

Operationalizing XR-MOT: A Workflow for Designing Extended Reality Learning Experiences

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ABSTRACT

Extended Reality (XR) is increasingly adopted in education to support immersive and experiential learning. However, educators often lack structured guidance for designing XR learning experiences that align pedagogical objectives with technological and organizational considerations. Existing frameworks primarily describe the relationships between these elements but provide limited support for the instructional design process. This paper operationalizes the XR-MOT framework by proposing a decision-driven workflow for XR instructional design. The workflow introduces the educational role of XR as the first design decision, distinguishing between teaching using XR and teaching XR, before guiding educators through educational needs analysis, learning objective definition, pedagogical design, XR learning experience design, and Management of Technology (MOT) considerations. A History of Architecture course is used to demonstrate the applicability of the proposed workflow, illustrating how instructional decisions systematically progress from educational goals to sustainable XR implementation. The proposed workflow extends the conceptual XR-MOT framework by providing practical guidance for educators and instructional designers while promoting pedagogy-driven, sustainable XR integration in education.

Index Terms: Extended Reality, XR Education, Instructional Design, Management of Technology, Decision Workflow.

1 INTRODUCTION

Extended Reality (XR), encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has emerged as a transformative technology for education by enabling immersive, interactive, and experiential learning environments. Over the past decade, XR has been increasingly adopted across disciplines, including medicine, engineering, architecture, science education, and cultural heritage, where it supports visualization of abstract concepts, simulation of complex procedures, collaborative learning, and authentic experiential activities [17, 11]. Numerous studies have reported improvements in learner engagement, motivation, conceptual understanding, and practical skill development when XR is appropriately integrated into instructional practice [31, 23].

Despite these promising outcomes, the successful adoption of XR extends beyond selecting suitable hardware and software. Effective XR integration requires educators to make a sequence of pedagogical, technological, and organizational decisions, including defining learning objectives, selecting instructional approaches, determining appropriate XR affordances, preparing instructors, managing technological resources, and evaluating educational outcomes. Previous studies have identified several barriers to sus-

tainable XR adoption, including insufficient pedagogical guidance, limited instructor preparedness, accessibility concerns, implementation costs, and the absence of structured implementation strategies [6, 29, 26].

Most existing research either evaluates the educational effectiveness of XR applications or develops individual XR learning environments [3, 1, 28]. Consequently, instructional design often follows a technology-first perspective in which decisions regarding VR, AR, or MR platforms are made before establishing the educational purpose that the technology is expected to serve. Such an approach risks adopting XR for its technological novelty rather than its pedagogical value, leading to fragmented implementations that are difficult to scale or sustain within educational institutions.

Furthermore, existing XR instructional design literature generally treats XR-enabled education as a single category [32]. However, two fundamentally different educational contexts exist. In the first, XR functions as the instructional medium, where students learn another subject through immersive technologies, such as anatomy, engineering, or cultural heritage. In the second, XR itself constitutes the learning subject, where students acquire competencies in XR development, interaction design, spatial computing, or immersive application development. Although these two contexts employ similar technologies, they differ substantially in their educational objectives, pedagogical strategies, technological requirements, and institutional considerations. Nevertheless, this distinction is rarely made explicit during instructional design, leaving educators without guidance on how the educational role of XR should influence subsequent design decisions.

Recently, the XR-MOT (Extended Reality–Management of Technology) framework was proposed as a conceptual framework to support the sustainable integration of XR in education by systematically combining four complementary dimensions: learning theories, pedagogical approaches, XR affordances, and Management of Technology (MOT) principles [13]. The framework emphasizes that effective XR integration extends beyond selecting immersive technologies by aligning educational objectives, pedagogical foundations, technological capabilities, and organizational considerations within a unified perspective. Rather than prescribing a specific instructional methodology, XR-MOT provides a conceptual foundation that explains how these dimensions collectively contribute to the design and sustainable adoption of XR-enhanced learning experiences.

While the XR-MOT framework establishes the relationships among these components, it intentionally remains technology- and pedagogy-agnostic and does not specify how educators should systematically progress through the instructional design process. In particular, it does not define the sequence of decisions required to translate the conceptual framework into actionable instructional practice. Consequently, educators are still left with the practical challenge of determining where to begin, how to align educational goals with XR technologies, and how to progress from educational requirements to sustainable implementation.

