Extended Realities and New Digital Approaches in Architecture Education: Model for Integration in the Design Process

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Abstract. Extended Reality (XR) combines Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) to create immersive environments. In architecture and urbanism, XR has the potential to transform project representation. Integrating XR and digital means requires a theoretical reflection on its impact on teaching, shifting focus from coded representations to aesthetic and qualitative aspects of design. This study aims to systematize XR integration in the Computer-Aided Architectural Drawing (CAAD) course. Employing the research-action method, immersive devices and strategies were planned, implemented, and evaluated. The proposed model facilitates XR adoption throughout the design process, utilizing BIM tools, VR headsets, and 3D printing. This research contributes to practice, promoting students' spatial representation skills and the ability to experience and design within the environment being created. And as a theoretical contribution, it examines the evolving design representation languages and the essence of teaching in the era of digital changes.

Keywords: Virtual environments, Extended Realities, Information Modeling, Design Process, Architecture Education.

1 Introduction

Contemporary society establishes an increasingly intense and complex relationship with information and communication processes, driven by the advancement of digital technologies and communication devices (Paula, 2015). This scenario results in greater accessibility and ubiquity of information, which potentially contributes to the dissemination of knowledge and democratization of information. On the other hand, this profusion of information also brings challenges that demand a critical approach to the selection, validation, and proper interpretation of available content.

In the field of architecture, Building Information Modeling (BIM) has experienced significant growth in recent years. This methodological approach uses information modeling to create detailed digital representations of buildings and infrastructure, including their physical, functional, and behavioral properties. This comprehensiveness allows for more accurate visualization, deeper analysis, and informed decision-making throughout the architectural project's life cycle (Penttila, 2006; Succar, 2009; Santos, 2012).

Furthermore, technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are emerging and being incorporated in the field of architecture and urban planning. VR provides interactive computer simulations that give users a sense of immersion in the simulation, while AR overlays interactive digital information onto the physical world, enriching the user experience. Mixed Reality represents the convergence between the physical and virtual worlds (Sherman & Craig, 2018). Together, these technologies are encompassed by the term "Extended Reality" (XR), which has been recognized as an effective tool in the educational context, enhancing the stages of the design process and improving learning outcomes in architecture courses (Hajirasouli & Banihashemi, 2022). Another technology being explored in the field of architecture and construction is Rapid Prototyping (RP). Used for producing models, mock-ups, prototypes, or construction elements in the area of research, teaching, and practice of architecture (Pupo, 2009, and Celani & Frajndlich, 2016).

Previous studies, such as those conducted by Di Serio et al. (2013), Elkoubaiti & Mrabet (2018), and Sánchez et al. (2015), emphasize that these technologies can address problems and gaps present in traditional teaching methods, establishing a new paradigm of architectural project representation, emphasizing spatial experience and aesthetic quality. Thus, it is relevant to reflect on how this context modifies the didactic structure of disciplines, shifting the focus from representations based on orthogonal projections to an approach that values spatial experience and aesthetics in the design process. Therefore, the integration of these technologies and digital media is being discussed in the new undergraduate curricula, especially in the Architecture and Urbanism course at the Universidade Federal do Ceará, aiming to facilitate the adoption of a new learning language, and developing spatial skills for project representation in the face of the constant emergence of new digital approaches.

In this context, this work aims to explore extended reality technologies and their applications in the architectural design process, creating a model for integrating these technologies that systematizes their implementation during the teaching/learning of the design process. The validation of this model was carried out in the Computer-Aided Architectural Design (CAAD) course of the Architecture and Urbanism course at the Universidade Federal do Ceará, using BIM, XR, and 3D printer prototyping.

2 Methodology

The Action Research method was employed due to the adopted approach and the exploratory nature of the study. Action Research is defined as a continuous, systematic, and empirically grounded attempt to improve practice (Tripp, 2005). This method follows the four phases of the Action Research cycle: plan, act, describe, and evaluate, in which there is a systematic oscillation between action in the practical field and investigation of that action.

This work is part of a broader master's research aimed at systematizing the use of Extended Reality (XR) technologies, associated with Building Information Modeling (BIM), in teaching architectural design process in the conception and development stages. The research is structured into three cycles of action research: Explore, Describe, and Prescribe. This article presents the results of the first cycle (Explore), whose objective is to identify functionalities, experiment applications and determine potentialities and limitations. The research was conducted in one course at the Universidade Federal do Ceará.

