

# A Theoretical Model of Using Extended Reality in Architecture Design Education

Mohamed Darwish<sup>a</sup>, Shaimaa Mohamed Kamel<sup>a</sup> and Ayman Assem<sup>a</sup>

<sup>a</sup> Department of Architecture Design, Faculty of Engineering, Ain Shams University, 1 Elsarayat St., Abbaseya, 11517 Cairo, Egypt

**Abstract:** Architecture design education is looking for new ways to become more efficient and adaptable to the needs of society. Intensive research is being conducted all over the world to determine how technology, specifically Extended Reality (XR), can be used in design education. The concept of Extended Reality is one of the newest developments that has gained popularity. This paper presents a theoretical model for integrating the basic concepts of XR, especially Virtual Reality (VR) and Augmented Reality (AR), with the architecture design process through the process-based studio teaching stages and the conditions of the design activity, whether it is happening in the design studio crits session or in individual design sessions. The theoretical model is developed through the examination of the architecture design process, the benefits, and previous attempts of using XR in design education. The paper presents the model key concepts, elements and potential applications and points out towards future direction of research.

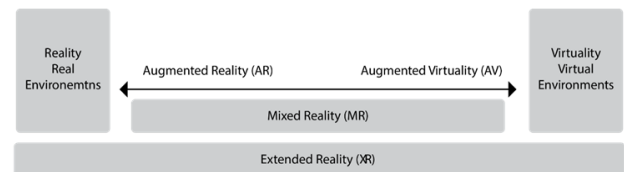
**Keywords:** Design Education; Architecture Design; Extended Reality; Virtual Reality; Augmented Reality.

## 1. INTRODUCTION

Technological improvements in computer-aided drawing and design tools have always had a significant influence on the architectural education process, allowing young architects to easily control, manage, analyze, visualize, and assess their designs [1]. The use of technological tools such as artificial intelligence (AI), rapid prototyping, additive manufacturing, automation in construction, and Extended Reality (XR) is one of the most promising teaching methods in the modern education system [2].

In the reality–virtuality continuum notion (Figure. 1) presented by Paul Milgram and Fumio Kishino [3,4], the Reality-Virtuality continuum was considered as a taxonomic classification that displays different degrees of Reality-Virtuality. On one side the real environment was placed and on the other side the virtual environment (Virtual Reality) was placed. In the middle of the continuum different degrees of integration between both environments was integrated including Augmented Reality and Augmented Virtuality[4].

XR refers to all mixed real-and-virtual worlds and human-machine interactions produced by computer technology and wearables. It comprises representative forms such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), as well as the realms in between [5].



**FIG1.** Reality-Virtuality continuum by Milgram and Kishino, with the concept of Extended reality by Dana Horváthová et al. [3]

Virtual Reality (VR) is defined by Sherman and Craig as a medium consisting of computer simulations that give the viewer a sensation of presence within the simulations[6]. In other words, it is an entirely computer-generated virtual environment in which the user may only interact with virtual items [3].

Immersion, interaction, and multi-sensory feedback contribute to the experiential nature of Virtual Reality environments [7]. This experimental nature of VR makes

it an ideal learning environment and appealing platform [8,9]. It is believed that a virtual environment provides users with a three-dimensional interactive experience that gives them the impression that they are in a real world rather than viewing an image, which improves learning by providing a real experience in any educational field conditions rather than imagining them. [7,10]

Augmented Reality (AR) as described by Azuma is a system or visualization approach that meets the following three criteria: a combination of real and virtual worlds, real-time interaction, and precise 3D registration of virtual and real items [11]. It is generally acknowledged as a real-time technology that augments a physical environment by incorporating virtual information into it [12]. Unlike virtual reality, augmented reality does not hide our surroundings; rather, it augments our current sense of presence in the physical world.

AR technology allows for collaborative interactions in real-world settings. As a result, people may interact with computer-generated elements as if they were real-world objects. Users may change the size, positioning, and direction of virtual items by superimposing them in a real-world environment. As a result, AR technology may inspire active student engagement in the construction of their own knowledge. As a result, it is an ideal media for use in the classroom. [13,14]

Depending on the context, mixed reality (MR) may mean many different things. As Maximilian Speicher revealed in 2019 after interviewing 10 AR/VR specialists from academia and business, as well as performing a literature study of 68 publications, there is no commonly agreed definition of MR, and expecting one to emerge in the near future is very impractical [15]. Accordingly, in this research it will be considered as a synonym of AR.

