Using Augmented Reality Prototypes in Design Education

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Abstract

Prototyping or model making in the Architectural and Interior Design process is an established method of design problem solving. By using prototypes, design students can better visualize structures and can give students a more concrete result when working on a design project. According to a study by Grosslight, Unger, Jay and Smith (1991), students are likely to think of prototypes as physical copies of reality that envelop various spatiotemporal views, instead of representations that envelop various theoretical perspectives. Past literature and research has suggests that student's rate building prototypes highly when compared with other types of representations, which implies that they are better able to learn the design process when using prototypes (Lemons, Carberry, Swan & Rogers, 2010). This study documents alternate modeling strategies utilizing technologies such as Virtual Reality (VR) and Augmented Reality (AR) in Architectural and Interior Design education through the Technology Acceptance Model to better understand how students perceive design solutions in early design studios. The results of the study suggest that design students found physical models to be comparable to AR models and that the AR technology was easy to use.

Key words

design education, Augmented Reality

1.0 Problem solving through Prototyping

The problem solving process has been discussed extensively in a number of studies (Lawson, 1983; Ackoff, 1974, Broadbent, 1973). Design problem solving has been discussed through methods such as insight problem solving (Chandrasekera, Vo and D'Souza, 2013) trial and error problem solving (Youmans, 2011), and formal and logical processes (Dorst, 2011). The effect of prototyping (which is essentially a trial and error method of problem solving) is discussed in a number of studies with regard to design problem solving (Kershaw, Hölttä-Otto and Yoon, 2011; Youmans, 2011; Viswanathan, and Linsey, 2009). In most of these studies where prototyping in the design process is discussed, one re-occurring theme is its effect on fixation (Youmans, 2011; Viswanathan, and Linsey, 2009).

Gestalt psychologists have extensively studied fixation as a phenomenon interchangeable with mental block found in design studies (Murty & Purcell, 2003). While a Mental block is defined as "A barrier in our minds preventing us from producing desired information" (Kozak, Weylin Sternglanz, Viswanathan, & Wegner, 2008, p. 1123) design fixation is identified as the inability of the designer to move away from an idea in order to resolve a problem in a new way (Jansson & Smith, 1991). Fixation is often identified as a process that interfere during creative reasoning and lead one to become fixated on a small number of unvaried solutions (Agogue and Cassotti, 2013), potentially becoming a hindrance in the creative design problem solving process. There have been a number of studies which suggests potential solutions in mitigating fixation effects in the design process. Some of these studies suggest encouraging group work (Youmans, 2011) and introducing analogical inspiration sources (Casakin, and Goldschmidt, 1999) as methods of alleviating fixation effects. Some studies have shown that physical prototyping increases fixation (Christensen, and Schunn, 2007).Designers may tend to fixate on the design during the time that they spend on making the physical prototype. This is considered as a sunk-cost effect in physical prototyping (Viswanathan and Lindsey, 2013). Digital prototypes maybe an approach to alleviate any fixation effects caused through physical prototyping, due to their ambiguous nature and time needed to generate them.

1.1 The effect of Digital Prototyping in Design problem solving

With regard to using AR in the design process, Kim and Maher (2008) suggests that digital prototyping using tangible user interfaces allows the opportunity to make more inferences from the visuo-spatial features freeing designers from fixation effects. They state that Tangible User Interfaces (TUI) allow more opportunities for trial and error type of problem solving through prototyping using epistemic actions. Kirsh and Maglio (1994) introduced the concepts of epistemic action and pragmatic action where they discussed how expert players of the popular video game tetris, conserve their cognitive resources by trying out different positions of the tetris cubes rather than trying to figure it out in their minds. These experimental moves, which they term epistemic actions, allow the players to use their cognitive resources for something else. Fitzmaurice (1996) uses the same terms in discussing

