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Virtual Reality as a Design Tool to Achieve Abstract Concepts of Spatial Experience: A Case Study of Design Studio Teaching

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Abstract VR technology is one of the tools used to achieve accurate physical space dimensions and placement of furnishings. The architectural space must evoke subjective emotions that would inevitably lead the users to perceive it as a location and, consequently, become a potentially significant space. However, a particular space experience has yet to be attained. Quantifying abstract conceptual ideas is more difficult in design education. This paper aims to prove the usability of VR as an effective design tool and an educational method to achieve a better understanding of a proposed design and successfully reach the desired outcome, especially regarding the abstract properties of the space. The paper describes a workflow of how the students would use the technology to revise and enhance their design proposal based on the experienced VR environment. A project was offered to the students; they were expected to tackle and solve problems about symbolism in their designs. Spatial experience is a crucial study element of the project. Students were asked to design an entire structure that could evoke certain feelings. The exercise left it to the students to choose an abstract value, meaning, or feeling to explore as architecture. A pre-compiled list included: Anti-gravity, Time travel, and Tranquility; through iteration between drawing boards, 3D modeling, and VR experience, they fine-tune their designs to achieve a pre-set quality. In conclusion, the VR technology was proved helpful and led to a tangible change in the proposed design based on the feedback from the workflow.

Keywords Virtual Reality, Design Methodology, Architectural Design, Computer Supported Design, Evaluation, Experienced VR Environment

1. Introduction

Previous experiments have been undertaken on using VR (Virtual Reality) in education, inspired by the bright prospect of technology to improve spatial awareness. With its long existence since the 1950s, Virtual Reality has been used in a variety of formats realistically only since the 1990s, from visualizing things on a flat-screen projection all the way to today's immersive goggles. The first Head-Mounted Display (HMD) for VR was produced around 1965. At the beginning of the 1990s, a report illustrated the idea of Virtual Reality, demonstrating the reality stage using both augmented reality, AR and virtual reality, VR[1]. The technology has a proven capacity to enhance the perception of the work of designers, particularly architects, by experiencing built spaces in an immersive way, where the illusion produced by the medium deceives human senses to assume it to be true. Additionally, the search for (Virtual Reality on Architecture Design) on the ProQuest database yields more than 11 thousand articles on architecture and design in various aspects.

The design industry depends significantly on visual communication. Virtual reality allows designers to create a more profound sense of realism and a clearer view of the project by designing while immersed in it. Historically, architects have been confined to the two-dimensional world of drafting tables and, lately, to the flat-screen world of computers used in the design studio. Everyone is taught to complement their 2D representations with physical models. Great architecture has been realized using all the different representation methods. However, one significant difference between today and the past is the opportunity to experience the designed building at full scale before its actual realization.

Before the industrial revolution, builders used to build full scaled mock-ups of parts of their buildings, a technique that enabled them to experience and imagine how the completed building would look like far beyond what a 2D representation would reveal. Today, it is not that common to be able to build parts of a building to experience it before finalizing a design decision. Instead, architects have mastered several visualization techniques that enable them to understand what they are designing as much as possible [2]. Virtual Reality is another new technique of visualization that is bringing better ways to experience a design before it gets built.

VR technology is a one of the tools to achieve proper physical space dimensions and accurate furniture placement. The architectural space usually invokes a set of subjective emotions that would inevitably lead the user to feel it and, therefore, potentially become a meaningful space. Abstract conceptual ideas are more challenging to quantify in design education. Judging the success of a design proposal to capture a particular abstract quality is also difficult. VR technology could prove to be highly effective to architecture students to learn how to master creating a desired spatial experience relaying a specific abstract concept [3].

This research hypothesis is that VR can be an effective tool to teach students to design experiences rather than just creating proper physical spaces.

The technology can help achieve the right mood and the right space experience in a design proposal.

The research objective is to measure the success of using a VR platform to generate a meaningful spatial experience by conducting a case study running in a design studio.

