YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

THE ROLE OF VIRTUAL ENVIRONMENTS IN ARCHITECTURAL DESIGN EDUCATION: SPATIAL PERCEPTION AND DISTANT COLLABORATION

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PRESENTATION DATE: 10-JAN-2019

BORNOVA / İZMİR
DECEMBER 2018

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ABSTRACT

THE ROLE OF VIRTUAL ENVIRONMENTS IN ARCHITECTURAL DESIGN EDUCATION: SPATIAL PERCEPTION AND DISTANT COLLABORATION

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DECEMBER 2018

Since architecture as a domain has different working fields, architectural education and practice have discussions about, as well as the definition of architecture. A consensus has been achieved to put design studios as a core element of architecture education. While traditional presentation methods are used widely, technological approaches emerged such as on-screen virtual environments and immersive virtual reality systems. To compare the effectiveness of traditional and technological architectural representation approaches, previous studies adopted experimental designs. However, the design of experiments in previous works were based on single event activities and required financially not feasible setups. The previous studies on virtual collaboration in architecture are based on raw data exchange, verbal communication and transferred texts without the use of collaborative 3D virtual environments. This study aims to investigate how digital presentation methods influence spatial perception, to analyze the distant feedback efficiency through the digital data, and to define an application of distant collaboration for architecture students. This study uses a semester of an elective course and sets of tasks for architecture students. The data collection, virtual presentation setups, and distant communication handled through low-cost and cross-platform digital applications. Various experiments have been conducted to compare different presentation methods and measure the effectiveness of distant collaboration and feedback process in virtual environments. Results indicated that digital presentation methods have various advantages for understanding the project, volumes, surfaces, organizations, etc. Also, digital review systems increased collaboration between students, by focusing on the architectural work rather than personal communication between themselves. As a significant outcome, participants were comfortable using both on-screen virtual environment and immersive virtual reality.

Key Words: architectural representation, spatial perception, feedback process, virtual environment, virtual reality, 3d digital modelling, distant collaboration, co-design

ÖZ

SANAL MEKÂNLARIN MİMARİ TASARIM EĞİTİMİNDEKİ ROLÜ: MEKÂNSAL ALGI VE UZAKTAN İŞBİRLİĞİ

Ölmez, Duhan
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ARALIK 2018

Bir disiplin olarak farklı çalışma alanları olan mimarlığın, eğitimi ve pratiğinin yanı sıra tanımıyla da ilgili tartışmalar günümüzde devam etmektedir. Tasarım stüdyoları mimarlık eğitiminin temel bir unsuru olarak kabul edilmiştir. Geleneksel yöntemler projeleri sunmak için yaygın olarak kullanılırken, ekran üzerindeki sanal ortamlar ve kapsayıcı sanal gerçeklik sistemleri gibi yeni teknolojik yaklaşımlar ortaya çıkmaya başladı. Geleneksel ve yenilikçi mimari temsil yöntemlerinin etkilerini karşılaştıran çalışmalar deneysel tasarımları benimsemiştir. Bununla birlikte, önceki çalışmalarda deneylerin tasarımı tek seferlik etkinliklere dayanmakta ve finansal olarak uygulanabilir olmayan sistemlere ihtiyaç duymaktadır. Mimaride sanal işbirliğini ölçen çalışmalar ise işbirlikçi 3D sanal ortamlar kullanmadan, ham veri alışverişi, sözlü iletişim ve aktarılan metinleri kullanmaktadır. Sonuç olarak; bu çalışma, sanal sunum yöntemlerinin mekansal algılamayı nasıl etkilediğini araştırmayı, dijital verilerle uzaktan geri besleme sürecinin etkinliğini analiz etmeyi ve mimarlık öğrencilerinin bu sistemleri nasıl kullanabileceğini tanımlamayı amaçlamaktadır. Çalışma bir dönemlik bir ders boyunca gerçekleştirildi ve dönem boyunca öğrencilere çeşitli ödevler verildi. Veri toplama, sanal sunum araçları ve uzaktan geri besleme süreci düşük maliyetli, platformlar arası çalışan dijital uygulamalarla sağlandı. Farklı sunum yöntemlerinin kullanımlarını karşılaştırmak ve üç boyutlu sanal ortamlarda uzaktan işbirliğinin etkinliğini ölçmek için çeşitli deneyler yapıldı. Sonuçlar, tüm dijital sunum yöntemlerinin projeyi, hacimleri, yüzeyleri, organizasyonları ve daha fazlasını anlama gibi farklı avantajlı kullanımlara sahip olduğunu gösterdi. Ayrıca, sonuçlar uzaktan, dijital inceleme ve işbirliği sürecinin öğrenciler arasındaki işbirliğini, kendi aralarındaki kişisel iletişimden ziyade mimari parçaya odaklanmalarından ötürü artırdığını ortaya koydu. Tüm araştırma süreci, katılımcıların her ikisini birlikte kullanması halinde, ekran üzerindeki sanal ortamları ve kapsayıcı sanal gerçeklik sistemleri konusunda rahat ettiklerini gösterdi.

