, symbol, or transparency, used to communicate an architectural property or relationship.

Graphic Meaning. The architectural significance produced through the selection, omission, organisation, and visual encoding of information.

Graphic Judgement. The capacity to determine whether a representation is appropriate, intelligible, and economical for its intended purpose.

Representational Judgement. The capacity to select and justify an appropriate system of projection, scale, abstraction, coding, and information content.

Graphic Culture. The disciplinary body of knowledge concerning the historical conventions, practices, and critical values of architectural representation.

Graphic Operation. An action performed upon a representation, including modelling, projecting, sectioning, filtering, annotating, comparing, and composing.

Graphic Economy. The deliberate restriction of graphical information to what is necessary for a representation's purpose.

Representational Coherence. Consistency among the model, its views, and its derived documents.

Hybrid Instrument of Graphic Language. A representational medium whose functions emerge through its combination with other analogue or digital techniques.

Provenance: interpretative formulation informed by Alberto Pérez-Gómez and Louise Pelletier.

2. Normative concepts derived from the ISO 19650, ISO 7817, and ISO 16739 series

AIM. Asset Information Model. The information model used to support the operation, maintenance, and management of an asset.

Alphanumerical Information. Non-geometrical information expressed through identifiers, classifications, properties, values, or textual data.

BIM. Building Information Modelling. The use of a shared digital representation of a built asset to support design, construction, operation, and decision-making throughout its life cycle.

BIM Model. A structured representation comprising geometrical information, alphanumerical information, and associated documentation, assembled to support specified information uses.

CDE. Common Data Environment. An agreed source of information used to collect, manage, and disseminate information containers through a controlled workflow.

Documentation



A discrete form of information associated with an object or information delivery but not necessarily encoded as geometry or object properties.

Geometrical Information. Information describing the shape, dimensions, location, orientation, and spatial relationships of an object.

Information Container. A named and persistent set of information retrievable from a file, system, or storage hierarchy.

Information Exchange. The controlled transfer of information between appointed parties according to specified requirements.

IFC. Industry Foundation Classes. An open, standardised data schema for representing and exchanging built-asset information.

Information Requirement. A specification of what information is required, when it is required, how it is to be produced, and for what purpose.

LOIN. Level of Information Need. A framework for specifying the extent and granularity of geometrical information, alphanumerical information, and documentation required for a defined purpose, actor, object, and delivery milestone.

Model Federation. The coordinated association of separate information models for combined review without necessarily merging their authorship structures.

PIM. Project Information Model. The information model developed during the delivery phase of an asset and used to support project design, construction, and decision-making.

Shared Model. An information model made accessible to multiple participants under agreed responsibilities, permissions, and procedures.

3. Objects, parameters, and spatial representation

Automation. The execution of representational or informational operations through predefined computational rules.

Annotation. Graphic or textual information added to a view to support identification, measurement, interpretation, or reference.

Graphic Field. The compositional space within which drawings, text, scales, and visual hierarchies are organised.

Graphic Style. A coordinated set of visual attributes controlling the appearance of represented information.

Oblique Projection. A parallel projection in which projectors intersect the projection plane obliquely.

Object Taxonomy. A classification structure through which model entities are organised into categories, types, and hierarchical relationships.

Parametric Seed Model. A partially developed parametric model provided as a structured starting point for learning or design exploration.

Provenance: associated with Müge Ülkü Meterelliyöz and Özlem Özener.

Parametric Thinking. Reasoning through variables, dependencies, constraints, and transformation rules.

Spatial Representation System. A geometrically defined method for translating three-dimensional spatial relations into graphical form.

Sectional Axonometric. An axonometric representation incorporating one or more cuts to reveal internal spatial organisation.

Template (BIM). A predefined set of rules controlling the organisation, appearance, and behaviour of views or documents.

View Dependency. The condition by which changes to the model or view configuration affect associated representations.

4. Space, form, and perception

Conceptual Massing. The development of primary volumes and spatial relationships before their detailed constructional definition.

Formal Analysis. The examination of the ordering principles and transformations that structure architectural form.

IfcSpace. An IFC entity used to represent a spatial area or volume within a built asset.

Provenance: ISO 16739-1, the ISO standard for Industry Foundation Classes.

Spatial Perception. The interpretation of position, orientation, depth, scale, and spatial relationships.

Spatial Reasoning. The cognitive capacity to understand, manipulate, and verify spatial relationships.

Spatial Vision. The capacity to mentally construct and transform three-dimensional configurations.

Stereotomic Conception. The conception of architecture through mass, excavation, continuity, and the formation of spatial voids.

Tectonic Conception. The conception of architecture through the articulation and assembly of constructive elements.

5. Interoperability and collaboration

Clash Detection. A computational process for identifying geometrical conflicts between model elements or disciplinary models.

Coordination. The management and verification of consistency among disciplinary models, systems, and documents.

Collaboration. The joint production and negotiation of knowledge through shared responsibilities, information, and decisions.