2. A Brief Definition of VR

There is no common definition of virtual reality; based on their experience, physicists, developers, and computer users have different definitions of it. Generally, Virtual Reality is an environment generated by the computer, to the person experiencing it, closely simulating the reality [4]. Reference [5] defined Virtual Reality using the five “i”s of VR, which are: “intensive, interactive, immersive, illustrative and intuitive.” Mentioning that by missing one of those characteristics, there will be no VR. One of the main differences between visualization and VR is the emphasis on the visual sense as a communication tool. Virtual Reality is defined as generating realities that do not exist yet or are totally unavailable, thus consisting of more created (synthetic) parts than AR. VR is about simulating reality for a certain degree depending on a human-computer interface in which the computer creates an immersive sensory environment that is interactively controlled by the user. The aspect of reality that has been most frequently addressed is the visual one. Sight is, for most people, the dominant perceptual sense and the principal means for acquiring information [6]. For architecture, computer models of physical buildings, land or seascapes, these are virtual realities whether or not they are mixed with real objects [7]. The most recent definition of VR is described by Dionisio and Gilbert as “computer-generated simulations of three-dimensional objects or environments with seemingly real, direct, or physical user interaction” [8].

In the book: Stepping into virtual reality, the authors [6] reasoned that the psychological aspects of the VR experience are an active research area. It needs to be clarified which factors in a simulation can produce specific user reactions regarding emotional response, involvement, and degree of interest. One of the most essential concepts that help us understand the psychology of the VR experience is the “sense of presence.” Presence can lead to involvement and emotional reactions from the user. Once the brain integrates the 3D images in the form of a coherent environment, different reactions can arise. We may feel deeply involved in the simulation and experience various emotions. Capitalizing on this quality, this study investigates the ability of VR to inform the design decision of abstract ideas such as feelings.

3. History of VR in the Design Studio

VR systems have been used in several disciplines; military, surgical skills training, games and entertainment [9], but less in architectural design (Donath & Regenbrecht, 1999; Knight et al., 2003; Hemmerling, 2008). Additionally, some researchers have investigated the prospect of using VR in the design studio in education [10]. Reference [11] described the experience of the Calibre Institute with the implementation and development of Virtual Reality for educational purposes. They asserted that the building industry is one of the few industries that lack the possibility of using full-scale prototypes to evaluate and test their designs, assuring that VR technology is capable of providing an evaluation of visual and experiential aspects of a design [11]. Reference [12] found that VR systems were effective tools for evaluating designs with immersive and semi-immersive systems because of the wide field of view and a perceived high level of immersion by the user. The same author has explained that Virtual Reality is used in architecture education in the designing process, as it provides the designer with a full image of spatial relationships of design components instead of depending on imagination alone. In other words, VR has this particularity that helps create the spatial and topological relationships of design.

4. Design Process and Concept

Design is a complex and sophisticated skill that can be found all around us, whether we realize it or not [13]. Broadly, designing is not an easy activity, especially architecture design, which requires advanced stages of critical thinking, imagination, and creativity. Teaching Design Studio is considered a challenging task. Therefore, educators search for new techniques to achieve their goals.

The architecture design process is a way of expressing and turning ideas into a tangible space [14]. It consists of several phases, starting with a pre-design phase or project study and ending with the entire project presentation, including required Construction Documents (CD) (Fig. 1). The process begins with the design programming stage, where preference is given to activities such as collecting, defining, and analyzing information [15]. The ideation stage would be regarded as critical in the entire process; the designer produces an organizational thought of the project defined as the concept. The third stage will include the proposed project problem solution followed by evaluation and criticism. Finally, after achieving a concrete answer, the use of presentation tools/software will be considered to enhance and develop a final presented output. The book, the Universal traveler [16] considered the design process as an analysis and synthesis activity consisting of steps depending on creative problem-solving skills (Fig. 2).

As per the American Heritage Dictionary, in general, a concept is defined as a general idea or understanding of those driven by specific cases or occurrences. Consequently, the design concept could be said to be a general strategy or an abstract idea for solving the design problem under particular conditions. Additionally, it forms the headline of the design tale and creates unity and clarity for the proposed project. The concept of design is conveyed as both verbal and visual. Verbal concepts come before the visual, as the visual is about how the designer expresses the verbal, although it depends on the designer's abilities, thoughts, and project nature.

Moreover, the designed receiver plays a critical role in this process. In the design concept, thoughts are translated either into actual words/sentences or as a visual presentation, including design theme, color scheme, materials, and lighting. Both are physically represented and could be evaluated by the receiver. However, one element that is included in the verbal concept and ordinary ways that is difficult to assess is experience. 2D and 3D drawings can convey and visualize the aesthetic as well as technical aspects of a project. 3D rendering engines dramatically improved the final presentation quality in the last few years. But VR allows the receiver to immerse inside the design emotionally with all sensations.