Anahtar Kelimeler: mimari sunum, mekansal algı, geri besleme süreci, sanal ortam, sanal gerçeklik, üç boyutlu dijital modelleme, uzaktan işbirliği, eş-tasarım

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor Assist. Prof. Dr. Onur Dursun for his guidance, support, and especially patience during this study. I appreciate those students enrolled to the elective course of Arch 4151 Virtual Environments for their interest, stamina and collaboration throughout the 2018 – 2019 Fall Semester of Yaşar University, İzmir. I would also like to thank to my colleague, roommate and friend Müge Sever for all the support and assistance she has provided during my thesis, I am sorry for messing up her table frequently and intentionally. Additionally, thanks to Türkan Cansu Koç Mohammed Azaden, Selin Güngör, Müge Sever (again), İrem Deniz Akçam, Feyza Durmuşlar, Erinç Yıldırım, Ece Buldan, Berfin Yıldız, Selin Karagözler Güleroğlu, Fulya Özbey, Cemre Çubukçuoğlu, Eda Paykoç and for tolerating my unbearable keyboard sound, grumpy conversations and my loud shouts in the corridors as well as covering me for the last month in Yaşar University.

I believe one thing has to be indicated, how helpful it was to have my car Lada Niva 1991 (known as Düldül), my hidden desk in the office, my 12 years old desktop computer with multiple screens and few other minion laptops. They were with me all the time and sacrificed a lot from themselves for this thesis to appear in a month. Those students always ask me what I am doing with all these equipment, if you are reading this, I am writing stuff while pretending like I am listening to you.

Finally, I am especially grateful to my fiancé Damla Gül Begüm Keke, who allowed me to work nonstop instead of spending time together with minimum damage to my mental health, as well as my family and friends, who brought me up to this point in my life and never stopped supporting my choices (except playing games, eating too much, talking loudly and doing funny things).

Duhan ÖLMEZ

Izmir, 2018

TEXT OF OATH

I declare and honestly confirm that my study, titled “THE ROLE OF VIRTUAL ENVIRONMENTS IN ARCHITECTURAL DESIGN EDUCATION: SPATIAL PERCEPTION AND DISTANT COLLABORATION” presented as a Master of Science Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Ölmez, Duhan
Signature

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February 11, 2019

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

VR	Virtual Reality
VE	Virtual Environment
AR	Augmented Reality
Q	Question, Questionnaire
MR	Mixed Reality
IVE	Immersive Virtual Environment
IVR	Immersive Virtual Reality
OSVE	On-Screen Virtual Environment
DOD	Digital Orthographic Drawing
DPB	Digital Presentation Board
DWV	Digital Walkthrough Video
OBJ	Object File Format
CPU	Central Processing Unit
GPU	Graphics Processing Unit
HMD	Head-Mounted Display
VRLE	Virtual Reality Learning Environments
HCI	Human Computer Interaction
3D	Three-Dimension
2D	Two-Dimension
TDA	Teamwork Activities in Collaborative Design
BIM	Building Information Modeling
MSCD	Modality Supported Collaborative Design
EBD	Evidence-Based Design Activity

NURBS	Non-Uniform Rational Basis Spline
GW	Group Work
IW	Individual Work

SYMBOLS:

%	Percentage

CHAPTER ONE
INTRODUCTION

1.1. BACKGROUND

"Just as the eye was made to see colours, and the ear to hear sounds, so the human mind was made to understand, not whatever you please, but quantity."