In the planning phase, action plans were established as a result of a workshop, aiming to integrate XR technologies into the architectural design education process during the subject. In the implementation phase (act), the action plans were put into practice in the classroom with all 26 students. It was decided not to employ control groups due to ethical and pedagogical considerations. Withholding a technology that shows promising benefits from certain students could create inequalities and potentially hinder their educational development. Subsequently, in the description phase, a prototype of the model for integrating Extended Reality technologies and their applications in architectural design teaching was structured, with the intention of being replicable in other universities. Finally, in the evaluation phase, the potentialities and constraints identified through observations of technology usage in the model were presented.

Therefore, the results presented in this article are organized into four parts: plan, act, describe, and evaluate. The Content Analysis method (Bardin, 2016) was employed to assess the effectiveness of the qualitative data collected during the XR applications in the course. This data was obtained by recording students' interactions with the equipment through video and audio recordings, which were later transcribed, categorized, and compared with the benefits of VR and AR presented by Kharvari and Kaiser (2022) and with rapid prototyping studied by Chua, Leong & Lim (2010).

In this way, a model was systematized that effectively uses XR technologies, BIM, and rapid prototyping in a course while continuing to convey the necessary programmatic content, but with the proposition of a new language.

3 Results

3.1 Plan

To plan the XR technologies integration in the architectural design education, we develop a workshop. As a result of the workshop, action plans were proposed for each subject with topics, objectives, tools, and project phases to enhance student learning.

Table 1. Action Plans for Integrating Extended Reality Technologies in Architectural Design Education.

Action Plans	1	2	3	4	5
[Specific Content or Practice]	Sculptural volumetry conception that meets the program	Architectural strategies with opaque and transparent surfaces	Thermal comfort and solar incidence and their impacts on the building	Definition of the internal layout of the building	Tactile understanding of the created design
[Theme or Discipline]	Computer-Aided Architectural Design				
[Target Audience]	Students in the third semester of Architecture and Urbanism				
[Objective]	Propose a qualitative evaluation of the proposed space as a solution	Conduct the design selection of textures and materials for the proposed facades	Develop quantitative studies for evaluating the proposed space based on data	Assess the architectural strategies and their implications for the end-user	Materialization of the final solution for tactile understanding at a scale of 1/100
[Means]	Immersive devices for visualizing in a subjective camera view (Oculus Rift S + Twinmotion + ArchiCAD)	Immersive devices for visualizing in a subjective camera view (Oculus Rift S + Twinmotion + ArchiCAD)	Algorithmic modeling software and augmented reality devices (Rhinoceros + Grasshopper + Fologram + ArchiCAD)	Immersive devices for visualizing in a subjective camera view (Oculus Quest 2 + Enscape + ArchiCAD)	Rapid prototyping devices (3D printer + Ultimaker Cura + ArchiCAD)
[Project Stage]	In the conception of volumetric forms	In the conception of the building	In the conception of the building	In the development of the building	In the materialization of the building

[Restriction]	The initial forms defined	The building modeled with floors and walls	The building modeled with its first openings	Building with internal layouts	The building fully modeled

Source: Authors

The plan was for the content of the course to be presented in a traditional manner but supplemented with immersive experiences to assist with the different needs of each project phase. To validate the model, the action plans were implemented in a 64-hour course with 26 students.

3.2 Act

The first action aimed to promote a qualitative evaluation of the space proposed by the student. It was applied was applied with 14 students. The design proposed was a formal/volumetric solution that met the functional program of a studio, with at least 2 bedrooms, while staying within the final cost limit of US$24,000. The students were introduced to Building Information Modeling using the Archicad software and utilized the Zone tool, to relate volumetrics and cost. Figure 1A shows the student engaging with VR equipment an immersive view during the early stages of a project, focusing on its concept and volume.

The second action took place after the contents of floor, wall, ceiling, and terrain were taught. In this experience, students were able to make design decisions within virtual reality by changing the textures of the building's façades. In this case, VR technologies helped in the project conception, not just for visualization, as in the previous stage. In Figure 1B, another student is seen using the same equipment as shown in Figure 1A. However, in this case, the interface displays various textured and colored spheres that students can select and incorporate into their projects within the virtual reality environment.

