

Expanding Protocols: Teaching Construction Through Immersive Virtual Learning Environments

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ABSTRACT: Extended Realities or XR has become an increased field of interest over the last decade. It is more accessible than ever, becoming an everyday component found in our homes, businesses and even our education. While there is still a lot of skepticism around the value of this technology, curiosity by many has allowed for different disciplines to embrace it. Its novelty has instigated new questions and spawned new methods of engagement. This paper discusses the use of this technology and documents the development of a proprietary virtual reality application. The application is used as a supplemental tool for teaching an introduction to construction course. Over a three-year period it was tested with different groups students to better understand their acceptance of the technology and ask if it had a meaningful impact on knowledge building related to the subject. It concludes by presenting the qualitative analysis, providing suggestions for how it should be understood and makes projections for next steps.

KEYWORDS: extended reality, education, construction, architecture

INTRODUCTION

As architects and educators, we have a role that requires us to transmit ideas, concepts, and knowledge through different mediums. The use of visual and physical mediums as representational examples is crucial in enhancing the process of understanding. While tried and tested methods of educating are still valuable, alternative methods of knowledge building stimulated experience, simulation and emulation are possible through advancements in technology. New innovations in the tech industry are constantly reinventing workflows for how we educate, communicate, and share information. According to Mario Carpo, “what matters is not so much what digital technologies can do, but what we could not do without them.”(Carpo 2023) To illustrate this, the paper discusses the enhancements and outcomes resulting from a shift in the teaching methodology for an introduction to construction course through the implementation of extended reality (XR). Spanning five years, an introduction to construction course at the University of Michigan has developed and gradually introduced extended reality applications as a supplemental learning experience for students. Reflecting on the complexity of building layers, this course explores the use of XR technology to enable students to become proficient in interpreting, synthesizing, and making two-dimensional representations to produce three-dimensional components.

This experimental method of teaching was tested against the original pedagogical framework that relied heavily on the presentation of construction systems through precedent. The existing course presents concepts and theory through textbooks, short videos, slides, readings or drawing examples and evaluates students using exams and graphic documentation exercises. Within this learning process, the understanding of scale, physical constraints and a grasp of visuospatial reasoning and relationships can be easily misinterpreted. As a result, rather than learning the student is left frustrated leading to a reduced level of comprehension. Recognizing these as areas for improvement raised the question about how knowledge building can be enhanced via extended realities. Do the visio-spatial capabilities of XR afford students an alternative means to comprehend and synthesize content? And second, how should that alternative reality be designed from an experience learning perspective for architectural education?

1.0 PEDAGOGICAL FRAMEWORK

1.1 Arch 317/417 Construction

The course is a requirement for two groups of students of architecture: undergraduates in their third year of a four-year program and master students with a non-architecture background in their first year. The residential course presents an overview of the materials, components and systems of construction that reveal the links between the ideation, elaboration, and realization of architectural form. Lectures are given weekly and cover topics such as an introduction to construction, technical documentation, material systems including masonry, concrete, wood, steel and glass, and their relationship to building elements including floors, roofs, walls, columns, and apertures as well as a brief overview of opportunities for integration towards environmental sensitivity and building performance. To complement the in-depth explanation of the material, lectures also take a detailed look at case studies that exemplify those construction systems. Parallel to the lectures, the lab portion of this course works through a series of exercises that take the subject matter through drawing, analysis, and discussion. These lab assignments reinforce the lectures by asking the student to actively consider and engage in the acts of making as they relate to the role of architectural construction in a historical and theoretical context and locate construction practices within the realm of integration and innovation. Lab exercises as well as weekly interactive challenges require students to demonstrate their

understanding of construction practices and their application. Overall, the goal of the course, as structured through lectures, labs and quizzes, is to provide the knowledge, understanding and ability to work with construction systems as an interrelated and influential aspect of architectural design.

1.2. On-site experience in an academic context

Within a pedagogical framework, the teaching of concept is the primary approach to learning, while the application of these concepts often is left to real life experience which in many cases only occurs after a student has left the classroom and begins to work in the field. While there are many approaches to how one might teach construction, this course focuses on teaching students about construction systems and construction drawing/detail literacy.