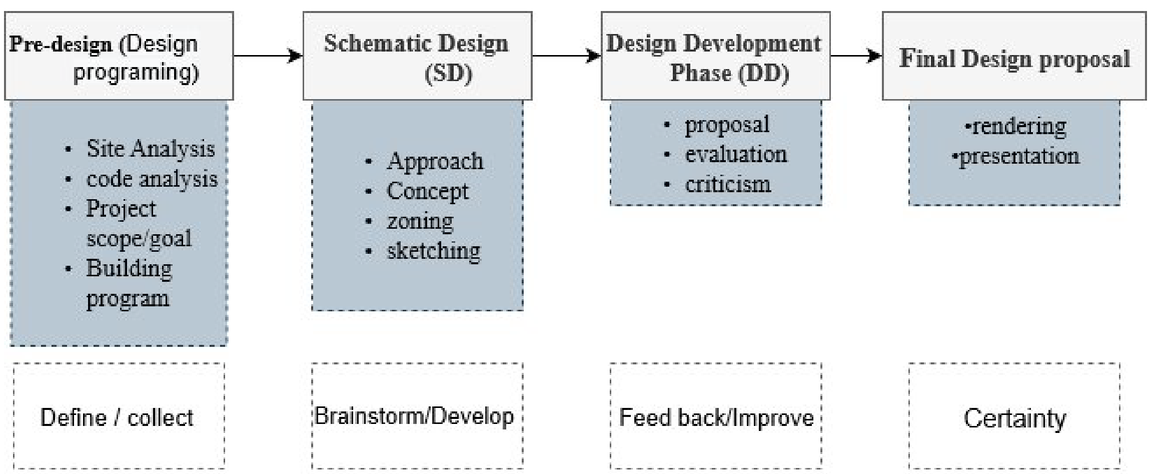

Figure 1. The Correlation between Designing steps, Design process and rational activity

Figure 2. Koberg and Bagnall design process steps.

5. Presence and Design Process

VR can play a critical role, as mentioned in the final stage, when students finalize their proposals. One element of the final design proposals could not be evaluated by traditional presentations, which is the *emotional space sensation experience*. Architecture design does not only represent a treated innovative form but also carries inner values that participate in space design success. This visualized value is related to the central design concept. The VR systems vary according to the amount of immersion they provide. Immersion is a perceptual state characterized by the feeling of being enveloped, included, and communicating with an atmosphere that consists of a constant stream of sensations and experiences [17]. The presence of the designer or client inside the space by using VR can help in understanding and evaluating the proposed design, moreover, examine the space functionality and the conceptual design as an experience. Presence expresses not only the physical transfer but also the emotional connection with space. The success of the virtual environment is related not only to the present but also to the involvement, in which designers will have the capability to interact with space emotionally (Fig. 3).