To address this limitation, this paper operationalizes the XR-MOT framework by proposing a decision-driven instructional

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workflow for designing XR learning experiences. Unlike conventional technology-centered approaches, the proposed workflow introduces the educational role of XR as the primary design decision, distinguishing between teaching using XR and teaching XR as a subject before selecting pedagogical strategies, XR affordances, or technology management activities. Based on this initial decision, the workflow guides educators through educational needs analysis, learning objective formulation, pedagogical design, XR experience design, and MOT considerations to support sustainable implementation.

The contributions of this paper are threefold. First, it transforms the conceptual XR-MOT framework into an operational instructional design workflow. Second, it introduces the educational role of XR as the initial decision point for XR instructional design, providing a structured distinction between teaching using XR and teaching XR. Third, it presents a decision-driven process that aligns educational objectives, pedagogical theory, XR affordances, and MOT principles to support the systematic design of sustainable XR learning experiences.

2 THE EDUCATIONAL ROLE OF XR AS THE FIRST DESIGN DECISION

Instructional design is inherently a decision-making process in which educators progressively define learning objectives, instructional strategies, learning activities, assessment methods, and the technologies required to support learning. Classical instructional design models, including ADDIE model and systematic instructional design approaches, advocate beginning with educational objectives and learner needs before selecting technological solutions [8, 12, 27]. Likewise, recent research in XR education argues that immersive technologies should be integrated only after aligning learning outcomes, pedagogical strategies, learner characteristics, and technological affordances [22, 10].

Despite these recommendations, many XR educational implementations continue to adopt a technology-first perspective. Decisions regarding whether to use VR, AR, or MR, as well as hardware platforms and software environments, are often made before establishing the educational purpose that XR is expected to fulfill. Such an approach risks selecting technology because of its novelty rather than its pedagogical value, leading to fragmented learning experiences that may be difficult to scale, evaluate, or sustain within educational institutions [17, 26, 6]. Furthermore, recent reviews highlight that effective XR integration requires balancing instructional design, learner needs, accessibility, institutional readiness, and technological capabilities rather than focusing solely on immersive technologies [10, 1].

To address this limitation, we propose that the educational role of XR be the first design decision in the XR-MOT workflow. Instead of beginning with the question, “Which XR technology should be used?”, educators should first determine, “What role should XR play in the learning experience?” This decision establishes the instructional context from which subsequent pedagogical, technological, and managerial decisions naturally follow. Such an approach is consistent with MOT, which emphasizes that technology selection should be driven by organizational objectives before implementation decisions are undertaken [14, 19, 9]. Based on the intended educational role, two primary instructional contexts are identified.

2.1 XR as a Learning Medium (Teaching Using XR)

In the first context, XR functions as an instructional medium through which learners acquire knowledge or skills belonging to another academic discipline. Here, XR, for instance, supports visualization, simulation, interaction, collaboration, and experiential learning without becoming the primary learning objective itself. Typical applications include medical simulation, engineering education, architectural visualization, cultural heritage exploration,

and science laboratories, where immersive environments provide authentic experiences that would otherwise be expensive, inaccessible, or hazardous to reproduce in conventional classrooms [2].

Since learners are not expected to acquire competencies in XR technologies themselves, instructional design should prioritize disciplinary learning outcomes. Learning theories and pedagogical approaches therefore guide the selection of XR affordances, while technology remains a supporting component of the instructional process. Consequently, XR should be adopted only when it provides demonstrable educational advantages over conventional teaching approaches, including enhanced spatial understanding, authentic experiential learning, or collaborative problem solving [23, 20, 22].

2.2 XR as a Learning Subject (Teaching XR)

The second educational context differs fundamentally. Here, XR itself becomes the learning subject, and students are expected to develop competencies related to immersive technologies. These competencies may include XR interaction design, immersive application development, spatial computing, human-computer interaction, rendering techniques, tracking systems, networking, and immersive software engineering.

Unlike the previous context, technology selection is no longer merely supportive but becomes part of the intended learning outcomes. Consequently, instructional design emphasizes practical laboratories, software development environments, iterative prototyping, collaborative design activities, and project-based learning to enable students to acquire professional XR competencies. Similar competency-based instructional approaches have been widely adopted in computing and engineering education, where authentic design projects provide opportunities to develop both technical expertise and professional skills [7, 30].

2.3 Implications for the XR-MOT Workflow

Although both educational contexts employ similar XR technologies, they differ substantially in their instructional objectives, pedagogical requirements, technology selection, and management considerations. When XR functions as a learning medium, pedagogical objectives determine the selection of XR technologies. Conversely, when XR itself constitutes the learning subject, technology selection forms part of the intended learning outcomes and directly influences curriculum design.

