Systematization of Scientific Production of Extended Reality in Teaching and Design Process in Architecture and Urbanism

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Abstract. Extended Reality (XR) technologies have the potential to help and improve the teaching and design process in Architecture and Urbanism, as they offer different ways of perceiving and representing space and various functionalities. Therefore, it is important to systematize scientific production in this area. This research aims to identify and analyze the main applications of XR in teaching and in the design process in Architecture and Urbanism, as well as its benefits and limitations. A systematic literature review of publications on CumInCAD and SBTIC, from 2015 to 2022, was carried out. The results show the growing emphasis of XR as a medium that offers benefits both for teaching and design practice. However, there are still limitations to be overcome to make XR more inclusive. As a contribution, a greater understanding of how XR has been applied in teaching is provided along with a reflection on its impact on the means of representation in the design process.

Keywords: Virtual reality, Augmented reality, Extended reality, Project Teaching, Architectural Project.

1 Introduction

Extended Reality (XR) is a concept that encompasses immersive technologies, such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). VR is an interface that offers users an immersive and multisensory experience within a digitally created synthetic environment. On the other hand, AR brings the virtual sphere into the physical environment through digital projections, merging real and virtual objects, for example. AR shares several characteristics with MR, where the latter not only bridges the real world and the virtual world but also enables interactivity. This immersion induces individuals to experience an inviting sensation of being in a complex and structured space and provides illusory stimuli, primarily targeting vision (Grau, 2007). Consequently, the utilization of this technology offers various potentials, particularly in education, as it allows for the simulation of desired environments and facilitates active teaching.

In the context of design education in architecture and urbanism, this technology proves beneficial as it enables a spatial sensory evaluation of projects and enhances the comprehension of the impacts of modifications made in the environment (Miyake et al., 2017). Furthermore, it can seamlessly integrate geometric components and information, fostering a positive symbiosis (Sauda, 2022).

In this manner, the integration of XR into the fields of architecture and urbanism is ushering in a profound transformation in the way these disciplines discuss, conceive, and interact with constructed spaces. The capability to create immersive and interactive virtual environments is fostering opportunities for stimulating creativity and professional development (Krakhofer & Kaftan, 2015; J. Wang et al., 2014, as cited by Ashour & Yan, 2020). Based on this foundation, this article presents the outcomes of a systematic literature review within the field, with the objective of identifying didactic experiences employing XR technology in design education, as well as exploring the advantages and limitations of this resource.

2 Methodology

2.1 Selection Method

As a methodological approach, we opted to conduct a systematic literature review (SLR) in the field, analyzing publications in CumInCAD and SBTIC from 2015 to 2022. The search was carried out using both combined and individual keywords.

In CumInCAD, we employed combinations of two keywords to refine the search, including "virtual reality" and "augmented reality," along with terms such as BIM, architecture, modeling, design, and teaching. For SBTIC, the selected keywords were "realidade virtual" (virtual reality) and "realidade aumentada" (augmented reality).

The data inclusion criteria were: (a) availability of works within the CumInCAD and SBTIC platforms, (b) inclusion of the mentioned keywords, (c) a publication date falling within the range of 2015 to 2022, (d) focus on didactic experiences and analysis involving the use of extended reality in Architecture and Urbanism, and related fields, and (e) reporting the advantages of using this tool for teaching purposes.

After the first stage, works were selected based on the examination of their respective abstracts (stage 2), with adherence to the previously mentioned criteria, with particular emphasis on item (d). In step 3, the articles were read in full, being analyzed and selected according to all the inclusion criteria. As a result, 18 articles were selected for further analysis.