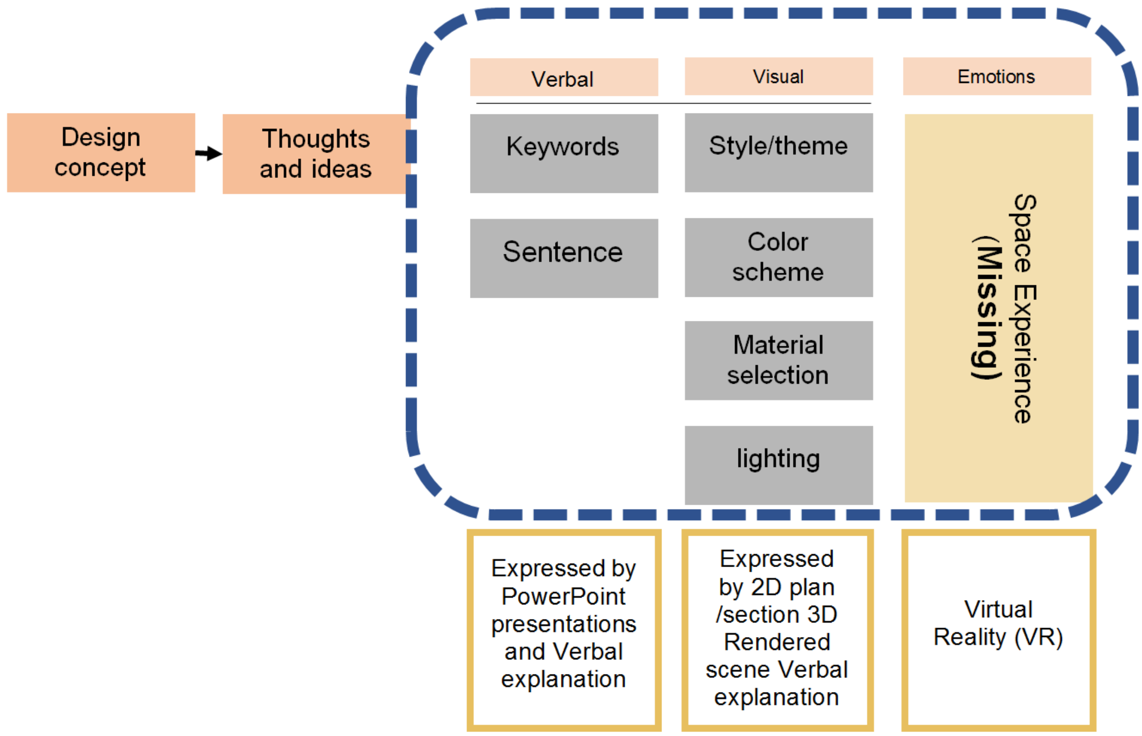

Figure 3. Design concept correlation with virtual reality use

6. Equipment

Hardware

The choices by that time were between two famous types, Oculus Rift and the HTC Vive. Although the HTC Vive had a higher price tag, it is a comprehensive PC-tethered virtual reality system that supports both motion controls and whole-room VR. It was an appropriate choice due to its ease of use and software accessibility (The Vive needs just one USB 2.0 port in addition to an open HDMI port to work). Fig. 4 shows the HTC Vive headset, touch controllers, and sensors and the setup used.

Figure 4. Design HTC Vive headset, touch controllers, and sensors

VR Software

When it came to the software decision, one of the main concerns was the availability of an educational license. Additionally, our target was hardware fitting and easy installation. The software had to be compatible with the proposed hardware and with architectural programs used. Moreover, the software should include a high level of reality simulation on the real-time rendering to easily simulate and mimic reality, including forms, materials, reflections, and lighting. At the same time, it should be compatible with the 3d modeling software used by most of the students.

7. Methodology

The purpose of this study is to explore the usefulness of VR in designing spaces that evoke particular feelings. The goal is to succeed in achieving abstract concepts of spatial experience. Besides understanding space, scale, and materiality, VR might be an effective tool to determine how space feels like. The study is a qualitative study where the outcome would be interpreted by the researchers.

The context of the experiment is Architecture Design Studio VI, where students are expected to tackle and solve problems about symbolism in their designs. Spatial experience is a crucial study element of the studio. For that particular project, the students were asked to design a full structure that can evoke certain feelings. The exercise left it to the students to choose an abstract value, meaning, or feeling to explore as architecture. A pre-compiled list included: Anti-gravity, Time travel, Tranquility, Purity, Clarity, Crystal, Chaos, Telekinesis, Summer, Winter, Paranormal, Metaphor, Metaphysical, Morphology, Morphisms, Mythical, Teleportation, Agoraphobia, Claustrophobia, Acrophobia, Lost, Despair, Joy, Fear, Ethereal, Transparency. The students were asked to produce their abstract ideas or choose from the given list.

The short project ran for two weeks, starting with an analysis of the meaning of the selected words, followed by discussions of what physical architectural elements would convey such feelings or abstract ideas and what spatial configurations would lead to experiencing meaning. Examples of famous works by renowned architects, such as Eisenman's "Memorial to the Murdered Jews of Europe" were studied and analyzed by the students.

Conceptual studies were generated using sketching and simple model-making, mostly away from computers and 3D modeling applications. In the design development phase, the students started modeling their solutions using a variety of applications ranging from Rhino3D, SketchUp, and 3DS MAX to Revit. In this phase, questions regarding the success of creating the desired experience/feeling were raised.