After this action, the students had to develop an activity in which they should enhance the building with an orientation study based on ventilation and insolation using Rhinoceros, an algorithmic modeling software, with Grasshopper, a visual programming language plugin. The results of this activity were observed in the third action in augmented reality.

In Figure 1C, a student is depicted using augmented reality on a smartphone to visualize the impact of insolation on their building. With this technology, it is possible to view the surroundings of the building, use zoom in and out, and even enter it for a more comprehensive analysis of the project from different perspectives.

The fourth experience has the aim of evaluate architectural strategies and their consequences for the end-user, allowing each student to experience and modify the layout in virtual reality, making design decisions from the user's perspective. However, a technological system that allowed such without losing the BIM connection or real-time alterations within the model had not yet been found.

Therefore, the students were organized in pairs to define the internal layout of the building, which one student immersed in virtual reality issued voice commands to the colleague, who made the changes in BIM with Archicad, that are immediately reflected in real-time through Enscape in the VR headset. The whole class could perform the activity and make design decisions immersed in virtual reality and integrated with BIM project (Figure 1D).

The final experience was the materialization involving a rapid prototyping workshop, focusing on instructing participants in preparing the BIM file for 3D printing and efficiently overseeing the printing process of the building. The students learn step by step on how to simplify the BIM model to avoid printing problems, such as very thin walls or excessive filament fillings. To optimize the process, the prints were grouped, allowing for the printing of two houses at a time (Figure 1E).

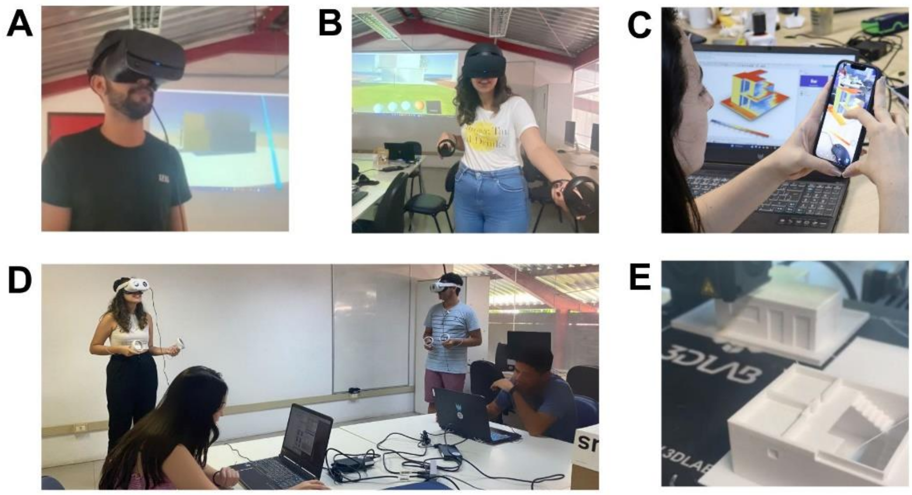

Figure 1. A. Student evaluating his initial proposals in VR; B. Student making design choices within VR; C. Student visualizing the impact of insolation on her building in AR; D. Students making design decisions and performing BIM alterations in VR; E. 3D printing machine producing the projects for a tactile comprehension exercise. Source: Authors.

This materialization experience allowed the students to experience the process of transforming their virtual projects into physical objects, providing a deeper understanding of design decisions, tactile comprehension, and the possibilities of digital materialization in architecture.

The mentioned five actions represented the execution of the action plans established at the beginning of this cycle. As emphasized by Tripp (2005), after the implementation of these actions, it is crucial to proceed with the joint description of these steps, consolidating and systematizing the process, which will enable the evaluation subsequently.

3.3 Describe

With the implementation of the five action plans, it is now possible to structure the prototype of the model for the integration of extended reality technologies and their applications in the architectural design teaching process. Figure 2 illustrates the integration process, commencing with the massing study. Even in the early stages of the design process, immersion allows for a visual exploration of the full-scale representation of these forms. Subsequently, with a more refined design, another immersion in virtual reality occurs to make decisions regarding materials and textures within the three-dimensional environment. Following this stage, the 'embodiment of schemes' begins, denoting the phase where initial concepts and schemes start to take on more tangible forms. Now, augmented reality evaluation becomes imperative, focusing on a critical analysis of openings and insolation, involving their conceptual solutions.