2.2 Analysis Method

For the classification of articles selected for this study, we adopted the identification of relevant parameters based on the interaction with the building model in VR or AR, focusing on educational aspects as presented in each article. Interactions with the model were classified into two distinct formats: visualization or modeling, each encompassing subcategories. Under visualization, we further divided it into "rotational visualization," which pertains to learning through visualizing and geometrically rotating the model, and "informational visualization," which enables the display of supplementary information facilitating a targeted understanding of the studied object. Regarding the subdivision of modeling, we analyzed articles based on the creation or modification of objects within the immersive model: the first allows the creation of new objects in space, while the “editing of objects" allows changing the location of predefined objects within the model, both emphasizing active learning. Following this categorization process, we documented the types of software and devices employed in didactic experiences described in the articles, providing a summary of the activities conducted in each one. Additionally, diagrams were utilized to concisely outline the advantages and limitations associated with the utilization of VR and AR, drawing from the insights gathered through our readings (see Figure 1).

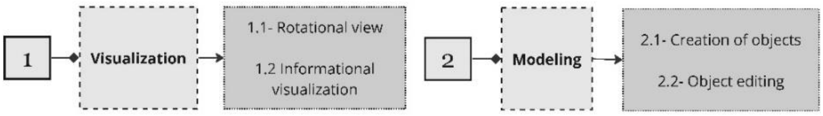

Figure 1. Types of interaction with the XR model focusing on learning. Source: Adapted from Silva & Groetelaars, 2021

3 Results and Discussion

This SLR aimed to investigate the various applications of XR technology in the teaching and design process of Architecture and Urbanism. In total, we analyzed 18 didactic experiences that utilized AR or VR formats to enhance learning, facilitating the systematic summarization of pertinent information, as presented in Tables 1, 2, 3, and 4. It was observed that out of the 18 projects, 12 solely allowed for visual interaction with the model, without permitting modifications during the process. An analysis of the software and devices used revealed frequent repetitions, indicating a limited variety of software with interoperability within the XR model. Regarding the reported experiences, we noted a substantial diversity and adaptability in their applications, both in AR and VR formats. In the VR environment, the predominant focus was on spatial perception of objects and project design. In the AR environment, there was a prevalence of informational visualization of objects and the assembly of complex objects, aided by image overlay.

Table 1. Systematization of information about software and equipment in the use of VR among the selected articles. Source: Authors

References	**Modeling programs**	**Transition programs**	**Used devices**
Agirachman & Shinozaki, 2021	Virtual Reality Design Reviewer (VRDR) (own study development)	Unity	Desktop, Oculus Ques
Anifowose et al., 2022	Revit,SketchUp, Substance Painter,SketchUV	Unity, Steam & Bolt	Desktop,VR headset
Liapi & Liosi, 2021	Rhinoceros 3D, Autodesk 3DS MAX	Unity	Desktop, Oculus Quest
Lin et al., 2021	Rhinoceros 3D, SketchUp, Maya	Unity, VR-Aided Design, Steam & Bolt	HTC Vive VR, desktop
Nguyen et al., 2020	Not reported	Not reported	HTC Vive VR

Santiago et al., 2021	Revit, ArchCad,SketchUp	Enscape, InsiteVR, Twinmotion, IrisVR (Prospect)	Desktop, Oculus Rift, HTC Vive
Sauda, 2022	Rhino3D	Unity	Smartphone,desktop, Microsoft Hololens
Schneider et al., 2018	Revit, VR-Studies,3D Studio Max	Game Engine Unreal, VREVAL (own study development), Dynamo	desktop, Oculus Quest, HTC Vive Pro

Table 2. Systematization of relevant information on the use of VR among the selected articles. Source: Authors