Incorporating digital technology into the educational process is viewed as one of the greatest obstacles faced by students and teachers; nonetheless, students are highly drawn to these tools. From educational institutions, there is a persistent demand on keeping old tactics, maybe out of concern that the complexity of some computer programs would alter the contents of the fields [16].

## 2. PAPER'S AIM AND METHODOLOGY

The main aim of this paper is to provide a theoretical model for using Extended Reality (XR) as an educational tool to be used in architecture design education. It starts by discussing the architecture design process. Then

illustrating why extended reality can be utilized in architecture design education, followed by a review of the previous research for using both VR and AR in the architecture design studio.

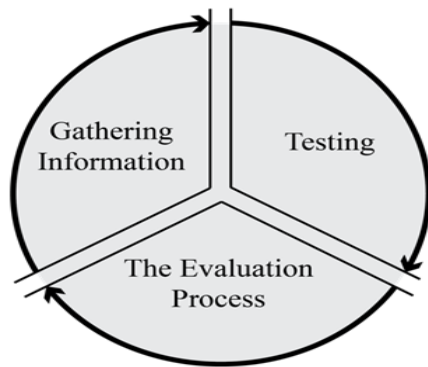
These components are utilized to form the suggested theoretical model. A three-dimensional matrix that consists of three main axes. The first axis involves process-based studio teaching stages divided into the different stages, elements and activities as described by Ashraf Salama [17] as this model is the most in-depth and specialized design process model that also includes the separate design activities used in the design studio. The second axis covering Reality-Virtuality Continuum simplified as the main two components of VR and AR. The third axis involves the conditions of the design activity whether it is happening in the design studio crits session or in individual design sessions.

## 3. ARCHITECTURAL DESIGN PROCESS

A design process is a systematic procedure for developing a product. Although there are several recognized descriptions of the design process, they are all characterized by a sequential process comprised of distinct phases [18,19]. Researchers described the design process using various approaches, including the stage-based approach, the problem-based approach, and the solution-based approach [19]. This section focuses on models given using a problem-oriented approach. Followed by a number of architectural design process proposals. The problem-based approach views the design process as an exploration into the problem. Several problem-based models were presented to characterize the design process [19,21-23]. This section focuses on three of these models: the Jones model [20], the Cross model [21], and the Pahl and Beitz model [18]. Jones' model (1963) is among the earliest explanations of the design process. Cross's and Pahl and Beitz's models are quite well-known among design scholars. In addition, these models demonstrated a simple but broad representation of the design process.

Jones, J. Christopher argued [23] that the design process does not reflect the process of creation, but rather is based on the notion of the derivation of the final product output elementary introductions, and the relationship between these elementary introductions and the final product is determined by three basic operations. At the beginning, there is information collection, which incorporates also the methods of organizing, analyzing, and verifying that the gathered data is relevant to the design position, and the incorporation of this data into the final picture.

Second, testing: integrate the design decisions through the process of displaying the designer's intellectual and intuitive abilities and personal experience. Finally, it is important to determine how these evaluations pertain to the design challenge as a whole [24,25]. As shown in Figure 2.



**FIG 2.** Jones, J. Christopher architectural design process model. Source: Jones J. Christopher [23]

It might be claimed that this process includes stages of analytical comprehension, critical analysis, and decision making. Nevertheless, the design process is not linear; the stages interact continuously [25,26].

Cross (1994) classified the design process as exploration, generation, assessment, and communication. First, designers examine the challenge or design space, then develop ideas. By analyzing solutions or concepts, designers may pick which to implement. In communication, the selected solution or concept is ready for manufacture or embedding in a more complicated product or system [22,27].