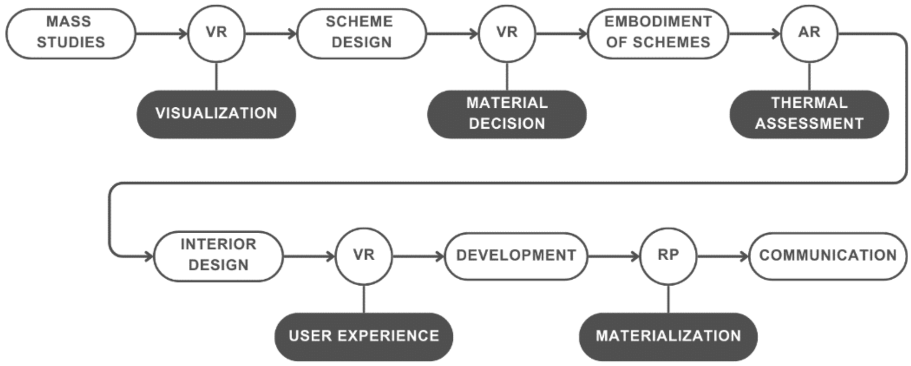

Figure 2. Prototype of the integration of extended reality technologies and their applications in the design process. Source: Authors.

Next comes the development of interior design, where entry into virtual reality enables modifications in Building Information Modeling (BIM) within the immersive experience, providing a critical user experience in the three-dimensional environment. Following this refinement, the process advances to rapid prototyping for the defined model's materialization, aiding in tactile comprehension. Subsequently, it proceeds to the communication phase, which includes the preparation of final drawings, specifications, and other necessary documents that, in the future, could be communicated byte by byte with the evolution of technology.

This forms a sequence, not necessarily ordered, of analysis, synthesis, evaluation, and decision-making at each stage (Lawson, 2005) to continue with the design process and move from the problem to the solution in each challenge.

At Table 2, we described the resources used in the presented action plans. This includes a detailed breakdown of the technological tools, software applications, and materials used to facilitate the execution of each action. Each resource was selected according to the specific objectives and requirements of the corresponding phase, ensuring a cohesive and effective implementation.

Table 2. Resources Used in Action Plans.

Action Plans	**Equipment**	**Technology**	**BIM Modeling Software**	**Complementary Software**
1	Gaming Laptop* + Oculus Rift S	VR	ArchiCAD 26	Twinmotion 2023
2				
3	Laptop** + Smartphone	AR		Rhinoceros 7 + Fologram 2020.3.21
4	Gaming Laptop* + Oculus Quest 2	VR		Enscape 3.5
5	Laptop** + 3D Printer	RP		Ultimaker Cura 5.4

*Gaming Laptop: 15.6-inch screen, Intel Core i7 processor, 512GB storage, 16GB memory, and an RTX 3070 8GB graphics card.
**Laptop: 15.6-inch screen, Intel Core i5 processor, 1000MB storage and 8GB memory.

Source: Authors.

Therefore, the research provides an initial systematization of how extended realities and digital means can be integrated into the teaching of the design process, reflecting its contribution to the education of future architects and urban planners.

3.4 Evaluate

To assess the potential contributions of the proposed model to design education, a comparative analysis was conducted. The advantages outlined in Kharvari and Kaiser's (2022) study on the integration of Virtual and Augmented Reality in Design Education were juxtaposed with the feedback obtained from students across actions 1 to 4. Employing the qualitative method of Content Analysis, all 22 benefits identified by Kharvari and Kaiser were observed and validated. In this manner, Table 03 highlights the categories of benefits identified more frequently in this research.

Moreover, the Content Analysis method was utilized to document and analyze the limitations identified during actions 1 to 4. The findings were employed to compile Table 04, with the intention of promoting progress in researches and future technologies.

Table 3. Table of Benefits and Quotes from Virtual Reality (VR) and Augmented Reality (AR) Experiences.