The VR system was introduced in this phase. Utilizing the service, "Kubity", to quickly translate SketchUp and Revit models to VR, the students converted their preliminary designs into a format that can be explored on the VR platform.

The process went as follows:

1) The students started by sketching and brainstorming after choosing one of the proposed feelings, which will be reflected in their final design output.
2) The students develop their 3D model in their package of choice where they would feel most comfortable.
3) If the resultant file formats were not compatible with the devised system, the instructor would help convert it into a suitable format. We were mostly focusing on SketchUp because of its forgiving nature and ease of use.

4) All the 3D model files were collected to be used with the VR viewing application using their Windows-based plugin.
5) The HTC Vive VR solution was used to visualize the models.
6) Students were requested to comment on their designs and reflect on how successful they were in achieving the spatial qualities they set to achieve. Each student would comment on their colleagues' work, judging if the desired quality has been achieved or not. Notes were taken.
7) Students went back to the sketching boards to modify or redesign their proposals according to the VR experience feedback.
8) Another round of VR exploration ran to ensure that the resultant proposal achieves the desired qualities.
9) Final presentation took place with drawing boards including orthographical presentations of the design proposals as well as the VR experience.
10) Qualitative analysis of the observation by the studio instructor of the collected comments and feedback of the students were conducted

Three meaningful examples of the student's work can be presented.

Most of the students got a chance to experience their projects in the VR environment. Three specific projects which significantly benefited from this experience will be presented. Each project had a unique problem to solve in VR.

7.1. Project 01: Chaos. (Fig. 5)

The student set to create a folly that would evoke a feeling of "*complete disorder and confusion*".

> *"The passageway begins inside a modular rectangular form. The form is subtracted with a distorted cylinder to create a passageway through the chaotic form."*

Through a process of transformations and arrays, the student modeled the idea on Rhino 3D and then experienced the resulting folly in the VR environment. The experience revealed a lack of inner space to comfortably experience the space. Reverting to the drawing board, different dimensions of the whole structure and the inner passage were tried. Another round of VR experience was tried to ensure the expected result was met.