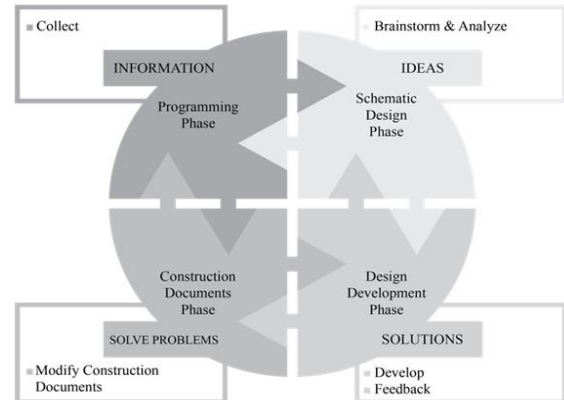
Pahl and Beitz (1996) outlined four design steps. first, Information or problem analysis phase is followed by concept generation. Before concepts are assessed, they are made more concrete through a process called "embodying." Then, the best concept is chosen [19,27].

The design process, in the context of these earlier models, is best understood as the creative procedure by which abstract concepts are translated into working models. Next, this paper discusses an overview of the design process from an architectural point of view.

**3.1 Design process from an architectural point of view**

London Bone Baker Architects state that during the schematic design phase, designers are able to review and modify the information in order to generate new ideas and evaluate previously existing concepts. During the design development phase, concepts are developed based on input from design solutions, while keeping in mind that

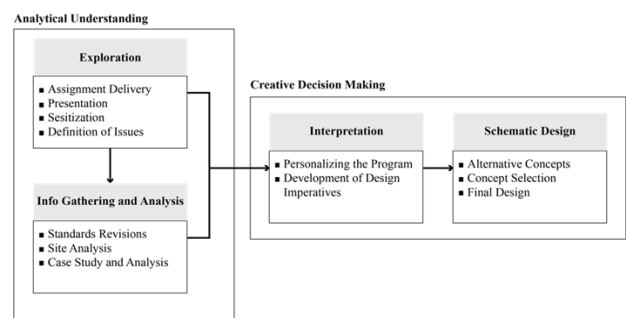
these solutions might be changed during document building. In reality, these four design stages overlap. The architect moves between two cascade stages to develop design information and ideas and to identify solutions, and repair issues [24].



**FIG 3.** London Bone Baker Architects architectural design process model. Source: London Bone Baker Architects [24]

According to Coolidge, the goals and priorities should inform the architectural design process. Creating the central design solution is the first and foremost goal. Then, the primary issue details and solution ideas should go hand in hand. The design would provide a series of inefficient choices at random without this procedure. The standard design process consists of four stages: pre-design, schematic design, design development, and documentation creation. Each design project, however, might have a unique sequence of stages depending on its goals and objectives [24].

Ashraf M. Salama [27] characterized architectural design as a reflective interaction between design subjects. He presented a design process model based on AIA, MIT, and RIBA's definitions and applications. A multilayered technique divides the model into two stages, each with two elements. First, analytical understanding involves data collection and research. Second, creative decision making includes interpretation and design concepts. Figure 4 is a conceptual representation of the design process model.



**FIG 4.** Stages of the proposed process-based studio teaching model. Source: Ashraf M. Salama [27]

The Exploration stage clarifies project goals through assignment delivery. In this phase, students learn about project and building-type design problems. An early program helps generate project ideas on what components should be included. In one or more studio sessions, essential design aspects and project challenges are discussed in groups. Accordingly, Students can specify programmatic, functional, contextual, and picture challenges.

The information-gathering stage includes three steps: a standards revision, a study of similar projects, and a site analysis to discover restrictions, and possibilities.

The stage of interpreting facts and information. Students must build a tailored program based on design issues, site analysis, standards, and case study findings and set priorities.

At least two alternative concepts are developed based on the tailored program and third-phase imperatives. Students debate two concepts and choose one to develop into two- and three-dimensional designs and a final design.

Ashraf Salama's model is the most in-depth and specialized design process model that has been used in the design studio. It has four main steps: exploration, gathering information, Interpretation, and then schematic design. This model will be used to develop the theoretical model of integrating extended realities technologies in the architecture design studio[24].