Historically, architectural plans and drawings have required a trained eye to interpret and synthesize a series of two-dimensional representations to produce three-dimensional constructs. In his essay, 'The Developed Surface', Robin Evans describes the architect's field of visibility in drawings. "It makes it possible to see some things more clearly by suppressing other things... Its power to represent is always partial, always more or less abstract. It never gives, nor can it give, a total picture of a project." (Evans 1986) The introduction of 3D modeling has effectively challenged this thinking by producing a more complete spatial representation of the reality without the need for the two-dimensional abstraction. However, within this process the understanding of scale and in some cases physical constraints are easily overlooked by an untrained individual. Reflecting on these methods of representation in an academic setting began to raise questions about the introduction immersive and hands-on methods of learning within a construction course. To supplement lectures and lab, initiatives to take students to active construction sites, host workshops with local construction trades and the introduction of digital technologies that would aid in the workflow of assignments as well as aid in the visualization of the course content was introduced. While these strategies presented challenges, the ability to provide students with on-site construction visits proved to be the most difficult. Due to liability and available opportunity, the integration of an on-site immersive construction experience within the classroom is many times unattainable.

In this scenario it is important to consider how technologies might be of aide and determine which technology might be the most appropriate. According to Jeremy Bailenson, director of the Virtual Human Interaction Lab at Stanford University, you must first ask the question, "what VR is good for?" To determine this, he uses the DICE framework which describes four scenarios: Dangerous, Impossible, Counterproductive or Expensive. Considering both dangerous and impossible as recurring scenarios, the course began to study alternative models and technology that would be less restrictive while allowing for a simulation of the experience of a construction site. This resulted in adapting extended realities, and specifically virtual reality, as a testing ground to understand, translate, and develop new possibilities for the integration of an "on-site" experience through an immersive environment for students.

1.3. What is XR and how can it be used in a school of architecture?

Extended reality (XR) is a term used to describe a fusion of all the realities, which are "... technology-mediated experiences enabled via a wide spectrum of hardware and software, including sensory interfaces, applications, and infrastructure". (XRSI, n.d.). XR includes virtual, augmented, and mixed reality as defined by Milgram et al. (1994) in which he describes a continuum between the real world and the completely virtual world. Progression along the continuum incorporates more digital content overlying the real environment until you reach the point where it is entirely digital. Each of these technologies has its own unique use in both education and real-world applications. Frameworks to guide the use of XR in teaching include both educational frameworks (mastery learning or experiential learning) and user-centered design (Salcedo et al. 2022). It is a technology that also affords new possibilities for collaboration, co-design/co-creation. XR in architecture is used in many ways in a professional capacity, including the design of spaces and new methods of fabrication through human-computer interaction (HCI). In addition, it is being used as an educational tool that goes beyond merely visualizing content by allowing for an embodied and simulated tangible experience with material.

2.0 DEVELOPING IMMERSIVE VISUALIZATION FOR CONSTRUCTION

2.1. Virtual Reality Prototype

Reflecting on the past methods for spatial visualization in architecture, combined with the need to supplement specific learning scenarios that were sometimes unattainable, the course began to explore alternative methods for visualizing course content. To begin to test out ideas the course was awarded funding through the Center for Research on Learning and Teaching, to develop a working prototype that leveraged virtual reality as a learning tool in the classroom. This initial immersive scene was paired with the lecture content on steel construction and a sophisticated but simple precedent that used steel as the primary method of construction, the Farnsworth House by Mies Van der Rohe.

The prototype used the computer modeling software Rhino 3D to create content that was later assembled in the Unity game engine. The Unity game engine provided a platform to integrate the 3D content and interactions with that content using the Oculus (Meta Quest) virtual reality head mounted display (HMD). This became the HMD of choice due to its cost effectiveness, availability in labs across campus, as well as the availability of the Oculus Integration Package in Unity. This package facilitated the use of prebuilt scripts and interactions that reduced the need to customize code to create desired interactions and navigation.