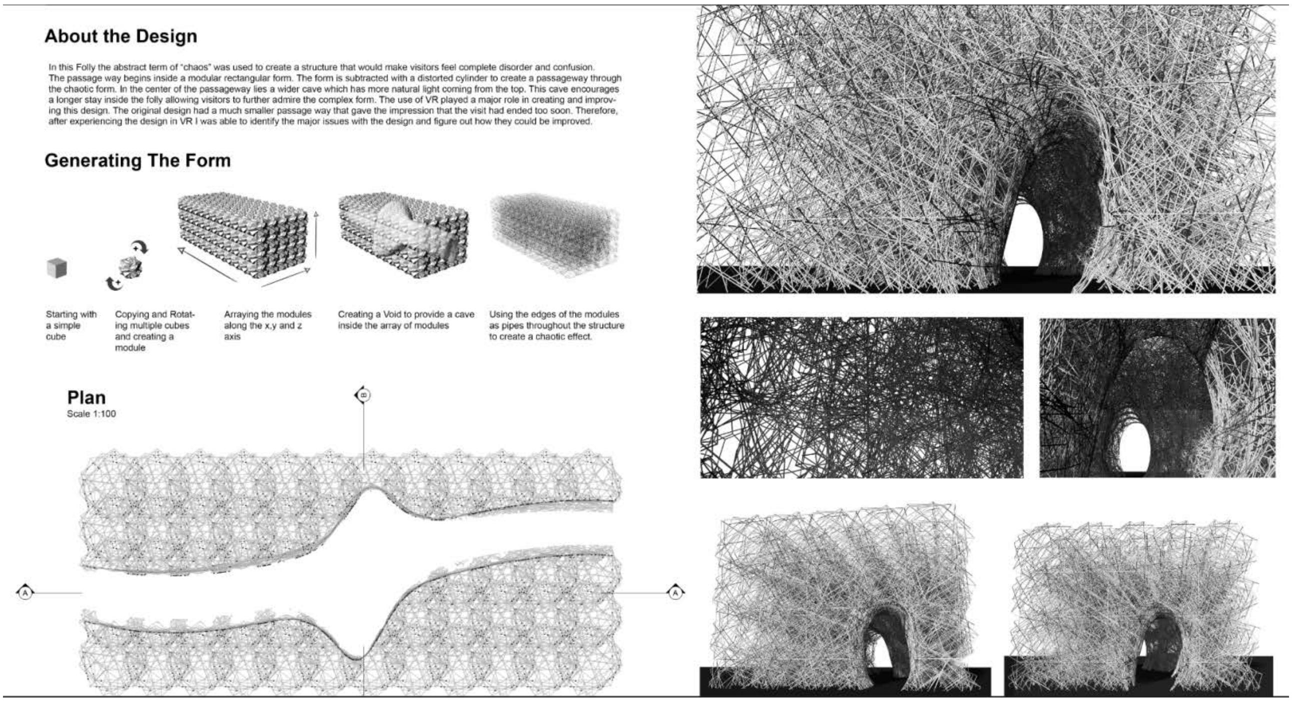

Figure 5. Chaos

7.2. Project 02: Levitation. (Fig. 6)

"Levitation refers to objects floating in the air against gravity. To achieve the sensation steps are created that gradually go up then down."

A different experience was sought in this design. The student wanted to achieve a sense of levitation where the user may experience an unearthly feeling of floatation.

The student utilized the VR experience to advance her proposal. Through a series of trial and error, she managed to refine her proposal to achieve her desired feeling.

The first proposal proved to be safe and missed many opportunities to feel risky and adventurous. Another aspect of this proposal was the use of the material. The student proposed using glass as the steps toward the top of the structure. Due to the visualizing capabilities and deficiencies, the glass material could have been a better solution. The students started exploring other solutions with no glass while focusing on reaching the same effect the glass steps would have achieved. Different size variations, as well as structural solutions, eventually succeeded in evoking the desired feeling.

7.3. Project 03: Discovery (Fig. 7)

The third example was a proposal to create a maze-like structure where solving it and reaching its center would bring feelings of joy of discovery. The innermost part of the structure would include an interesting sculpture, but the user must travel through the maze and feel disorientation but can finally reach the inner chamber with its reward. The walls were removed to let light and to reveal the inner structure to the users making it more intriguing.

"The project started with a simple maze with enclosed walls all around. Testing the design through VR tools showed the maze as being too simple. Hence the maze was modified and made more challenging."