Figure 1 illustrates the proposed classification of the educational role of XR as the initial decision (referred later as Stage 0) in the instructional design process. Rather than selecting XR technologies at the outset, educators first determine whether XR serves as a learning medium to support another discipline or as the learning subject itself. This initial distinction establishes two complementary instructional pathways that subsequently converge into the common XR-MOT decision workflow. To further clarify the implications of this decision, Table 1 compares the two educational roles across key instructional design dimensions, including learning objectives, pedagogical priorities, technology selection, assessment, and management considerations. Although both contexts employ similar XR technologies, they require different instructional strategies and design priorities. This comparison highlights why identifying the educational role of XR is essential before proceeding with the subsequent stages of the proposed workflow.

3 THE XR-MOT DECISION WORKFLOW

Building upon the educational role of XR established in the previous section, the proposed XR-MOT workflow operationalizes the conceptual framework into a structured decision-support process for instructional design. Rather than prescribing a fixed implementation methodology, the workflow provides a sequence of interconnected design decisions that guide educators from identifying the

Table 1: Comparison of the two primary educational roles of XR and their implications for instructional design.

Instructional Design	XR as a Learning Medium	XR as a Learning Subject
Primary objective	Support learning in another discipline	Develop competencies in XR technologies
Role of XR	Instructional medium	Learning subject
Typical disciplines	Medicine, engineering, architecture, science, cultural heritage	Computer science, HCI, game development, spatial computing
Learning outcomes	Domain knowledge, conceptual understanding, practical skills	XR programming, interaction design, application development, technical competence
Primary design focus	Pedagogical effectiveness	Technical competency development
Technology selection	Supports pedagogical objectives	Constitutes part of the intended learning outcomes
Typical learning theories	Situated learning, experiential learning, constructivism	Experiential learning, constructivism
Typical pedagogical approaches	Inquiry-based learning, collaborative learning, problem-based learning	Project-based learning, laboratory work, studio-based learning
Typical XR activities	Immersive simulations, virtual field trips, collaborative exploration	XR application development, interaction prototyping, usability evaluation
Assessment focus	Knowledge acquisition, problem solving, learner engagement	Technical implementation, software artifacts, interaction quality
Management priorities	Accessibility, instructor readiness, deployment, learner support	Hardware infrastructure, development platforms, laboratory resources

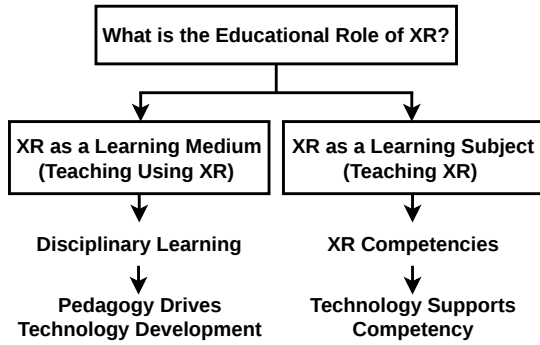


Figure 1: Educational roles of XR in the proposed XR-MOT decision workflow.

educational context to planning the sustainable implementation of XR-based learning experiences. Unlike conventional XR design approaches that frequently begin with technology selection, the proposed workflow adopts a pedagogy-driven perspective in which educational objectives determine subsequent technological and managerial decisions. This approach is consistent with established instructional design methodologies, in which learner needs, instructional objectives, and pedagogical strategies precede the selection of media and technology. Similarly, from an MOT perspective, technology should be selected and implemented only after organizational objectives and stakeholder requirements have been clearly identified.

Figure 2 illustrates the proposed XR-MOT decision workflow. Each stage addresses a specific instructional design question, produces a tangible design outcome, and provides the necessary input for the subsequent stage. Consequently, the workflow supports a systematic progression from educational requirements to sustainable implementation while maintaining alignment between pedagogy, XR affordances, and technology management principles. The workflow consists of six sequential design stages as follows:

3.1 Stage 1: Educational Need

Following the identification of the educational role of XR, educators first determine whether XR is pedagogically justified for the intended learning experience. Rather than assuming that immersive technologies always improve learning, this stage evaluates the educational value of XR by considering factors such as visualization of abstract concepts, simulation of hazardous or inaccessible environments, experiential learning, collaboration, spatial understanding, and learner engagement. If conventional instructional approaches adequately satisfy these requirements, XR may not provide additional educational value [18, 15]. This stage, therefore, establishes the pedagogical justification for adopting XR before technological decisions are made.