#### 4. UTILIZING XR IN ARCHITECTURE DESIGN TEACHING AND LEARNING

In this section, we discuss the important capabilities of extended reality and describe its educational dimensions in architectural design education. As an evolving new educational tool in communication, extended reality technologies became more advanced. Yesterday, architectural design studios have used traditional sketches and design tools to illustrate their ideas and modify reality in students' imaginations. Nowadays, with the evolution of extended reality technologies, architectural design studios have gone further into integrating the new technologies of extended reality in the design process itself not only as a presentation tool. We consider extended reality as an enhancement tool for Spatial ability in architecture design students.

Many recent studies have adopted the use of current technologies to assist spatial ability research. As one

approach, Extended reality (XR) is among the most popularly used technologies[28]. It has been shown that XR facilitates spatial learning by providing a setting that may reduce extraneous cognitive load [28,29] and by providing a medium for digital prototyping that aims the problem solving dilemma in architecture design learning [30].

#### 4.1 Cognitive load theory

Cognitive load theory (CLT) explains how our working memory can only accommodate a limited number of simultaneous activities [31]. Learning becomes ineffective when the cognitive load surpasses the capacity of working memory [32]. Intrinsic load, extraneous load, and germane load are the three types of cognitive load [32]. Intrinsic load is the notion that all tasks have a certain level of inherent complexity. However, educators can reduce the difficulty of a job by dividing it into subtasks [32]. Extraneous load is the cognitive load that results from the presentation of information [33]. Good educators will strive to reduce this sort of cognitive load by delivering material in a manner that is easily processed. Lastly, germane load refers to the cognitive load that generates schema to process newly acquired knowledge [32]. CLT states that cognitive load is composed of intrinsic load, extraneous load, and germane load. educators are urged to regulate intrinsic load, decrease extraneous load, and maximize germane load in order to improve learning effectiveness [28].

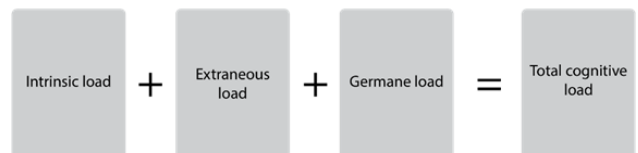


FIG 5. Cognitive Load Theory. Source: Sweller 1998.[31]

Data suggests that displaying information in VR might lessen the unnecessary load. According to EEG-based cognitive load measurements, viewing a 2D computer-based tutorial video results in a much greater cognitive load index than watching a 3D computer-based tutorial video [34]. Specific learning benefits, such as decreased cognitive load, have been documented by some studies as a result of using AR in education [35]. For instance, Lee used paired-sample t-tests to evaluate the mental effort and mental load ratings of the experimental and control groups, finding a statistically significant difference between the two [36].

This overview shows that XR Technologies (VR and AR) present unique opportunities to show and edit three-dimensional things in space, making them suitable study

and training tools for spatial ability. These technologies enable users to actively interact with and see the spatial properties of three-dimensional objects. Objects can be modified and viewed in real time and in real scale. This should make it easier for people to comprehend spatial concepts and practices spatial abilities by lowering extraneous cognitive load. Consequently, the objective of our research is to utilize this property of XR to facilitate spatial learning in the educational architectural design studio.

#### **4.2 Problem solving through prototyping**

A lot of studies have gone into detail into the problem-solving process [37,38]. Insight issue solving [39], trial and error problem solving [40], and formal and logical procedures have all been studied in relation to design problem solving [41]. A variety of research discussed the influence of prototyping (which is basically a trial-and-error approach of problem solving) on design problem solving [40,42,43]. One recurring issue in most of these studies, where prototyping in the design process is highlighted, is its influence on fixation [40,43].

Gestalt psychologists have explored fixation as a design-related mental block [44]. Mental block is "a barrier in our thoughts that prevents us from creating desired information" [45], whereas design fixation is the designer's inability to shift away from a concept to solve an issue in a different way [46]. Fixation can interfere with creative reasoning and lead to a small set of unvaried solutions [47], hindering creative design issue solving. Several research indicate ways to reduce design fixation. Some research recommends group work [40] and analogical inspiration sources [48] to alleviate fixation effects. Some research demonstrate that physical prototyping promotes fixation [49]. While making the actual prototype, designers may focus on the design [50]. on the other hand, Digital prototypes may reduce fixation produced by physical prototyping owing to their ambiguity and generation time [30].