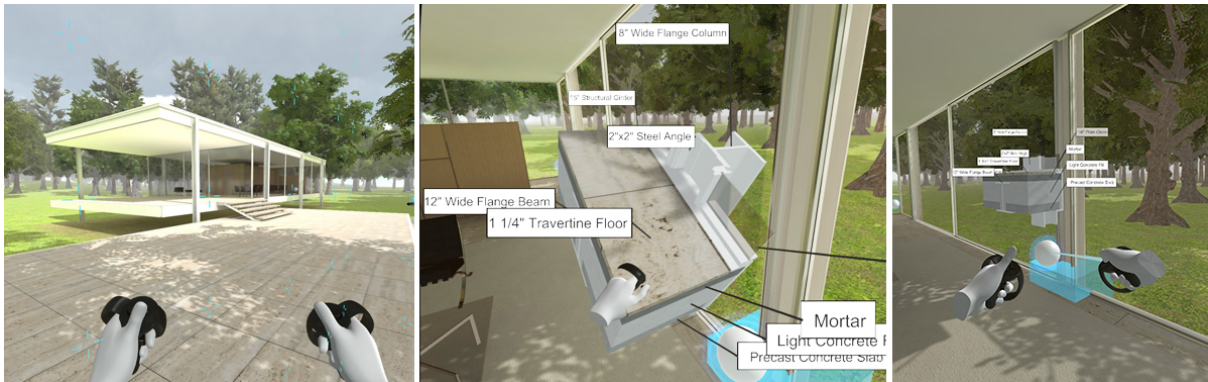


Figure 1: VR Prototype scene using the Farnsworth House. Source: (Jonathan Rule 2018)

The initial experience uses the concept of open world gaming. This type of play uses a simple exploratory scenario where free exploration and no end goal take priority over linear and structured play. To take advantage of the capabilities of the virtual, the test scene allowed for interaction beyond simply viewing a digital recreation of the house. Through a series of identified moments in the building, hotspots were created to allow for students to pull out details of the building to reveal how the different elements come together as an assembly. These three-dimensional elements were also paired with detail drawings of that location to allow students to understand the relationship between the two-dimensional detail and the three-dimensional element.

The initial prototype was introduced to students alongside the lecture about the house. To test the weather the prototype scene helped students understand the content, the class was divided into two groups. One group was allowed to use the virtual reality scene and the other could only rely on what was learned during the lecture. Both groups were asked to answer a set of multiple-choice questions related to the house. The results showed that the group with access to the virtual reality experience performed better on the quiz than those that did not. In addition, the students who had access to the VR application were given a qualitative survey to ask them about their experience. This survey resulted in a very positive response when asked if they felt the VR application helped them gain a better understanding of the content that was presented in the lecture.

2.2. Virtual Reality Application Development

To further understand the effects of virtual reality on students learning process the project evolved into a more robust version of the experience through a series of in-depth modules related to the material content of the course. To achieve this the course partnered with the Center for Academic Innovation through the XR Initiative at the University of Michigan. The program was a pilot program that selected eight projects from different fields to advance multidisciplinary learning and teaching and create innovative learning experiences through extended realities. The resulting project for the construction course brought together game developers, architects, and experts in educational technology to develop the second iteration of the prototype which was titled, 'Augmented Tectonics'.

The process for development built on what was learned in the prototyping phase but with adjustments made to support workflow between multiple groups as well as adapt critical insight from experts in educational technology. Unlike the previous model, the new application moved away from open ended play and chose to adapt a linear engagement of the content that integrated specific goals and segmented the learning experiences into finite modules. These modules were important in controlling the amount of time a student would be immersed in an environment which was recommended to not be more than 30 minutes.