3.2 Stage 2: Learning Objectives

Once the educational need has been established, the desired learning outcomes are defined. Depending on the educational role identified in Section 2 (Stage 0), these outcomes may represent disciplinary knowledge and practical skills (teaching using XR) or technical competencies related to immersive technologies (teaching XR). Clearly defining learning objectives provides the foundation for selecting appropriate pedagogical strategies and determining how XR can best support the intended learning experience.

3.3 Stage 3: Pedagogical Design

Learning objectives are subsequently translated into instructional strategies through appropriate learning theories and pedagogical approaches. Constructivism [4], experiential learning [20], situated learning [21], and social learning [5] provide theoretical foundations for designing immersive learning environments, while pedagogical approaches such as project-based learning [30], inquiry-based learning [24], and scaffolding determine how learners engage with XR experiences [16]. At this stage, instructional decisions remain independent of specific XR technologies, ensuring that pedagogy continues to guide technology rather than the reverse.

3.4 Stage 4: XR Learning Experience Design

Having established the pedagogical strategy, educators design the XR learning experience by selecting the XR affordances that best

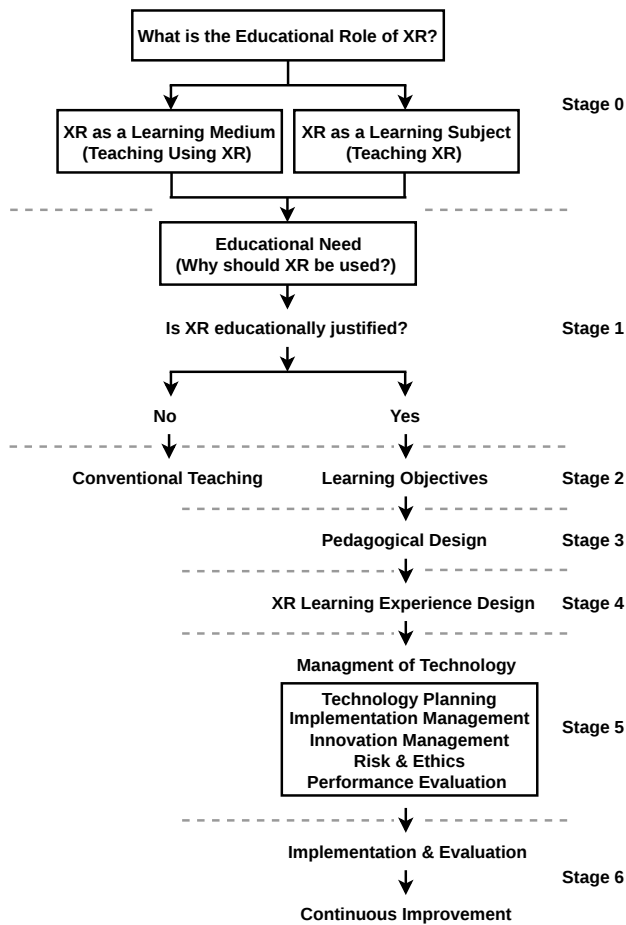


Figure 2: The proposed XR-MOT decision workflow showing the sequence of educational, pedagogical, technological, and management decisions.

support the intended instructional activities. This stage includes decisions regarding the use of VR, AR, or MR technologies, interaction techniques, immersion levels, collaborative features, visualization methods, hardware platforms, and software environments. Rather than being driven by technological novelty, these decisions are directly informed by the pedagogical requirements identified in the previous stages.

3.5 Stage 5: Management of Technology (MOT)

The final design stage applies the MOT principles introduced in the original XR-MOT framework. These include technology planning, implementation management, innovation management, risk and ethics assessment, and performance evaluation [13]. Integrating these considerations within the instructional design process enables educational institutions to address infrastructure requirements, instructor preparedness, accessibility, learner safety, long-term sustainability, and continuous improvement as part of a unified implementation strategy rather than as isolated administrative activities [19].

3.6 Stage 6: Iterative Evaluation and Continuous Improvement

Although the workflow is presented sequentially, it is inherently iterative. Results obtained during implementation and evaluation

may require revisiting earlier design decisions, including learning objectives, pedagogical strategies, or XR experience design. Continuous evaluation therefore supports the refinement of both instructional practices and technological deployment, ensuring that XR integration remains aligned with evolving educational objectives, learner needs, and institutional priorities. This iterative perspective reflects both contemporary instructional design methodologies and the continuous improvement principles advocated within MOT principles.