Johannes Kepler (Burrt, 1924)

As a word group, "Virtual Reality" includes two clashing definitions. While "virtual" corresponds something that is merely conceptual from physical reality (Beal, 2018), reality stands for the quality or state of being existent (Merriam-Webster, 2018). When these two components combined, even if virtual reality is known for perceiving computer-generated graphics nowadays, the meaning corresponds to the process of interpreting imaginary data to create a meaningful outcome for individuals whether it is a story, photo, movie, computer game etc. The recorded idea of "virtual reality", introducing a fictional creation or exaggerated real-life stories started with storytelling by cave paintings in ancient era (Selby, 2009). Changed its form through history and came to 21st Century by turning into computer-games, highly realistic fictional movies, immersive virtual environments etc. and continues with many forms and more to erect (BigFishPresentations, 2012; Hyland & Hyland, 2018).

Virtual reality was a narrative and non-immersive action to exchange ideas and stories from one to another until early 1990s. Invention of first flight simulations has created the idea of immersive technologies which imitate real-life situations within a device. These simulators were actual machines to surround individuals to provide them an interactive and immersive virtual environment (Navy Heritage Project, 2008). Very first conceptual thoughts of head-mounted displays (HMD) as immersive virtual reality systems use in 21st Century, started with a written fictional story within a form of goggles (Weinbaum, 1935). Since then, immersive virtual reality head-mounted displays advanced rapidly, nowadays, everyone can access a virtual reality device to experience imaginary data created by many others (Beqiri, 2018). VR tools extensively used in many areas such as medical applications, virtual anatomy, surgery training and rehabilitation, education, art, entertainment, military applications for navy, army or air force etc. (Burdea & Coiffet, 2003) Since the very first researches on virtual reality technologies up to today, simulations of real emergencies and critical situations were the main focus of virtual reality in education. Additionally, for the last decade, VR technologies also used for design related topics such as evaluating designs, virtual prototyping, architectural walkthrough, ergonomic studies and much more (Okechukwu & Udoka, 2011a). However, when educational applications met with virtual reality, it is most of the time used as two-dimensional on-screen images or animations, not immersive environments in head-mounted displays (Bell & Fogler, 1995a; Bricken & Winn, 1992; Byrne, 1996a; Eslinger, 1993a).

Design education requires vital teamwork, decision making along with conceptual thinking and inspiration (Page, Thorsteinsson, & Ha, 2007). The most common use of virtual reality learning environments (VRLE) is education in architecture, product, and industrial design, urban planning, interior design, and landscape design. These disciplines require a certain amount of communication between individuals to continue the design process. Virtual tools used to create a group work environment for students and instructors as well as a method to design conceptual elements. As a design discipline, architectural practice and education are highly cognitive which require collaborative work and understanding of imaginary spaces (Valkenburg & Dorst, 1998). Design collaboration is a problematic scheme because of its multidimensional cognitive interaction and various demands from stakeholders of design outcome (Bråthen, 2015; Luyten, 2015). Contemporary improvements in building industry encouraged digital supported collaboration and communication to improve architectural design process (Azmi, Chai, & Chin, 2018). Numerous different digital platforms have been used over the years for such aim in virtual environments of computer-generated graphics. At first, computer-aided design tools have been used to transform traditional representation and design tools into computers' virtual environments. Later, building information modelling made data exchange between parties easier to handle, improved design collaboration and communication over architectural documentations, again in virtual environments (Portman, Natapov, & Fisher-Gewirtzman, 2015). Due to extensive use of digital supported tools in design disciplines, standard definitions for both "virtual environment" and especially "virtual reality” are hard to find and often misused. Over the years, immersive virtual reality (IVR) as a surrounding immersive spatial perception and communication tool is confused with virtual environments (VE) which are on-screen displays of drawings, perspectives, three-dimensional models etc. The Webster Collegiate Dictionary (1983) had no definition until few decades ago. Later, virtual reality is defined as “computer-generated environment that, to the person experiencing it, closely resembles reality” (Webster, 2014). Sherman and Judkins defined five “I” of virtual reality as it is being used now, intensive, interactive, immersive, illustrative and intuitive. Without any of these characteristics, there are no virtual reality but only a virtual environment to use in many ways (Sherman & Judkins, 1992).