Collaborative Authorship. The joint development of a model or representation in which participants share responsibility for its coherence and meaning.

Open BIM. A collaborative approach based on open standards and interoperable information exchanges rather than dependence on a single proprietary platform.

6. BIM competence and education

BIM Competence. The integrated knowledge, skills, and attitudes required to act effectively within BIM-enabled processes.

BIM Literacy. The capacity to understand and critically employ BIM processes, information structures, standards, representations, and collaborative practices.

BIM Washing. The superficial presentation of software-based teaching or practice as BIM without substantive information management, coordination, or collaboration.

Provenance: term discussed by Mark Shelbourn and colleagues.

BIM Skill. The ability to perform a specific operation within a BIM environment.

Software Proficiency. The ability to operate a particular software application accurately and efficiently.

7. Pedagogical concepts

Active Learning. Learning through direct participation in analysis, application, discussion, or problem-solving.

Assessment Task. A task designed to produce evidence of the extent to which intended learning outcomes have been achieved.

Authentic Learning. Learning through tasks and conditions that approximate disciplinary or professional practice.

BIM-Enabled Pedagogy. An approach in which BIM supports the integration of design, construction, systems, materials, and professional knowledge.

Provenance: formulated by Ming Hu.

Cognitive Alteration. A change in how learners understand building systems and relationships through interactive parametric modelling.

Provenance: employed by Müge Ülkü Meterelliyöz and Özlem Özener.

Constructive Alignment. The deliberate alignment of intended learning outcomes, learning activities, and assessment tasks.

Provenance: attributed to John Biggs.

Constructivism. A learning theory according to which knowledge is actively constructed through experience, prior understanding, and reflection.

DMP. Drafting-Based Modelling Pedagogy. A software-centred pedagogical approach primarily oriented towards modelling and document production.

Provenance: terminology employed by Ming Hu.

Dual-Channel Framework. A pedagogical framework connecting building-system knowledge with parametric and object-oriented modelling.

Provenance: developed by Müge Ülkü Meterelliyöz and Özlem Özener.

Experiential Learning. Learning through the transformation of experience by reflection and conceptualisation.

Provenance: associated with David Kolb.

Intended Learning Outcomes. Explicit statements of what learners should know, understand, or be able to do after instruction.

Just-in-Time Instruction. Instructional support provided when a specific need emerges during a learning activity.

Learner-Centred Learning. An approach that gives learners an active role in decision-making, inquiry, and knowledge construction.

Learning Activity. A structured task through which learners develop specified knowledge or competence.

Learning by Doing. The development of knowledge through purposeful practical activity and reflection.

Mediating Artefact. A material or symbolic tool that mediates cognition, communication, and collective activity.

PjBL. Project-Based Learning. A pedagogical approach organised around the sustained development of a project or product.

PBL. Problem-Based Learning. A pedagogical approach in which learning is structured around the investigation of an open-ended problem.

Social Constructivism. A theory that understands learning as socially mediated through interaction, language, and cultural tools.

Provenance: associated with Lev Vygotsky.

Scaffolding. Temporary instructional support that enables learners to perform tasks beyond their current independent capacity.

Thinking-in-Action. The development of understanding through acting upon a situation and interpreting the consequences of that action.

8. Research and analytical methods

Curricular Mapping. The systematic alignment of learning outcomes, competencies, content, activities, and assessment across a curriculum.



Grounded Theory. An iterative qualitative methodology in which concepts and explanatory categories are developed from systematically analysed data.

Provenance: developed by Barney Glaser and Anselm Strauss.

PRISMA-ScR. A reporting framework designed to improve the transparency and completeness of scoping reviews.

Provenance: developed by Andrea Tricco and colleagues.

Scoping Review. A review method used to map the scope, characteristics, concepts, and gaps of a heterogeneous body of evidence.

Sensitising Framework. A provisional conceptual structure that guides empirical attention without imposing fixed explanatory categories.

SWOT Analysis. A strategic framework for identifying strengths, weaknesses, opportunities, and threats.

Thematic Synthesis. The systematic organisation and interpretation of evidence through recurring themes.

9. Complementary technologies and workflows

CAD. Computer-Aided Design. The use of computing systems to create and modify graphical design information.

Capture-to-Model. The broader process of capturing, interpreting, validating, and modelling information about an existing asset.

GIS. Geographic Information System. A computational system for managing, analysing, and visualising georeferenced information.

HBIM. Heritage Building Information Modelling. The application of information modelling to the documentation, interpretation, conservation, and management of heritage assets.

Hybrid Workflow (BIM). A representational process combining BIM with other analogue or digital media.

Scan-to-Model. The conversion of captured spatial data, particularly point clouds, into a structured digital model.

Virtual Mock-Up. A digital simulation used to examine spatial, visual, or constructional conditions before physical implementation.

Visual Programming. The construction of computational procedures through graphical nodes and relationships.

VR. Virtual Reality. An immersive digital environment supporting spatial observation and interaction.