4 APPLYING THE XR-MOT DECISION WORKFLOW: AN EXAMPLE FROM HISTORY OF ARCHITECTURE COURSE

To illustrate the applicability of the proposed XR-MOT decision workflow, this section presents a design example for the History of Architecture course (ART140) for undergraduate students. The example demonstrates how the workflow can support instructional design decisions in a real course context; it does not claim to provide empirical validation of learning effectiveness. Within ART140, students are expected to understand historical architecture not merely as a chronological succession of visual styles, but as spatial, cultural, structural, environmental, temporal, and experiential systems.

In conventional classroom settings, students often study historical buildings through lectures, plans, photographs, chronological timelines, and textual descriptions. Although these resources remain essential, they may limit students' ability to perceive scale, spatial sequence, circulation, enclosure, light, structural logic, materiality, and the embodied experience of moving through historical architecture. This creates a pedagogical need for a learning environment that enables students to examine architectural heritage more spatially, analytically, and evidenceably than static representations alone can support.

Following the XR-MOT workflow, the first design decision concerns the educational role of XR (as defined in Stage 0). In ART140, XR is not treated as the learning subject. Students are not being trained to develop XR applications, program immersive environments, or design extended reality systems. Instead, XR functions as a learning medium that supports disciplinary learning in architectural history and heritage education. Accordingly, the design follows the "teaching using XR" pathway of the workflow, where pedagogy determines the role of technology rather than technology determining the pedagogy.

The first stage evaluates whether XR is educationally justified. In this course context, XR is justified when the selected historical buildings or sites are geographically distant, physically inaccessible, partially ruined, difficult to visit repeatedly, or insufficiently understood through photographs and drawings alone. XR can allow students to virtually access reconstructed or represented historical environments, observe architectural elements from multiple viewpoints, compare spatial relationships, and experience movement sequences that are difficult to communicate through conventional course materials. The value of XR therefore lies in its ability to make the spatial and experiential dimensions of architectural history more visible, discussable, and assessable.

Based on this educational need, the learning objectives remain disciplinary rather than technical. Students are expected to identify key architectural elements, explain spatial organization, interpret the relationship between form, function, structure, climate, materiality, and cultural meaning, and support their interpretations with visual and spatial evidence collected during the immersive activity. The objective is not simply to increase engagement through immersion, but to strengthen architectural reasoning by helping students move from visual recognition to evidence-based interpretation.

The pedagogical design is then shaped by situated learning, experiential learning, inquiry-based learning, and guided reflection. Students are placed within an authentic or reconstructed spatial context and asked to investigate architecture through structured mis-

sions. For example, they may be asked to trace an entry sequence, identify spatial hierarchy, compare zones of public and private use, observe the role of light in shaping perception, locate structural systems, or explain how cultural and environmental values are reflected in architectural form. Collaborative discussion and reflective tasks further support the transition from observation to interpretation by requiring students to justify what they noticed and why it matters architecturally.

Only after these pedagogical requirements are defined does the workflow move to XR learning experience design. A virtual environment can be used to allow students to explore a selected historical monument or heritage site individually or collaboratively. The environment may include navigable spatial zones, observation points, embedded inquiry prompts, digital artifacts, annotated viewpoints, screenshots, and reflection tasks. Students interact with the environment not as passive viewers, but as investigators collecting spatial evidence to support architectural analysis. In this sense, the XR experience becomes an evidence-generating learning setting rather than a technological demonstration.

The MOT stage (Stage 5) addresses the practical and institutional requirements needed for sustainable implementation. These include selecting an accessible XR platform, ensuring that students can participate through available devices, preparing the instructor to facilitate the activity, orienting students before entering the environment, managing technical support, addressing learner comfort and accessibility, and aligning assessment with course learning outcomes. Assessment may include evidence cards, annotated screenshots, short analytical reflections, group presentations, peer discussion, or rubric-based evaluation of spatial understanding and architectural interpretation.

Finally, the workflow requires iterative evaluation and continuous improvement (Stage 6). After implementation, the instructor can review student reflections, common misconceptions, quality of evidence, navigation difficulties, and the extent to which students connect spatial observations to historical and cultural interpretation. These findings can inform revisions to the XR environment, inquiry prompts, assessment rubric, or preparatory classroom activities. Through this iterative cycle, XR integration becomes progressively aligned with the pedagogical goals of ART140 and the broader institutional objective of sustainable technology-enhanced learning.