VR Benefits	**Example/Quote**
High Mental Rotation Ability	"The entrance to my house is on the other side, wait, I'll go over there so you can see."
Improved Design Product	"The scale is completely different, and then you start to realize if a space is sufficient for a action or not."
Enhanced Spatial Perception	"It's because with VR, I feel like I have a better sense of scale. I think that by seeing the size of a person in real life, you can really get a sense of it."
More focus on conceptual Stage of Design	"Oh, it didn't project out that much. We can move this block a bit further that way, and it'll look good too. Now, I'm not sure if I should put the entrance here or on this side... looking at it, I think here is better after all."
Improved Design Adaptation Process	"I had planned some spaces, which in my mind were going to work out great, but when I saw it in the immersive experience, it actually turned out to be very small, and there was no way to fit the stairs."
Positive Experience	"Very easy. Loved it. I thought it was amazing. Visualizing in VR is 100% different from just moving things around on the computer."
Promoting Critical Thinking	"I'm going to create an opening here that wasn't there before, I'll move the table over here because I saw in VR that it fits. After I climbed the stairs, I realized I needed to remove that part of the slab over there, otherwise a person wouldn't be able to pass through."
AR Benefits	**Example/Quote**
Enhaced Spatial Comprehension	"This side is the sunny side, hence the yellow. Over on the other side, which is blue, is where it's cooler in the house, where the bedrooms are."
Emotional Effects	"I wasn't familiar with it, and it's very interesting because I can walk more, I have more freedom with the smartphone."
Beneficial for Architectural Visualization	"You can see much better by walking around than on the computer."

Source: Authors

Table 4. Table of Restrictions and Quotes from Virtual Reality (VR) and Augmented Reality (AR) Experiences.

VR Restrictions	Example/Quote
Disorientation and dizziness	"I feel nauseous, sort of getting dizzy. Can I have a chair, please?"
Need for adaptation and initial learning	"Oh my god, I keep bumping into everything. Oops, I'm inside the wall. Ahh, how do I get out of here?"
Weight of the equipment	"And also because the goggles are heavy, I got a headache."
Equipment cable/wire	"At first, the proposal... oh my god, I'm afraid of tangling the wire here."
High processing requirements	"Everything turned black now... it appeared, but now the image is shaking."
Absence of BIM changes within VR	"This window doesn't fit anymore in this place, can I delete it here?"
AR Restrictions	**Example/Quote**
Dizziness	"Okay, now I'm dizzy. I was paying attention to the background and the house, and it confused me."
Need for initial learning	"How do I turn around here? I'm turning upside down."

Source: Authors

Action 5 implemented Chua, Leong & Lim's (2010) definition of rapid prototypes' roles in the design process, including experimentation, testing, communication, synthesis, and planning.

In the proposed model, rapid prototyping was primarily used for communicating and interacting, allowing students to have a tactile understanding of the created project, and enabling them to interact with their designs. Additionally, it was also used for synthesis and integration, bringing together all the prototyped buildings in the same physical "village" as we had done virtually in action 4. As a constraint, the printing time and the fine finishing that needs to be done at the end are aspects that can be improved with the advancement of technology.

Thus, rapid prototyping, through 3D printing with PLA filaments, proved to be a valuable tool in the process of understanding, synthesis, and evaluation of the architectural proposal developed by the students.

4 Discussion and conclusion

Based on the obtained results, it is evident that the proposed model provides significant contributions to the teaching of the architectural design process, encompassing both practice and theory. The use of extended reality technologies demonstrated concrete benefits, notably in improving spatial visualization and understanding by the students. The immersive and interactive exploration of projects stimulated students' motivation, resulting in greater engagement and interest in the architectural creation process.

The integration of virtual reality technologies, from the initial stages of conception to BIM modifications within immersive experiences, along with rapid prototyping and augmented reality visualization, not only emphasized the effectiveness of existing technologies but also demonstrated their harmonious integration with established design disciplines in architecture and urbanism courses. This systematic approach integrated education and technology, empowering students with tools to refine spatial perception, critical thinking, and user-centric motivation for the final project.

In conclusion, the integration of extended realities not only complements but also expands the educational repertoire in architecture and urbanism, promoting an approach focused on the three-dimensional spatial experience. This research represents a significant advancement towards excellence in the teaching and practice of architecture and urbanism, affirming that technological innovation can be a crucial ally in shaping future professionals.

It is essential to highlight that the limitations encountered in the application of extended reality technologies serve as focal points for future research. This includes the upcoming cycle of action research, which is also a component of the ongoing master's study and will constitute the "Description" phase.

Thus, a model for integrating XR technologies in architectural design education was proposed and tested, spanning from conception to materialization using BIM, extended reality technologies and new digital means. This model facilitates the adoption of a new learning language, fosters the development of spatial representation skills in design, and discusses representation languages in the design process over the constant emergence of new digital tools.

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