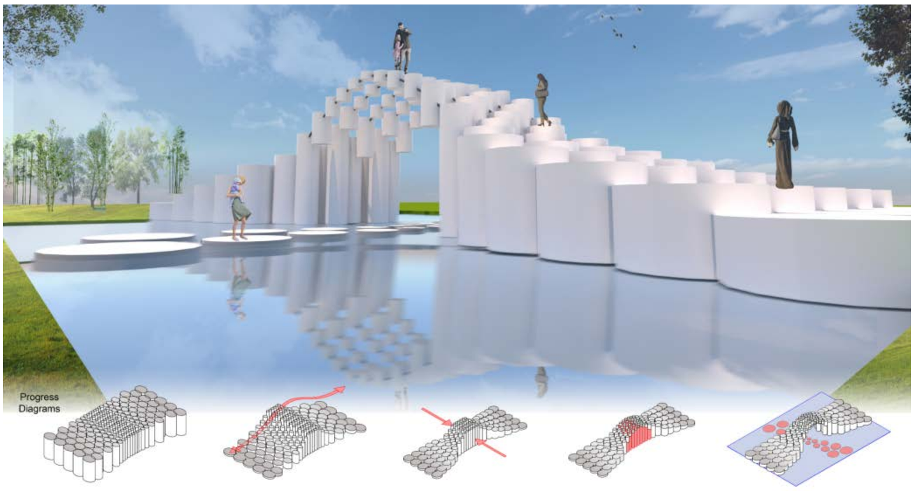

Figure 6. Levitation

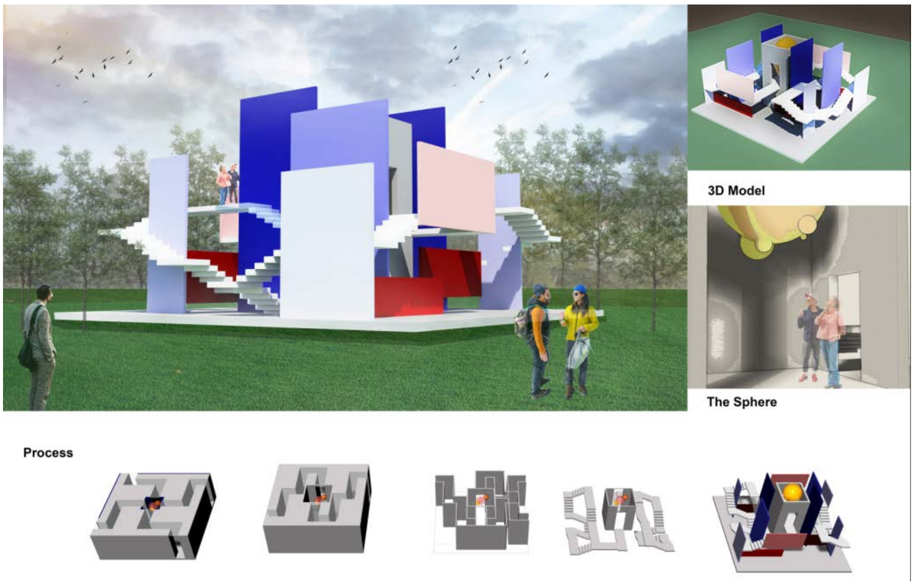

Figure 7. Discovery

The projects went through several cycles of modifications based on the acquired feedback of the students from the VR experience. Each student set to achieve a particular spatial experience started with paper sketches, then moved to computer modeling. Despite their fine skill of modeling, their judgment of success in achieving the desired experience was proven inadequate after experiencing their proposals on VR.

The students collected notes on their own experiences as well as their peers' experiences. The simple question: "Was the design successful in achieving the set goal?" and "Why?" was the basis of the second round.

Impressions of the experience were recorded and notes on how to improve the designs were taken. Another round of sketching and modeling that was based on the feedback was initiated.

8. Findings

The introduction of the VR experience was done in two stages; stage one was to introduce the students to the medium and its potential. We achieved this by using readymade models of famous architectural projects, namely the Sydney Opera House and Peter Eisenman's Memorial to the Murdered Jews of Europe. In this first stage, the ready-made projects served to experience the scale. The students were able to comprehend the difference between seeing the model on the computer screen and experiencing it in a VR environment. In the second stage, the students used their own design studies.

To measure the outcome of the experiment, the researcher conducted two data collection sessions, one after each of the previous stages:

First, after the first introduction of the technology when the students tried well-known architectural examples.

Second, after the students tried the technology on their own proposals and applied the desired modifications.

To collect and analyze the impact of VR technology on the decision-making process, a short essay was requested from the participating students in the first stage, then another survey was conducted among the participating students for the second stage as well.

A word frequency analysis (Table 1) of all the students' responses revealed a clear tendency to describe feelings evoked by experiencing the model in the VR environment.

Table 1. Students' response word frequency analysis after the first introduction to VR

Word	Occurrences	Frequency	Rank
felt	17	4.50%	1
model	10	2.70%	2
very	10	2.70%	2
able	7	1.90%	3
inside	7	1.90%	3
memorial	6	1.60%	4
see	6	1.60%	4
being	6	1.60%	4
building	5	1.30%	5
how	5	1.30%	5

Some of the students' feedback toward the Sydney Opera House were:

> *"…the scale of the model was much more realistic and bigger than what you see on screen."*

> *"Trying the VR for the opera house gave me a vague idea about experiencing the scale of the building in person. But because the 3d model quality was not too nice and because of the lack of details it was a little underwhelming."*

The reaction to the second example, the Berlin Memorial, was more intense with more emotions:

> *"… being in the memorial made me feel very intimidated by the big concrete blocks. I felt trapped and even claustrophobic."*

> *"…When I first saw the rectangular boxes (of the Berlin Jewish memorial) I was reminded of tombs. I felt very sad thinking about the many dead people that could be inside. So many people. The further I looked the more they seemed to get."*

The reaction of the students can be visualized with a word cloud composed of the 20 most used words in their written short essays (Fig. 8).