2.3. Development Platform

The development of the application used Unreal Engine made by Epic Games. This decision came out of establishing a clear workflow between the application developers and the architects. While Unity is capable of similar workflows, Unreal at the time of development was better suited for the task. First, it facilitated the development content using a familiar modeling software, Rhino 3D. This along with the Datasmith application provided by Unreal Engine, allows for a direct connection between the modeling software and the game engine. As models are built, they are directly linked to the established scene without the need for exporting and importing to take place. In addition, through the layer structure of the files, it becomes possible to directly set up collision with static meshes inside Rhino. Collisions are what make virtual space "tangible" by limiting a person's ability to move through objects by giving them simulated physical properties. The second, advantage was the integration of Perforce's Helix Core which allowed for version control. Version control allows multiple people to work on a single build while storing and tracking changes being made to all the digital assets, including source code and 3D models. As the project became more complex and with more people working on development it was important to have a common repository where changes being made were trackable and identifiable.

2.4. Development Phases

The development phases included: discovery, research, asset development, prototype review/testing and implementation. Each phase was to be carried out sequentially; however, unforeseen challenges related to the technology and limitations of its capabilities required the reassessment of objectives at various stages.

2.5. Discovery and Research

The discovery phase involved conducting a survey of what existed for virtual reality learning platforms, identifying best practices, and establishing connections to course content. This design research aided selecting an organizational framework of a gallery space for the curation of content. The gallery became a logical solution for various reasons. First, the scale of the space could be constrained to meet the immersive time requirements. Second, the series of rooms established a system that could be added on to for future expansion while simultaneously breaking up content into manageable chunks. Lastly, it did not rely on a singular precedent project which is limiting because of its specificity and inability to demonstrate the breadth of concepts and methods that one might encounter in construction.

This stage was followed by a research phase, which analyzed methods of curation for physical objects and digital objects. Careful consideration was given to understanding opportunities and limitation of displaying two-dimensional content and three-dimensional content. The translation of this material to a digital space is a challenge and limited by the ability of the technology to properly display polygons and pixels when rendering a smooth experience. This phase also considered possibilities for simulating illumination in the galleries based on real world examples.

2.6. Asset and Interaction Development

The development phase included the team of architects and application developers working in parallel on building assets as well as making those assets interactive. Taking what was learned in the first two stages the design team began to give shape to the galleries and their internal organization. To bring these containers into conversation with the content, each gallery was constructed using the material it was showcasing. The initial gallery that was developed was for the metals module which primarily focused on steel construction. Three spaces were configured as standalone pavilions that contained an introduction to metal processing, followed by details and cladding, with the last pavilion comparing two precedents buildings.