Kim and Maher [51] believe that merging digital prototype with tangible user interfaces in VR and AR design frees designers from fixation effects. They say TUIs allow greater trial-and-error problem solving by prototyping utilizing epistemic activities. Kirsh and Maglio [52] introduced epistemic action and pragmatic action by discussing how professional tetris players conserve cognitive resources by testing out alternative cube locations rather than figuring it out in their thoughts. These experimental actions, called epistemic actions, free up players' cognitive resources. Youman [40] argues

that reducing Cognitive Load reduces design fixation. Epistemic acts reduce cognitive load by allowing flexible design manipulation. This reduces cognitive load, preventing fixation. This does not mean that epistemic action eliminates fixation, only that it minimizes its consequences. Fixation negatively impacts the creative process [53,54]. Benefiting from reduced cognitive load and lessening the chance of fixation, the design process is aided by the use of XR interfaces and epistemic acts.

A subcategory of prototypes exists within the field of technology. It is digital prototyping. Virtual Reality and Augmented Reality are two types of simulated environments that are often used as digital prototyping tools.

Numerous research have used VR and AR settings to look at exercises that enhance spatial ability [55-57]. These researches have taken into account both digital modalities while taking into account the two key distinguishing elements of augmented reality and virtual reality: transparency and controllability of the interface. Through digital prototyping, AR and VR have been found to have a significant influence on design education [58].

##### **4.2.1 Virtual Reality**

Virtual reality technology has been utilized widely in educational fields, as well as in other research projects. Experiments on navigation have been conducted in large-scale virtual environments to see how it affects spatial ability. More educational trials regarding improving spatial abilities have been carried out in small-scale virtual worlds [59]. Virtual reality prototypes have been found to be highly helpful in the design process [60]. According to the findings of the study by Westerdahl et al. (2006), the participants stated the VR model was a helpful tool for making decisions about a building's design.

##### **4.2.2 Augmented Reality**

AR overlays virtual components on the actual environment, whereas VR immerses the viewer in a computer-generated world. AR combines virtual and physical surroundings to augment reality.

Several research examine AR in Education [61-64]. There have been studies on why augmented reality might be an effective tool for design exploration [51,65]. Simple things like adjusting a room's color in real time or viewing a building's site may benefit designers. With wearable AR devices, AR experiences will improve in quality and "relative realism" (equivalent to immersion and presence in virtual environments).



Ibanez, Di Serio, Villaran, and Kloos (2014) [58] compared student learning through AR and web-based apps. Students that used the AR-based software had more positive feelings and were more focused on their design task. The results showed that students utilizing augmented reality understood the job better than those who used a web-based tool.

#### 4.3 Examples

Cheng Zhang and Bing Chen (2018) created a virtual reality-based immersive learning and teaching tool. It generates a virtual 3D environment that assists architectural engineering students in conceiving their design ideas, planning the layout, designing the structure, constructing the products, and interacting directly with the products they designed. It was tested on 31 students. They were given the task of conceiving building design concepts, designing the structure, and interacting directly with the surroundings. Even though the environment only supported a single user at a time, the students could also add tags with comments to one another's work. Students' remarks demonstrated that they were enthusiastic in learning academic subjects through such a technical game. After playing this game, the majority of students were eager to invest additional time in seeking solutions [66].

In two semester-long, Bobby Nisha (2019) surveyed students with backgrounds in Urban design, planning, geography, civil engineering, and GIS to determine how effective the use of HMD VR was as a teaching tool. In the first module, students created a spatial typology for an urban environment by arranging elements like roads, neighbourhoods, landmarks, and nodes. In the end, 3D prints were made of the spatial compositions. Students were tasked with creating a virtual reality (VR) tour experience in Module 2 by tracking the spatial development of cities [67].

The design procedures of architecture students who integrated VR into their regular studio instruction were studied by Hadas Sopher, Dafna Fisher Gewirtzman, and Yehuda E. Kalay (2019). Crits were conducted on an Immersive Virtual Environment IVE, with students presenting their work to instructors and peers for feedback and analysis before doing full-scale virtual walkthroughs of their own designs. The study's findings showed that IVE is linked to higher rates of convergence productivity in design tasks. The article was released in 2019, however the data were gathered in the late 2013 and early 2016 time periods [68].