Graspable User Interfaces (or TUI). These Tangible User Interfaces such as Augmented Reality (AR) interfaces allows more epistemic action (Fitzmaurice, 1996) thereby reducing the cognitive load and conserving mental effort that the designer has to spend. Youman (2011) states that when Cognitive Load is reduced, the fixation effect in design is reduced as well. Epistemic actions allow a designer to manipulate the design freely, reducing the cognitive load. At the same time this reduction in cognitive load allows the designer to avoid fixation. This does not imply that fixation can be eliminated by allowing epistemic action alone, but merely that epistemic action reduces fixation effects. However, Studies have shown that fixation adversely affects the creative process (Kohn & Smith, 2009; Smith & Blankenship, 1989, 1991) and therefore, it can be stated that when AR interfaces are used in the design process, epistemic actions reduces cognitive load and reduces the chances of fixation, positively affecting the creative process.

1.11Physical Prototypes

In Architecture and in Interior Design physical prototypes provide a small scale, three-dimensional blueprint for the structure that will be built. Physical prototypes often serve as an inspiration for design students, and can be beneficial teaching aids. In most instances these prototypes can be deconstructed and reconstructed by students so they can get a better idea of development of the design ideation process.

The use of physical prototype can be open-ended, which allows for opportunity of new ideas to arise throughout the design process. Physical prototypes in architectural design come in various forms, including: exterior, interior, landscaping design, urban, engineering and construction. Exterior prototype are generally prototypes of buildings, and can include landscaping or other key pieces surrounding the building; interior prototypes show spaces inside of a building or a room, and are detailed with furniture arrangement, colors, and other decorative touches; landscaping prototype feature walkways, bridges, gardens, etc. Urban prototypes represent a whole town or the planning and development of a new subdivision or shopping center, and are usually comprised of multiple buildings and streets (Gibson, Kvan, Thomas & Ming, 2002).

However, as mentioned earlier, some studies suggest that using physical prototypes in the design education process leads to fixation. Hence, it is necessary to explore the possibility of using alternate prototyping techniques. In this study we explore the use of digital prototypes in design education focusing on Augmented Reality technology.

1.12 Digital Prototypes

A subset category of prototypes lies within technology. Two commonly used technological prototypes are through the use of simulated environments called Virtual Reality and Augmented Reality.

Virtual Reality

Virtual reality (Fig 1) has been extensively used in educational domains and numerous research projects have employed VR technology as well. Large-scale virtual environments have been used to conduct navigational experiments and investigate its effect on spatial abilities. Small scale virtual environments have been used to conduct more educational experiments about enhancing spatial abilities (Dünser, Steinbügl, Kaufmann, & Glück, 2006).

A meta-analysis by Merchant et al. (2014) examined several studies on virtual reality in education. Some of the important findings from this meta-analysis were that games display higher learning capacities and gains than simulations and virtual worlds, and that students learn more when using virtual reality individually instead of in a group.

Virtual reality prototypes have proven to be very useful during the design process (Westerdahl et al., 2006). The results of Westerdahl et al. (2006) study showed that the respondents felt the VR model was a useful aid in the decision-making process concerning the design of a building.

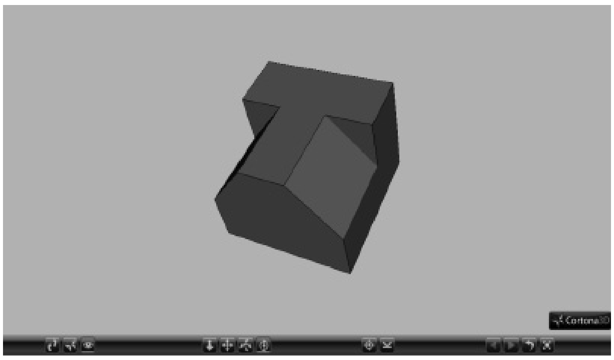

Figure 1. Virtual Reality

Augmented Reality

Augmented reality has been defined as a variation of VR (Azuma 1997). While VR completely immerses the user inside a computer-generated environment, AR allows the overlaying of virtual elements onto the physical environment (Fig 2). AR can be considered a hybrid of virtual and physical environments, and it supplements reality rather than replacing it.