1.2. PROBLEM STATEMENT

Architectural education aims to give knowledge for designing of complex systems, environments, structures for living, working, playing and learning; including concerns related with engineering, architecture, urban planning, functional analysis and their integration (Bissonnaise, 2001). Because of these various extends of architecture education, curriculums composed of sets of different courses including architectural design, building construction, history of architecture, structures, materials, equipment, professional code, professional practice, art and even more (Muschenheim, 1964). Due to numerous responsibilities of architects, architectural education is not absolute: How to educate architects and what to teach became even more uncertain over the last decades as discussed in Programs and Manifestoes on 20th Century Architecture in 1970. There are many thoughts about what should be included or excluded from architectural education, what should categorizations be like and how architecture education should be handled through the history (The MIT Press, 1971). Despite this situation, academics and professionals have one major consensus on architecture education: Just like any other design discipline education, architectural education should present mainly a studio-based teaching/learning model (Büyükkeçeci, 2017).

Teamwork between close or distant parties in architectural design studios is one of the key features of architectural practice and education (Bråthen, 2015). Especially group projects require constructive collaboration to share their ideas and visions to achieve singe goal for the sake of projects (Idi & Khaidzir, 2018). Traditional methods of collaboration such as sharing orthographic drawings, sketching, physical model-making, brain-storming are still being used in early stages of design, yet new methods have been started to emerge to overcome difficulties of complex detailing and advanced spatial creation and exploration (Froese, 2010). BIM and CAD systems offer more user-friendly digital design environments for flexible and digital-supported collaboration (Jonson, 2005). However, these systems usually work within distant members just by sharing design documents from one to another via emails, shared cloud platforms, contributing nothing on design process but only helps to share complete drawings (e.g. Balamuralithara & Woods, 2009; Frost & Warren, 2000; Kvan, Maher, Cheng, & Schmitt, 2000; Tidafi & Iordanova, 2006). Additionally, use of such systems often lacks spatial experience and creative thinking when it comes to architectural terms. Architects and future architects in their educations frequently face problems with understanding of volumes which they create easily with BIM and CAD systems, during their design processes (e.g. Bråthen, 2015; Edwards, Li, & Wang, 2015; Guidera & MacPherson, 2008; Alcinia Z Sampaio, Rosario, Gomes, & Santos, 2013).