References	Interaction with the model	Didactic experience of the study
Agirachman & Shinozaki, 2021	(1.1) (1.2)	Developed a system for students to use virtual reality to evaluate their design projects against accessibility standards for wheelchair users. In addition, it automatically records points in non-compliant rooms, facilitating later analysis.
Anifowose et al., 2022	(1.1) (2.1) (2.2)	VR prototypes for wall mounting and placement, using SwiftWall as a case study
Liapi & Liosi, 2021	(1.1) (1.2)	It demonstrates the conception of a museum using principles of shape grammar, leading to the development of spatial systems that are repeated at different scales. Using virtual reality, it was possible to create a continuous space experience, which expands in an organized way as new exhibitions are incorporated.
Lin et al., 2021	(1.1) (1.2) (2.1) (2.2)	It presents an approach that allows the creation of architectural models in virtual reality, expanding interaction during the architectural design process. The user can communicate with the designer and offer suggestions on the design.
Nguyen et al., 2020	(1.1)	It presents and compares two experimental approaches to analyzing architecture: the creation of virtual and physical prototypes.
Santiago et al., 2021	(1.1)	Study highlights and qualitatively evaluates programs used in VR, classifying, and listing their positive and negative points.
Sauda, 2022	(1.1) (1.2) (2.2)	Using VR in a project at the Mount Zion Archaeological Park, Jerusalem, to enable design solutions and a better understanding of the available information, allowing the choice of routes and the setting of integrative architectural spaces.

Schneider et al., 2018	(1.1) (1.2)	Conducted an activity where students needed to develop the interior of a building from a human-centered perspective. The process was divided into design stages, and they used the VREVAL modules to conduct the studies, analyze the spaces and obtain information to redesign the building more appropriately to the users' needs.

Table 3. Systematization of information about programs and equipment in the use of AR among the selected articles. Source: Authors

References	Modeling programs	Transition programs	Used devices
Ashour & Yan, 2020	GPS, IMU, system LANDMARK, Autodesk Revit, FBX format, 3ds Max	Unity, ARCore, ARKit	Desktop, Sensor Kinect V2, range sensor (LiDAR), iPhone, HoloLens
Costa et al., 2017	ARch4models (own study development),	ARch4models, Kinect Fusion	desktop, tablet, Microsoft Kinect
Dezen-Kempter et al., 2020	Revit, Dynamo,3ds Max	Unity,Vuforia	laser scanning (TSL), Unmanned Aerial Vehicle (UAV), smartphone, desktop
Hansen & Kjems, 2019	Bentley MicroStation, Autocad ,3DS MAX	Unity, ARKit	Ipad and desktop
Lharchi et al., 2020	Rhinoceros 3D	Unity, Datagram Protocol Autodesk Forge	Desktop, HoloLens
Miyake et al., 2017	Revit, 3ds MAX	Unity, Game Engine	android -tablet or smartphone, sensor GPS
Nanasca & Beebe, 2022	Mad Mapper 3.7.4, Touch Designer, Rhinoceros 3D /Grasshopper	Unity, Vuforia, Fologram	Desktop, projetor Lightform LF2 was connected to a robotic arm ABB IRB1600, HoloLens, iPhone
Qian, 2019	Rhinoceros 3D /Grasshopper	Unity	Kinect, projector, desktop, Microsoft HoloLens
Weissenböck, 2021	Rhinoceros 3D /Grasshopper,Reflector3, Apower Mirror	Fologram	Marcadores “ArUco, smartphone, desktop

Zancaneli et al., 2019	Revit	Unity	Desktop, smartphone with android platform

Table 04. Systematization of relevant information on the use of AR/MR among the selected articles. Source: Authors

References	**Interaction with the model**	**Didactic experience of the study**
Ashour & Yan, 2020	(1.2)	Prototype to solve issues related to recording and monitoring models in constantly changing environments, employing tracking and motion sensors
Costa et al., 2017	(1.1) (1.2)	Created and analyzed an augmented reality (AR) application capable of augmenting scale models with real-time design information, enabling the archiving of this information.
Dezen-Kempter et al., 2020	(1.1) (1.2)	It aimed to implement the visualization in augmented reality of two masterpieces of Modern Architecture, with the objective of disseminating historical content in an innovative and immersive way in completely synthetic environments.
Hansen & Kjems, 2019	(1.2)	Developed and evaluated operational prototypes that leverage ARKit's tracking capabilities to test their effectiveness in outdoor environments.
Lharchi et al., 2020	(1.1) (1.2) (2.1)	Integrative approach to enable inexperienced users to assemble complex structures without prior training, with image overlay.
Miyake et al., 2017	(1.1)	Developed an augmented reality system without the need for external markers, using visual SLAM, with the aim of facilitating the planning and design of buildings in an intuitive and realistic way.
Nanasca & Beebe, 2022	(1.1) (1.2)	Demonstrate different applications for mapping Dynamic Projection onto simple objects, adding coverage and classifications to their layers.
Qian, 2019	(1.2) (1.2)	The use of devices to guide the creation of physical objects, in real time, using the overlay of these elements.