Miligram and Kishino (1994) define AR as a middle ground between virtual and physical environments. They mention two types of mixed realties: Augmented Reality and Augmented Virtuality. They state that in Augmented Reality the physical world is enhanced using virtual elements and in Augmented Virtuality the virtual environment is enhanced using physical (or real) elements.

A number of studies have employed VR and AR environments to investigate exercises that improve spatial ability (Rafi, Samsudin and Ismail, 2006; Durlach et al. 2000; Sorby 2009; Chandrasekera, Yoon and Balakrishnan, 2012). These studies have incorporated both digital modalities, giving consideration to the two main defining characteristics of AR and VR: transparency and controllability of the interface. AR has been identified as having a large potential to impact design education (Ibañez, Di Serio, Villaran & Kloos, 2014).

Figure 2. Augmented Reality

There have been a number of studies which look at the use of Augmented Reality in Education (Billinghurst, 2002; Shelton, 2002; Pasaréti et al., 2011; Kaufmann, 2003; Chen, 2006). There have been investigations made as to why Augmented Reality would be a good medium for design exploration (Kim and Maher 2008, Seichter and Schnabel, 2005). Even though the use of Virtual reality has been documented in design education (De Vries and Achten, 1998), studies focusing on the use of Augmented Reality in Architectural and Interior Design education have been scarce.

From very simple aspects such as changing the color of a room in real time to looking how a building sits on a site can be very helpful for designers. Simple mobile applications such as Sightspace allows for the placing of a building in an actual site and looking at it using most mobile devices (Tablets and Smart phones). With the advent of wearable AR devices, the quality and "relative realism" (which is a similar concept to immersion and presence in virtual environments) is bound to increase in these AR experiences. Using software such as Metaio and Junaio (while Junaio is an AR browser, the Metaio Creator is used to create AR content) designers are now able to easily create convincing AR experiences without using any complex coding.

A study by Ibañez, Di Serio, Villaran & Kloos (2014) investigated the differences in students' learning from an AR-based application and a web-based application. Results indicated that the students who used the AR-based application had more positive feelings afterward, and showed higher levels of concentration while partaking in their design task. Because of this, the results led to the conclusion that students who used augmented reality attained a deeper understanding of the task at hand than those using a web-based application. While similar studies have been conducted in other educational domains, there have been few attempts to identify the possibilities of using AR in Architecture and Interior Design education.

This study focuses on an Architectural design project provided to students of an early design studio. The objective was for students to experiment with different forms. In most cases the material properties of physical model making materials tend to define and limit the capabilities of student's design ideas. Keeping this in mind the students were instructed to use 3D modeling software such as 3Ds Max and Sketchup while using BuildAR in order to augment the virtual model.

1.2 Technology Acceptance Model

Technology Acceptance Model (TAM) is the most widely used theoretical framework that looks at technology acceptance and there have been different iterations of the basic model (Fig 3). The two main variables that TAM incorporates are Perceived usefulness and Perceived ease-of-use (Davis ,1989). The Technology acceptance model was developed in order to identify the user's intention and bias to use a particular technology based upon its qualities of usefulness and ease of use (Davis, 1989). Some studies have identified Usability as a subcomponent of acceptability (Kaasinen, 2005), since usability and utility are considered subcomponents of usefulness (Nielsen, 1993).