In her 2018 paper, Nora Argelia Aguilera Gonzalez examined how VR and AR may be used in a first- and second-year descriptive geometry course for architects and industrial designers. Students begin with hand-drawn sketches before moving on to 3D modelling in SketchUp, the non-immersive virtual reality employed in this research. The model is then enhanced for viewing in AR to double-check its proportions before being sent to a laser cutter to be made into a physical replica [69].

Two researchers from 2020, Yangzhicheng Lu and Tomoyuki Ishida, created a platform for Mixed Reality in the field of interior design. When wearing a transparent HMD, users may take 3D scans of physical rooms and subsequently decorate them with digital furnishings. 22 willing college students took part in an experiment to evaluate the system's presence, operability, usefulness, and efficacy. The majority of respondents endorsed all five of these changes. [70].

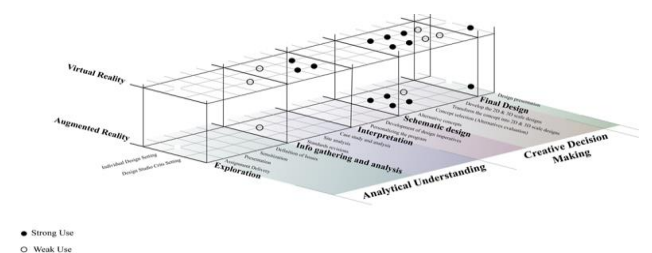
#### 5. THE PROPOSED THEORETICAL MODEL

The proposed theoretical model presented in this paper depends on the basic key concepts discussed earlier to develop a theoretical model to show how Extended reality technologies can be used in architecture design education. This proposed model integrates the design process in the process-based teaching stages, reality-virtuality continuum, and the conditions of the design activity. The main three axes of the framework are:

The first axis: Process based studio teaching stages by Ashraf Salama. As this model is the most in-depth and specialized design process model that also includes the separate design activities used in the design studio.

The second axis: Reality-Virtuality Continuum simplified as the main two components of VR and AR.

The third axis: illustrate the conditions of the design activity whether it is happening in the design studio crits session or in individual design sessions.



**FIG 6** Theoretical model to show how Extended reality technologies can be used in architecture design education.

Source: the author

It is noted during the exploration element that the involvement of XR technologies in the developed theoretical model is limited to the use of VR in the definition of issue activities. One of the benefits of using VR technologies is their effectiveness as an empathy intervention[71]. VR allows students to experience the problems that their clients face in order to better understand the problem by putting themselves in their clients' shoes. This can be accomplished in a design studio crit setting where students can use these VR experiences to discuss issues with their tutor and how it may affect their design.

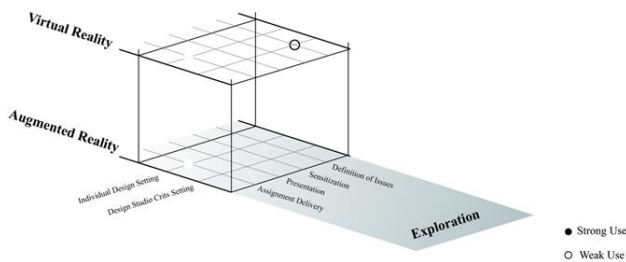


FIG 7. Theoretical model - Exploration Element. Source: the author

In terms of information gathering and analysis, VR and AR can be used at various stages. VR can be used to evaluate and analyses case studies [72]. To better evaluate and analyze the design, students can walk through the buildings or projects they select for their case study. This can be done in design studio sessions with the tutor to discuss this analysis, or it can be done independently by the students in their individual design setting. VR can also be used as a tool to virtually visit the site, saving time and resources while giving students the opportunity to see the site, know what the views are from and into the site, and gain a better understanding of the scale of the site and its surroundings. In the standard revisions phase, both VR and AR have the potential to be used. This phase includes, for example, revising the recommended dimensions of the various spaces and furniture clearance. These activities can benefit from the use of VR and AR because they can help students understand size and proportions [73].