This example demonstrates how the XR-MOT decision workflow can guide the design of an architectural history learning experience without beginning from the technology itself. The process begins with the educational role of XR, establishes the pedagogical justification, defines learning objectives, selects suitable learning strategies, and only then determines the XR experience and technology management requirements. In ART140, XR therefore serves as a purposeful educational medium to make architectural history more spatial, experiential, and evidence-based. Table 2 summarizes the application of the proposed XR-MOT decision workflow to the History of Architecture course.

5 DISCUSSION

The proposed XR-MOT decision workflow extends existing conceptual frameworks by providing structured guidance for instructional design rather than focusing solely on the relationships between pedagogical theories, XR affordances, and technology management principles. Its primary contribution is the introduction of the educational role of XR as the first instructional design decision, enabling educators to distinguish between two fundamentally different educational contexts: teaching using XR and teaching XR. This distinction influences every subsequent design decision, from defining learning objectives to selecting pedagogical approaches and planning technological implementation.

Unlike technology-driven XR development, the proposed work-

flow adopts a pedagogy-driven perspective in which immersive technologies are selected only after establishing their educational purpose. Consequently, technology becomes an enabler of learning rather than the starting point of instructional design. This approach is consistent with both instructional design theory and Management of Technology principles, ensuring that educational objectives, learner needs, and institutional considerations remain central throughout the design process.

From an institutional perspective, the workflow also provides practical value beyond individual course design. By explicitly incorporating technology planning, implementation management, innovation, risk assessment, and performance evaluation, the workflow supports educational institutions in developing sustainable strategies for XR adoption. Rather than viewing XR implementation as an isolated technological initiative, the proposed approach positions XR as part of a broader educational and organizational ecosystem.

The proposed workflow remains conceptual and has not yet been empirically validated. Furthermore, although the workflow is designed to be sufficiently general for different educational contexts, specific disciplines may require additional domain-specific design considerations. Future work will therefore focus on expert validation through Delphi studies [25], pilot classroom implementations across multiple disciplines, and the development of practical decision-support tools that further operationalize the proposed workflow.

6 CONCLUSION

This paper operationalized the previously proposed XR-MOT framework by introducing a decision-driven instructional workflow for designing XR learning experiences. The workflow transforms conceptual relationships between XR affordances, learning theories, pedagogical approaches, and MOT principles into a structured sequence of instructional design decisions that can guide educators throughout the development of XR-based learning experiences.

The principal contribution of this work is the introduction of the educational role of XR as the first instructional design decision. By explicitly distinguishing between teaching using XR and teaching XR, the proposed workflow establishes a pedagogically grounded foundation from which subsequent educational, technological, and managerial decisions naturally emerge. This decision-driven perspective encourages educators to justify the use of XR based on educational value rather than technological availability.

Although the proposed workflow is conceptual, it provides a practical foundation for systematic and sustainable XR integration across diverse educational contexts. Future work will focus on empirical validation through expert review, classroom deployment, and the development of software-supported decision tools that assist educators in applying the XR-MOT workflow during instructional design.

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Table 2: Applying the proposed XR-MOT decision workflow to the History of Architecture course (ART140).

Stage	Workflow	Decision in ART140 Course
Stage 0	Educational Role	Teaching using XR; XR serves as a learning medium for architectural history and heritage education.
Stage 1	Educational Need	Students need to examine historical architecture spatially, particularly when sites are distant, inaccessible, partially ruined, difficult to revisit, or insufficiently understood through static representations.
Stage 2	Learning Objectives	Identify architectural elements; explain spatial organization; interpret relationships among form, function, structure, climate, materiality, and cultural meaning; and support interpretations using visual and spatial evidence.
Stage 3	Pedagogical Design	Situated learning, experiential learning, inquiry-based learning, structured missions, guided observation, collaborative discussion, and reflective analysis.
Stage 4	XR Learning Experience Design	Virtual exploration of a selected historical monument or heritage site with navigable zones, observation points, embedded prompts, digital artifacts, annotated viewpoints, screenshots, and reflection tasks.
Stage 5	Management of Technology	Accessible platform selection, instructor preparation, student orientation, device availability, technical support, learner comfort, accessibility considerations, and alignment of assessment with course learning outcomes.
Stage 6	Iterative Evaluation	Review student reflections, misconceptions, evidence quality, navigation difficulties, and the relationship between spatial observation and historical-cultural interpretation to continuously refine the XR activity.

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