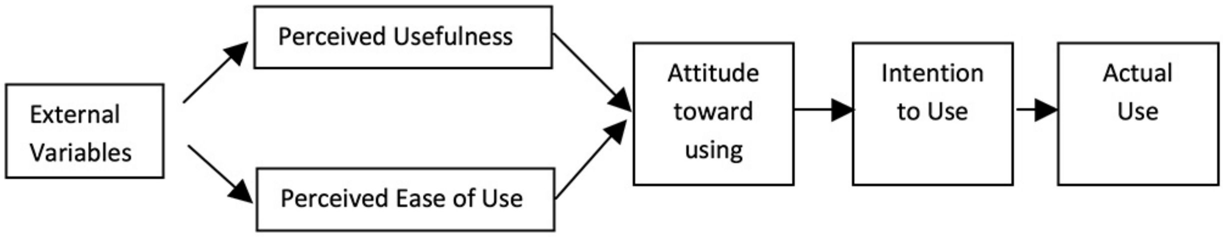

Figure 3. Technology Acceptance Prototyype (Davis, 1989)

Even though AR technology has been in existence for several decades, there is a gap in the knowledge on how human factors are affected by AR (Huang, Alem, and Livingston, 2012). A better understanding of user experience and user acceptance factors in Augmented Reality environments becomes important due to a number of reasons. With the emergence of new hardware that has the capability of supporting augmented reality applications, interest has been increasing on how to use this technology efficiently. For most designers with little or no knowledge on coding, it is only now that the tools are becoming available for creating seamless AR content. Studies of this type will allow the development of specific and general design and usage guidelines for augmented reality technology, not only in design education and design practice but in other fields of study as well. Moreover, understanding human perception on AR will allow the acceleration of introducing such technology to mainstream functional use.

Giving consideration to the use of AR in Architectural and Interior Design studios and the Technology Acceptance model, the primary hypothesis in this study was that student's Perceived Ease of Use and Perceived Usefulness of using AR tools in design would be significantly positive.

A secondary hypothesis was that Perceived Ease of Use and Perceived Usefulness of AR tools would predict their Intention to use AR in design.

2.0 The Design project

Students at a mid-western college in the US were given a project to design a monument for love, using a song as an inspiration. The relationship between music and design has been celebrated since antiquity. Vitruvius (Pollio, 1914) states that a good architect should "understand music, be acquainted with the consonance theory and mathematical relationships between the sounds". The students were required to choose a musical composition and then abstract it through a spatial structure which depicted their concept of love. The main objective of this project was for students to experiment with alternate forms and understand the principles of architectural abstraction. Students were required to make AR models of their project so as not to constraint them with properties of the available physical model making materials.

In terms of deliverables, students were required to make several presentations throughout the course of the project. They started out by presenting precedent studies on the abstract feelings that they were attempting to depict in their design. For their mid review and final review critique they presented their schemes focusing on conceptual development and spatial choreography. The students were encouraged to present their schemes as a journey through the design, expressing each space in terms of volume, material and emotion.

Students were instructed to proceed with design ideation through sketching before proceeding to digital modeling (Fig 4). In sketching out their design ideas students were encouraged to use different mediums