Weissenböck, 2021	(1.1) (2.2)	It presents a remote teaching class that performs a task in which students use AR to design a personalized intervention for their own domestic space through personalized paper markers that generate a tracking code helping to locate the created model
Zancaneli et al., 2019	(1.1) (2.2)	Prototype to aid in the detection of structural conflicts in projects with model visualization in AR.

Additionally, during the analysis of the articles, numerous benefits associated with the utilization of AR and VR were identified, as presented in Figures 2 and 3. These benefits encompassed both pedagogical advantages and considerations regarding the equipment employed in this technology. In educational applications, these experiences proved to be highly effective in enhancing learning, particularly in the context of the design process. However, several limitations were also noted, as illustrated in Figure 4. The most frequently cited limitations included a lack of programming knowledge among architecture students and limited interoperability with certain software programs. Such constraints either restricted or posed challenges to fully harnessing the potential offered by XR technology in teaching.

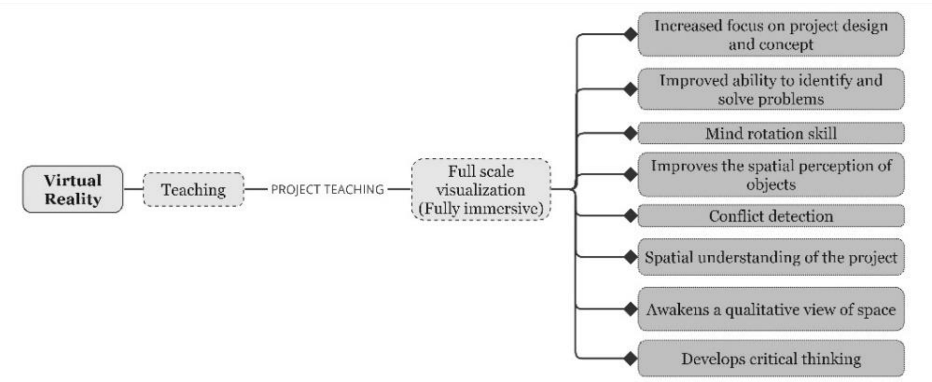

Figure 2. Benefits found in articles for the use of Augmented/Mixed Reality. Source: Authors

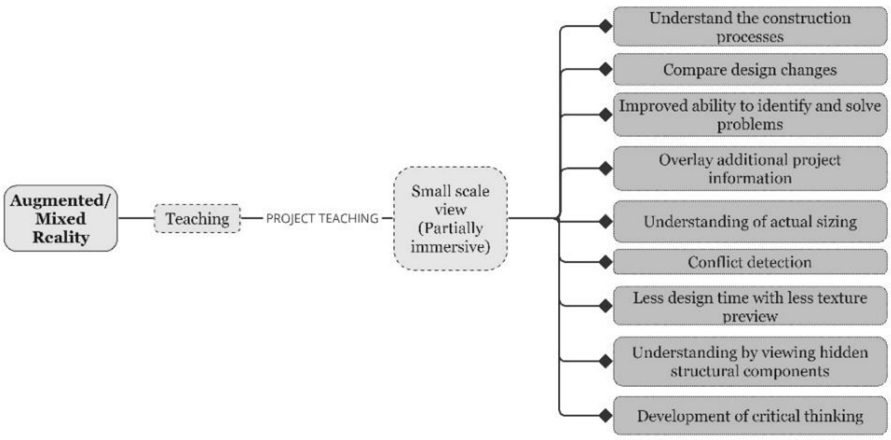

Figure 3. Benefits found in selected articles for the use of Virtual Reality. Source: Authors