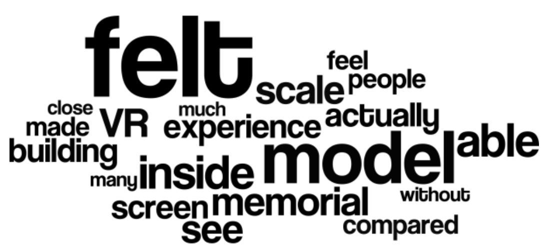

Figure 8. A word cloud of the 20 most used words in the students' short essays of the first stage

The second stage concluded with a survey of 7 questions:

1) How did you feel when you experienced your colleagues' work in VR? (Qualitative)
2) Did it match their announced expectations? (Yes, No)
3) Was it different from watching the design on the computer screen? (Qualitative)
4) If yes, how different? (Qualitative)
5) Did you benefit from using the VR with your own design? (Yes, No)
   Explain (Qualitative)
6) Did you change your design after your VR experience? (Qualitative)
   How many times, approximately? (Quantitative)
7) What was the change? (Qualitative)

Question no. 1: The responses can be summarized in the following word cloud (Fig. 9)

Figure 9. A word cloud of the 20 most used words in question 1

Where words such as *feel*, *like*, and *felt* are the top recurring words along with "love, *huge*, *interesting*, and *good* are indicating an emotional reaction to the design.

Question no. 2: The answers to question 2 were 89% *Yes.*

Question no. 3: The answers to question 3 were 100% *Yes.*

Question no. 4: The responses can be summarized in the following word cloud (Fig. 10)

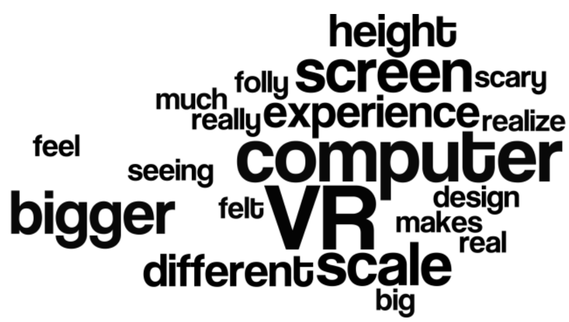

Figure 10. A word cloud of the 20 most used words in question 4

Among the wide distribution of the words, the most relevant word is *scale.* The perception of the scale of the design was the most relevant among the students. They were surprised at how unrealistic the perception of scale on computer screens versus the VR environment was.

Question no. 5: The answer to question 5 was 100% *Yes.* The students unanimously agreed that the VR experience made them change their design to better realize their concepts.

Questions no. 6 and 7: The answers were 78% *Yes.* The response indicates the student's ability to respond to the observed shortcomings of their proposals.

The analysis of all the response word frequency across all the questions:

Table 2. Students' response word frequency analysis after the second use of VR

Word	Occurrences	Frequency	Rank
yes	32	4.80%	1
felt	21	3.20%	2
like	17	2.60%	3
feel	17	2.60%	3
did	15	2.30%	4
design	12	1.80%	5
made	10	1.50%	6
experience	9	1.40%	7
walls	8	1.20%	8
very	8	1.20%	8

The response analysis reveals a consistently positive attitude toward the experience as a whole. The students were excited to try the technology and committed themselves to the feedback they received from their peers toward the enhancement of their design proposals. The resulting recommendations were much closer to the original set goals at the beginning of the exercise.

9. Conclusions

The benefits of using a VR system to examine a design proposal are remarkable. Despite how well the solutions were presented on paper, utilizing all the techniques architects learn to represent their building and to communicate the design intent and perceive scale, some aspect of the experience yearns to be communicated. The spatial experience where meanings are expected to be transferred and felt, in particular, is different when perceived inside the immersive space with VR than as a 2D printed perspective drawing.

Questions such as:

How high is a hall? Would it feel agoraphobic?

How wide is a corridor? Would it feel claustrophobic inside?

How dark is a particular material when not receiving enough light? Would that infer a feeling of sadness?

How threatening is a structural element when seen from underneath? Would it evoke fear?

Such questions were ambiguous and challenging to evaluate with 2D drawings or 3D conventional communication methods. The students gained a better understanding of their creations after experiencing them in VR. Their judgment on what they wanted to achieve was clearer, and their decisions to fix their designs were more effective. A comprehensive analysis of the results was presented.

VR proved to be helpful in evaluating such qualities of space. These benefits make VR a compelling new tool in education. It is now possible to describe to the students more dimensions of the design process that was harder to grasp before, which will significantly change the way we teach.

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