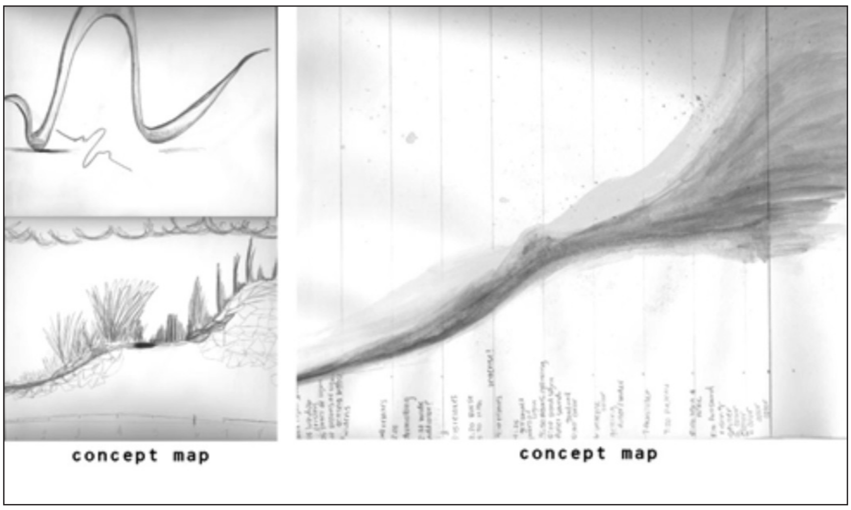

Fig 4: Student's development sketches of the Monument for Love

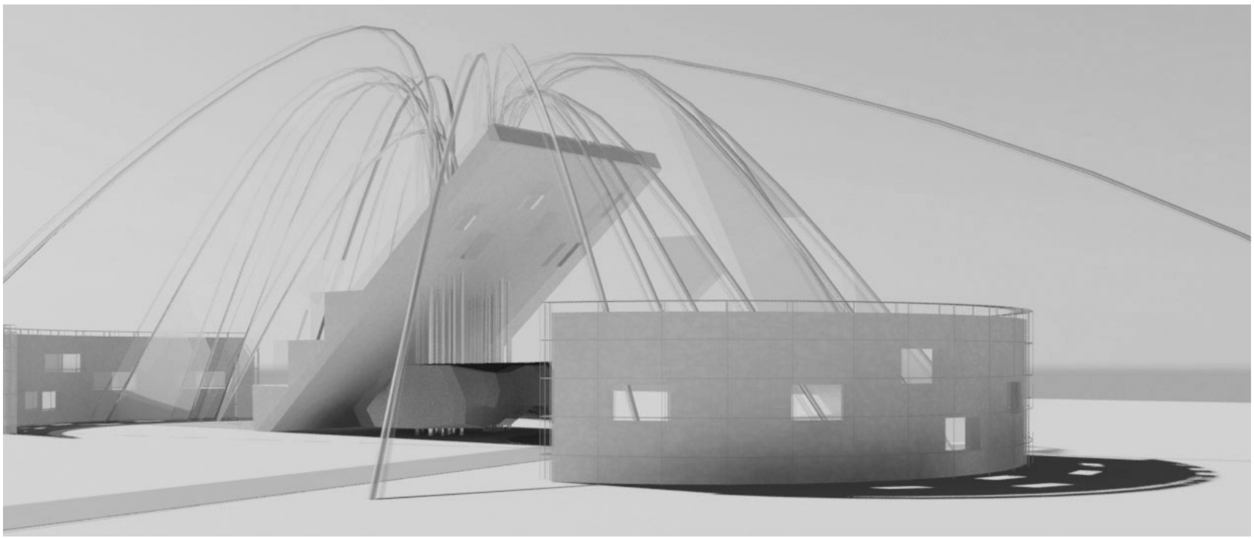

Figure 5. Stereoscopic images

Apart from instructing and providing lectures on how to use digital tools such as 3Ds Max, Sketchup, BuildAR, Photoshop and Illustrator, they were also provided with formal lectures on the basics of various formats in Architectural Diagramming.

After initial sketches of the design were completed, students started modeling using software such as 3Ds Max and Sketchup. Some students even experimented with stereoscopic vision (Fig 5) using 3Ds Max to better understand the spatial properties of the form.

After modeling in 3Ds Max/Sketchup, students exported the model as a .3ds format file. In order to augment the model, the students used an AR software called BuildAR (Fig 6). This software was developed by Hit Labs, at the University of Canterbury-NZ, and is marketed as a tool for building AR scenes for those without any knowledge of programming. The software supports marker based AR scenes, and can be used with any computer equipped with a webcam.

The BuildAR software provides two preconfigured markers, or the user can create their own markers. The software provides a means to overlay the virtual model over the marker, reposition it, scale it or rotate it. Students used their own laptops to test the AR models before presenting them in Studio.