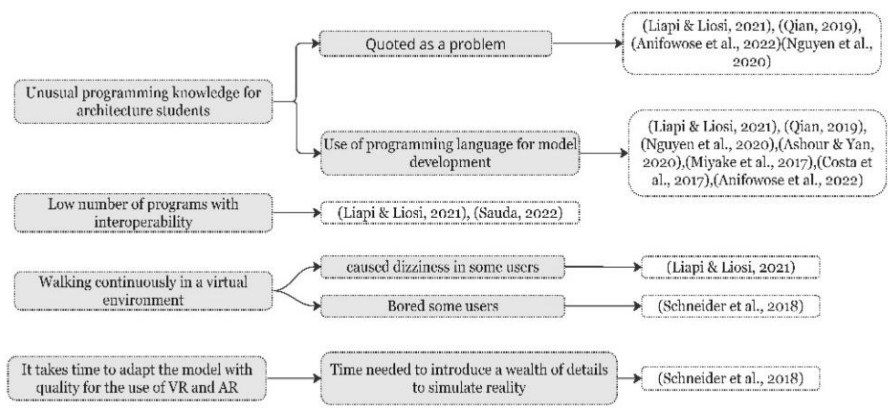

Figure 4. Limitations found in the articles for the use of Augmented/Mixed and Virtual Reality. Source: Authors

From the results of the SLR of the selected literature, it is evident that XR technology offers numerous applications in the teaching and design processes of Architecture and Urbanism. The analysis of 18 didactic experiences employing AR or VR formats revealed distinct approaches within each immersive environment.

In VR, a predominant emphasis was placed on enhancing spatial perception of objects. The immersive nature of this environment enables detailed visualization from various perspectives, facilitating critical and qualitative spatial analysis. This perceptual capacity is instrumental in making informed design decisions and can serve as a valuable tool for enhancing learning in Architecture and Urbanism projects. Conversely, AR was characterized by a more frequent utilization of overlaid information on the base project. This approach allows for the presentation of information beyond the geometric sphere, encompassing structural systems, conflicting elements, measurements, and general project data. This informational perspective delivers objective insights about the model, thereby rendering learning more didactic and targeted. Additionally, AR proved to be a valuable tool for assembling complex structures, offering a safe and controlled means of executing design tasks.

Despite the evident benefits of these applications, the review also unveiled certain limitations and challenges. One key point of concern pertains to the predominance of visual interaction with the model in the studies analyzed. Few articles explored the modeling functionality within the XR environment, signifying that there is ample room for further development and utilization of this feature. Another identified limitation was the scarcity of programs and platforms facilitating the seamless transition from traditional 3D models to immersive environments. This limited interoperability restricts users' options and necessitates specific programming knowledge for real-time modifications. A potential solution to these limitations involved the creation of specialized applications and programs, but this approach still requires technical programming expertise, posing a potential barrier for some users. In the context of VR, another challenge is the discomfort caused by continuous virtual space traversal. To mitigate this issue, certain experiments incorporated the use of controls that enable users to select their destination, thereby eliminating the need for simulated long walks.

4 Conclusion

Given the diverse and adaptable nature of XR applications, this review underscores the significance of XR technology as a tool that enhances teaching and design practices within the fields of Architecture and Urbanism. The discussion surrounding the identified limitations and challenges underscores the necessity for technological advancements and initiatives aimed at making this technology more accessible and user-friendly. This would enable the effective utilization of XR's benefits across various educational and design contexts. This analysis represents a significant contribution to the field, as it offers valuable insights into how Extended Reality technologies have been employed in teaching, drawing from didactic experiences conducted in numerous universities worldwide. In future research, we aspire to delve further into different learning approaches employing XR.

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