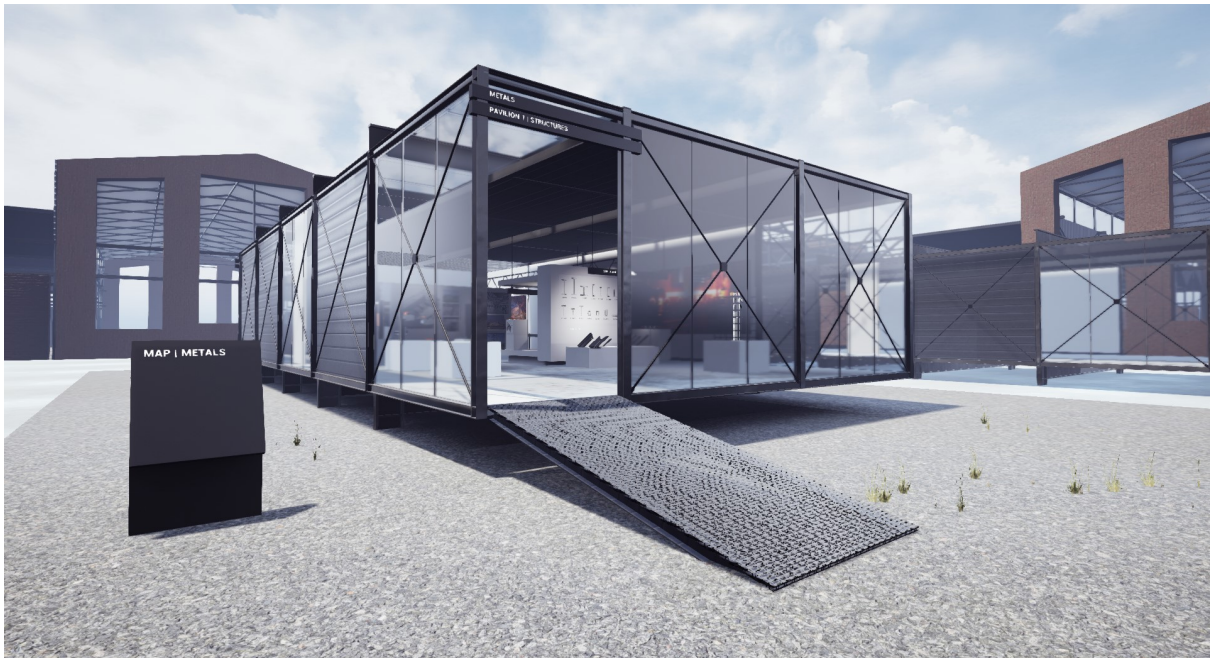


Figure 2: Version 1.0 Metals Gallery. Source: (Jonathan Rule 2019)

As content was created for the pavilion, the application development team was tasked with adding interactivity to the various assets in the virtual world. To turn the models from static objects to dynamic pieces required in-depth storyboarding to communicate the intention behind the interactive visualization. These interactions had a range of complexity, from a simple button press to trigger an animation, to more complex interactions that would require students to assemble structures and size steel members. It was also important to introduce a recordable metric to be able to assess the student's ability to understand the presented information. This took the form of questions at the exit threshold of each gallery and a matching challenge at the end of the module. To move between galleries, students first must answer a series of questions or participate in a scavenger hunt based on the content they just reviewed. Once they answer the question correctly the next space is unlocked, and they can proceed.

To end the module students are presented with a matching challenge. This challenge combines a randomized set of details related to the module, drawn as two-dimensional drawings as well as their three-dimensional representation. The challenge requires students to correctly associate the model with its respective drawing.



Figure 3: Matching Challenge. Source: (Jonathan Rule 2019)

To record the progress of an individual, the application was linked to a live google spreadsheet. The spreadsheet would record completion of the different thresholds, and matching challenges as well as record a timestamp and platform used, VR or desktop.

2.7. Playtesting

Before fully implementing the application into the course, it was crucial to review and test the initial module. While the development team understood the design and user interface very well, it cannot be assumed that someone using the application for the first time would have the same experience. To facilitate this phase of inquiry, the team turned to VR playtesting and specifically the Meta Playtesting guide. This process employed ten student testers and involved a series of questions that were asked while they were immersed in the application and afterwards. According to Schell Games, “the goal of playtest questions is to get unadulterated feelings from the person. You do not want to lead them in any way, but you want to find out what they thought.” (Schell Games, n.d.) For example, during immersion subjects are asked to describe what they are doing at specific moments. This helps the development team assess whether the scene or interaction is being used in the intended manner.



Figure 4: Playtesting analysis with students. Source: (Jonathan Rule 2020)

The post-play interview, included questions like; was there anything you wanted to do that you couldn't? This helped the team to gauge elements that might have been overlooked. After playtesting, the team synthesized and prioritized areas of improvement based on the responses. Some of these improvements included the following. Limited access to a headset, or motion sickness resulting from the use of a headset, necessitated that the app also include a desktop version, free of virtual reality. The desktop version could be navigated via a computer screen using keyboard controls and a mouse. While this version did not allow for an immersive experience it was important to make available as to not exclude anyone from accessing the content. A second improvement included developing a clear method of way finding. During playtesting it was observed that students were not sure where to go next. The metals module allowed for students to leave the pavilions and roam which caused confusion. This was resolved by restricting movement to the interior of the galleries and ganging them together to create a linear sequence between content. This also established a clear start, finish, and separation between groupings of content where threshold questions or challenges could be placed and found easily. Each module would now start with an overall description of the content and a level map as a visual guide. Within the gallery spaces, way finding was emphasized through arrows and a sequential numbering of an audio guide. While audio was provided, students also mentioned that it would be beneficial to have sub-titles or text for the audio since some learn better through reading.