Figure 6. Marker based Augmented Reality

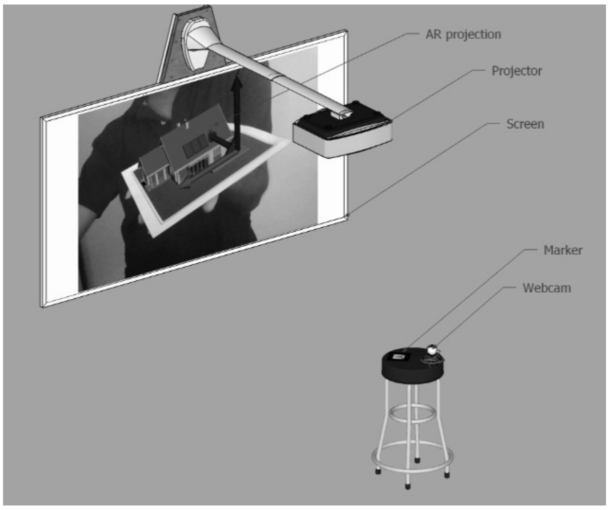

Figure 7. Diagram of the AR setup in studio presentation

The webcam identified the marker and overlaid the student's models which were pre-loaded to the program. Using a webcam and a marker, students projected their AR models to a screen (Fig 7). The invited critiques were able to use the marker to look at the models from different angles (Fig 8).

As a culmination of this project students arranged to exhibit their projects. This was envisioned as an interactive exhibition where visitors were able to listen to the music compositions through QR codes, while viewing the designs. The students also exhibited an AR model which could be viewed using an AR application available on smart phones (Fig 9).

3.0 Method

A volunteer sample of 15 Undergraduate students at a mid-western university in the US was selected for this study. The subjects were provided with a design problem

Figure 8. Students presenting AR prototype in a critique

Figure 9. Mobile AR exhibition

and were instructed to use Sketchup, and 3Ds Max for prototyping and rendering purposes. Finally they were instructed to use BuildAR for augmenting the virtual prototype.

After presenting their schemes the subjects were provided with an online questionnaire based on the Technology Acceptance Model (TAM) to assess their attitudes towards the technology used. Out of the 15 students only 9 students completed the survey. Out of the 9 subjects n=3 were male and n=6 were female.

The instrument consisted of 10 questions regarding assessing the acceptance of the technology by the user. These questions were based on previous Technology Acceptance Model questionnaires (Lai and Li, 2005; Park, 2009). The use of short/concise questionnaires to measure usability has been established by previous studies. The UMUX (Finstad, 2010) is a reliable, valid, and sensitive scale to measure user experience effectively The UMUX is a four item questionnaire. A more concise two item UMUX lite version is also considered to be a valid tool to be used in user experience studies (Lewis, Utesch, and Maher, 2013).

In the instrument, 2 question were on Intention to Use (IU), 2 questions were on Perceived Usefulness (PU), and 6 questions were on Perceived Ease of Use (PEU). The statistical package SPSS was used for analyzing the data. The Chronbach's alpha for PEU was 0.725 (after eliminating question #3) and Chronbach's alpha for PU was 0.763. Chronbach's Alpha for intention to use was 0.62.

Respondents were asked to rate their opinion using a 5-point Likert scale ranging from 1=Strongly disagree, 2=Disagree, 3=Neither, 4=Agree and 5=Strongly agree, for Perceived Ease of Use (PEU), Perceived Usefulness (PU) and Intension to Use (IU). Due to the low number of participants a factor analysis was not conducted.