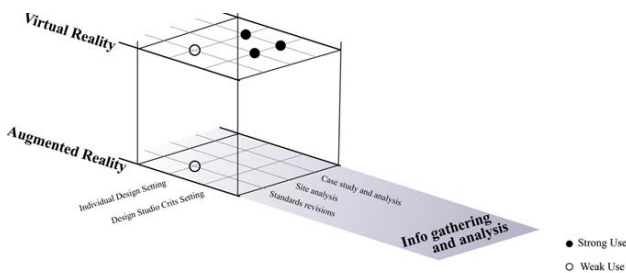


FIG 8. Theoretical model - Info Gathering and Analysis Element. Source: the author

During the schematic design element, the use of XR is most visible. XR can be used for a variety of purposes during this phase. It can be used in both design studio crits and individual design settings as a rapid digital prototyping tool. As previously discussed, this allows students to explore multiple design concepts and alternatives in a short period of time, which can reduce fixation. XR has the potential to be used as an evaluation tool during the concept selection phase as well. Both VR and AR can be very beneficial because they allow students and tutors to experience design alternatives in real scale or as a digital prototype, allowing students to make better evaluations and design decisions both individually and in crit sessions with their tutor.

VR can also be used to create 3D models. Allowing students to model their designs in 1:1 scale to reduce problems caused by a lack of spatial experience in novice architecture students. VR allows students to better understand the geometrical attributes of the model by allowing them to move, rotate, and inspect the 3D model from all angles, increasing their spatial ability, which is essential when creating their 2D and 3D scale designs.

Finally, both VR and AR are regarded as suitable mediums for students to present their projects. Students can use VR as a tool for full-scale walk-through simulations of both the interior and exterior of a project. AR, on the other hand, is a great tool for visualizing a project on a small-scale using marker-based AR or in full scale in the project's actual location, which is best used to evaluate how the project interacts with its surroundings

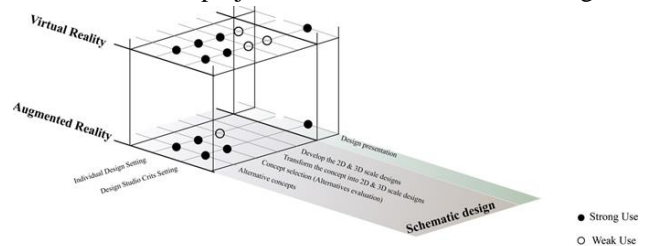


FIG 9. Theoretical model - Schematic Design Element. Source: the author

## 6. CONCLUSION

Extended Reality applications became more common as technology advanced. As a result, XR apps may be employed in a variety of fields as education and architecture design. In the future, XR technology will be a part of our daily lives, with various applications to make our lives easier, more productive and fun.

The theoretical model proposed by this study illustrates how to integrate XR in the architectural design education. It does so by presenting a three-dimensional matrix that integrate the design process in the architecture design studio, the conditions of the design activity and the XR technology used. The study argues that using XR has the potential to improve the architecture design learning process by both reducing the extraneous load and facilitating the digital prototyping process.

## 7.FUTURE WORKS

The current paper has opened up new possibilities for additional research and development using XR in architecture design education, including the following:

- The development of a system that integrates all architectural design processes into a single package. The diversity of tools and the time spent transferring files and model types between different software is one of the main challenges for theoretical model implementation.
- A review of the hardware that can be used in both VR and AR to determine which tools are suitable for which task. VR can be accessed through multiple types of devices like head mounted displays (HMD) and CAVE rooms. AR on the other hand can be accessed through HMD, smartphones and others. In recent years, some tools became more accessible. so, a review of these devices and when to use each one in the architecture design process is essential to take full advantages of the technological advancement in the field of XR.
- The theoretical model is only a model to determine if a design process can utilize the use of VR or AR. But it doesn't explain in detail how can it be used and what are the actual benefits and challenges of each use case. Further research in every point of intersection of the theoretical model is needed to determine the actual usefulness of this hypothesis.
- The integration between XR and other design approaches. For example, the computational design. How can the VR and AR tools be used in computational design to facilitate the process of digital prototyping and form testing.

This paper presented a theoretical model for using XR technology in architecture design education. This XR assisted learning can provide tutors with a variety of educational strategies, allowing students to have a more immersive and beneficial learning experience.

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