Figure 5: Module map and quiz threshold. Source: (Jonathan Rule 2024)

Lastly, the start menu was redesigned to restrict free roaming and allow for direct access to the different modules. This space integrated a training module that would introduce students to the navigation system and the nuances of interacting with the content. These adaptations were made to the current metals module and added directly to the subsequent modules for wood, concrete, and masonry construction.



Figure 6: Concrete module: foundations, columns, and slabs. Source: (Jonathan Rule 2024)

3.0 RESULTS

3.1. Post XR Surveys

The application Augmented Tectonics was fully implemented into the construction course from 2021 – 2023, covering four material modules: metals, masonry, concrete, and wood. During the semester students attended the lecture for each of these materials and were given two weeks to complete the respective module. At the end of each semester students are asked to take a survey to assess the use and acceptance of the application in the teaching and learning process. Over the three years there has been a response yield between 122 students (2021) and 78 students (2023). Below are the results of a selection of qualitative questions compared over the years in addition to select student responses.

3.2. Knowledge Building

Students were asked to evaluate on a scale of 1 – 10 with 1 being low and 10 being high, how they felt the Augmented Tectonics platform aided in gaining knowledge about the content of the course. The results indicate that this has mostly been a positive method for learning with most students reporting between a 7 and 10 and comments including, “Awesome use of technology and great educational aid to visual learning.”

3.3. Enhancing Understanding of Lecture Content

The next question asked students to respond to the applications ability to help them better understand the content that was presented in the lectures. These responses hoped to illustrate that it had a positive impact of resolving unanswered questions a student might have regarding content. Like the previous question students primarily found this supplemental support favorable with many responses between 7 and 10 and comments including, “I feel like this was a good way to show us what we were learning in class without having to use actual physical versions.”

3.4. Understanding 2D to 3D Translation

This question asked if the experience helped the student further understand 2D drawings of 3D objects as they relate construction and construction details. Once again, the results support the claim that the application was a helpful resource, with feedback including, “I like that I was able to see how materials were connected to one another more closely. The 3D view made it a lot easier to understand.”

3.5. Improved Visualization

Building on the applications ability to help understand three-dimensional content, the next question asked if the experience helped improve the visualization of complex assemblies and details. As with the previous questions most students scored this positively between 7 and 10, with comments including, “I thought it's a great idea to do these VR quiz/videos. I learned a lot more because the different building layer were very clear visually.”

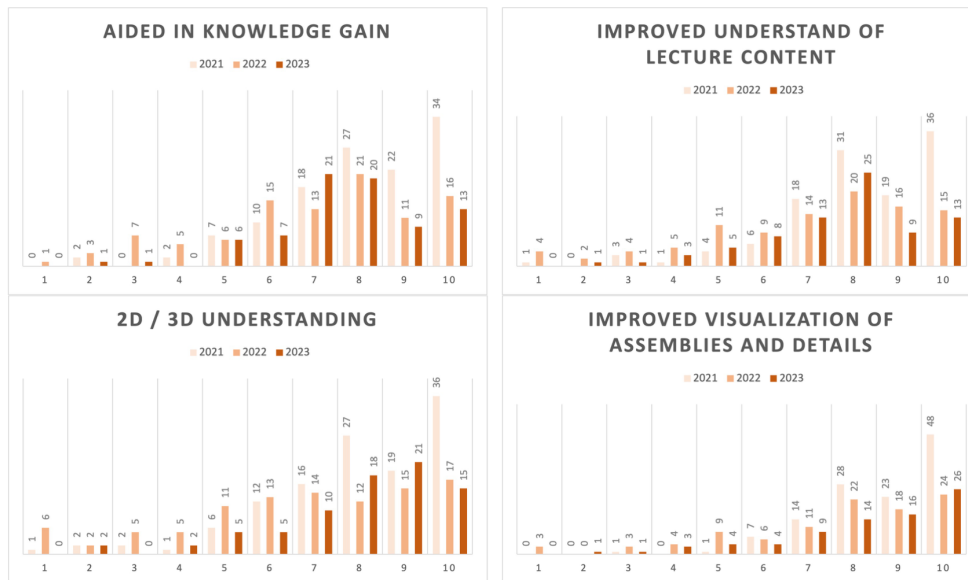


Figure 5: Recorded student response data 3.2, 3.3, 3.4, 3.5. Source: (Jonathan Rule 2024)