4.0 Discussion and Analysis

The survey was based on the Technology Acceptance Model and contained questions that were modified but previously used in other questionnaires. Technology Acceptance questionnaires contain questions on Perceived Ease of Use (PEU) and Perceived Usability (PU) of the technology as well as the Intent to Use (IU) it later on. For the question "I think I would like to use Augmented Reality in my designs frequently" while 45% agreed or strongly agreed, 45% either disagreed or strongly disagreed. One subject stated neither. It would have been useful to evaluate their computer literacy rate in order to observe if there were any correlations between computer literacy and the potential for using new technology. Regarding the complexity and the ease of use there were interesting feedback provided. While for the question "I found the Augmented Reality simulation to be unnecessarily complex", 67% disagreed while 11% agreed, for the question "I found the Augmented Reality simulation easy to use, 45% disagreed and 33% agreed. The two questions essentially ask the respondents of the ease of use of AR software. While the majority disagrees that the system is complex to use, some perceived that the system was not easy to use.

Similar to the first question on usability the question "I think that I would need the support of a technical person to be able to use this Augmented Reality simulation" had similar reactions providing that 45% either agreed or strongly agreed and 45% either disagreed or strongly disagreed.

To the question "I felt that the Augmented Reality model might have compared accurately to a physical model" 11% strongly agreed 33% disagreed. 55% replied neither. While the end result of prototyping is to provide a method of solving a design problem, it should be noted that physical and AR prototyping are two different methods having inherent qualities that may not be comparable to one another. When asked about a

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Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
PEU	9	2.33	3.83	3.0185	.52337
IU	9	1.50	5.00	3.1667	1.17260
PU	9	2.50	5.00	3.5556	.72648
Valid N (listwise)	9				

Table 01 Descriptive statistics

comparison between a physical model and an Augmented Reality model through the question "I felt that the Augmented Reality model might have been inconsistent compared to a physical model." 56% of the respondents disagreed suggesting that students thought that both models may have been comparable, while 22% agreed. Similar to the previous questions on ease of use, the question "I think that most people will be able to learn to use the Augmented Reality simulation very quickly" had the group divided with 33% agreeing, 33% disagreeing while the rest remained neutral.

For the question "I thought the Augmented Reality simulation was difficult to use" 56% disagreed while 22% agreed. For the question "I felt confident in using the Augmented Reality simulation" 45% disagreed and 22% agreed. For the question "I needed to learn a lot before I could use the Augmented Reality simulation" 33% disagreed and 56% either agreed or strongly agreed. This result suggests that while the students perceived that the AR system was easy to use, they were not confident in their skills in using such a system. Since this was an early design studio, the students were still beginning to understand how to use different digital tools and that may have been the reason for this result.

While simple regression analysis was conducted to test if PEU or PU predicted IU, no significance was found.

5.0 Conclusion

While it is acknowledged that the low number of subjects makes the results less reliable, it should be understood that usually in design studio setting the number of students are kept low to provide better feedback from the instructor, keeping with the original idea of the design studio as a master-apprentice relationship. However, the author acknowledges that the study should be further enhanced using a larger number of subjects with the possibility of using two or more sections of a design studio. Given the novelty of the topic area of using AR models in Architecture and Interior design education, this study can be considered more a case study on how new technologies can be incorporated within the design curriculum. In future iterations of this study it is expected that questions regarding computer use/computer knowledge will be included to better understand how experience with computer systems may affect the usability and user expectations of Augmented Reality.

The study looked at how students used Augmented Reality prototypes in Architectural and Interior Design problem solving. Students subjective perceptions were documented through a survey based on the Technology Acceptance Model (TAM). The two main variables that the TAM survey identified were Perceived Ease of Use (PEU) and Perceived Usefulness (PU). While the primary (positive significance for PEU and PU) and secondary (PEU and PU correlation with IU) hypotheses were not supported by the results of the study some interesting aspects were seen with regard to the comparing AR models with physical models where it was suggested that physical models are comparable to augmented reality models and that they were easy to use. Given the flexibility of digital tools in providing novel means of solving design problems, AR prototyping provides us with a unique method for design representation.

While this study theoretically discusses why AR would be a potential tool to be used in design and design education due to the fact that it may help in alleviating fixation, the study does not provide empirical evidence to support this claim. Investigating the potential of AR in reducing fixation is considered a future direction of this study.

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