3.6. Course Metrics Platform

During the course two types of content review methods were administered. The first was the threshold questions and challenges built into the application. The second was a multiple-choice quiz using google forms. When asked which content review method was preferred, students highly valued the in-application method with an average of 83% approval over the three years. When asked why, some students answered that they felt the thresholds and challenges were directly applicable to what they were learning about. The multiple-choice quizzes required rote memorization of content that might or might not be meaningful. Many of the students that preferred the multi-choice method did so due to legibility issues and motion sickness that occurred while going through the desktop or virtual reality version.

3.7. User Interface Platform

All students were required to use the application in virtual reality at least once. Virtual reality can be complicated for first time users to set up and in this case required an in-class tutorial to show students how to connect the head mounted displays to the computer and application. As part of the introduction tutorial to get students acclimated to the technology, each student completed the in-app tutorial as well as the first assigned module using virtual reality. Afterwards, students had the option to choose how to engage with the application. The students were given access to three labs on campus. Two of which were equipped with virtual reality headsets and one with the desktop system. When asked which platform they used, the survey revealed (Table 1) that over the years, most students chose to use the desktop option over a more immersive virtual reality experience.

Table 1: UX Platform Preference Source: (Jonathan Rule 2024)

	2021	2022	2023
Virtual Reality	40.20%	3%	7.70%
Desktop	45.90%	88%	74.40%
Both	13.90%	9%	17.90%

3.8. Interpreting the Results

These qualitative responses were helpful in beginning to understand the value of creating an experience like this for learning. While the results reveal a limited use of virtual reality by students it is also important to understand that the data does not present this medium as a failure. More robust studies have been conducted on the effects individuals being repeatedly exposed to the technology. According to Eugy Han:

Inferences based on single session exposures or obtained through analysis of just a few sessions when participants are adjusting to the novelty of a medium are plagued with technical difficulties and can be misleading or incomplete.” (Han 2022)

First time users are usually apprehensive about setting up the headsets and how it is used. The unfamiliarity results in many users quickly abandoning the technology for something that is quicker to access and more familiar. In addition, this platform does not account for the benefits that group interaction can have within these immersive worlds. Studies by Khojashteh and Stevenson-Won reveal that participants in group situations become more comfortable with the medium and through collaboration learn its affordances. (Khojashteh and Won 2021)

CONCLUSION

This use study tests the potential extended realities poses in a teaching and learning environment for a specific scenario of architecture construction. Beyond this example, these tools also hold opportunities for communication between remote or collocated individuals immersed in multisensory spatial experiences. But for now, the use of these despatialized visualization technologies has seemingly generated more of a ripple than a wave when compared to other technologies adapted by architecture and as illustrated in the diagram “Prevalence of computation in Architectural Design.” (Garcia et al. 2023) This can be attributed to several reasons but primarily is a question of access. Virtual reality, for one, is still expensive and has not fully been adapted by the public. However, even in a scenario where the technology is available, the process for a new user to navigate setting up the hardware and feeling comfortable using the new tool is a complicated process. Most first-time users, as mentioned before, become apprehensive at this stage and prefer a quicker and more familiar platform. This is not to say that virtual reality will not become more user friendly over time, but for now it is a hurdle that impedes a more widespread use. Despite these limitations, XR’s latent potential and reflecting on the history of technology in architecture, one can only ask, will extended realities remain as a ripple or is it an undetected tsunami? The example studied here remains inconclusive in answering this question, but it does, returning to Carpo’s statement, offer an example to reflect on what we could not do without XR based immersive virtual learning environments in the classroom and hint at the possibilities that they hold for the future of architectural education.

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