Immersive VR (IVR) systems embraced by architects as design concept presentation tools. Very first use of IVR systems in architectural design process highlighted the actual use of virtual reality within architecture discipline. The technology added another dimension of immersion and interactivity for three-dimensional computer-generated models and allowed individuals to explore their creations (Burdea & Coiffet, 2003). Researchers indicate immersive virtual environments empowered designers to explore imaginative spaces as well as express themselves with greater ease (X. Wang & Schnabel, 2008). Communication through immersive virtual environments is also proved as a useful method to perceive planned volumes (Koutsabasis, Vosinakis, Malisova, & Paparounas, 2012). To reach such results, previous studies established ways to turn imaginary spaces into virtual reality scenes, to explore their ideas, to experience spaces and to communicate through those systems with students and professionals. In general, technical and financial problems related with three-dimensional virtual reality systems in collaboration and perception are: (1) Manually re-design and re-model projects in a certain way to showcase in virtual reality, data exchange problems between CAD/BIM to IVR (e.g. Campbell & Wells, 1994), (2) confusion of virtual reality, use of walkthrough videos, CAD drawings, BIM models, 3D digital models etc. instead of immersive virtual environment to experience the design (e.g. Sun, Fukuda, Tokuhara, & Yabuki, 2014), (3) financially not feasible setup with high-end computer systems, expensive VR equipment, scheduling problems with insufficient equipment amount (e.g. Kan, Duffy, & Su, 2001), (4) use of numerous platforms together to provide collaborative design process between parties, creating coordination problems (e.g. Fröst, 2002), (5) hand gesture unfamiliarity in virtual environments to communicate and modelling virtually, limitation of creation methods in immersive virtual environments (e.g. Donath & Regenbrecht, 1996), (6) steep learning curve of 3D modelling and 3D sketching in immersive virtual environments, students devoting themselves to learn systems instead of using their current knowledge for detailing and drawing (e.g. Rahimian & Ibrahim, 2011).

Apart from technology related problems, the research design of previous works posed significant issues. In general, experiments were designed and later conducted to compare certain outcomes between physical and digital environments. While experiment group tried to understand a project from physical models, control group explored same project by three-dimensional digital models. Results indicated physical models were easier to understand due to its perceptibility in physical appearance. Also, models used in experiment were urban design models with building masses, which requires users to only understand shapes instead of volumetric perception or feeling of the space. Questionnaires also based on geometrical shapes of buildings like "Which one is taller?", "Which one is behind?", "How long this building is?" (Sun et al., 2014). These questions appear to be useful to understand mass organizations, not serving to spatial perception in virtual environments. Also, better perception in physical models may have occurred due to graphics quality of digital three-dimensional (3D) environment. All these conditions obviously are in advantage of physical models against digital ones, and therefore the results are biased towards physical models.

Different architectural representation methods served to understand several aspects of design in previous studies. For instance, while 3D sketching used for conceptual design, it was highly useless for detailed design (e.g. Leigh, Johnson, Vasilakis, & DeFanti, 1996; Rahimian & Ibrahim, 2011) or CAD drawings to demonstrate narrative collaboration on project evaluation in face-to-face critique sessions, but significantly limited to brain-storm for volumetric perception in project process (e.g. L. Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Whyte, Bouchlaghem, Thorpe, & McCaffer, 2000). While architects and architecture students prepare their projects for a specific design problem, they use various methods at different periods of process (Farrelly, 2008). Due to this multi-dimensional use of methods in process, each one of those methods respond specific requirements of designers towards exploring different perspectives related with design. BIM, CAD, IVR, VE, 3D Sketching, perspective drawing, mesh modelling, whatever system is being used alone in design process, are insufficient to conclude the design process by itself.

1.3. RESEARCH QUESTIONS, AIMS AND OBJECTIVES

Addressing the problems indicated in Section 1.2, the current study aims to investigate the role of virtual environments on architectural collaboration and spatial communication in architectural education. To offer a solution for technical and financial problems faced in previous studies, and to provide a common ground for data exchange in three-dimensional virtual environment, a software is proposed. This software enables to conduct comparisons between representation methods whether virtual environments enhance spatial perception as well as architectural communication and collaboration between parties. However, justification of such software and its comparison with previously used systems are excluded from the scope of the current work, since those systems are not commercial and out of access. The software within the content of this study is designed to collect data and to allow participants to perceive, to communicate, to collaborate, and to evaluate for investigating following questions, (1) how digital architectural representation methods influence architects' perception of space? (2) How can distant collaboration between architects in virtual environments effect the project development process?

One of the main goals in this study is to determine which architectural project representation method in design process is useful to understand the specified characteristics of the architectural project. Since physical models and presentation boards are the most conventional and proved methods to present certain aspects of the projects, physical appearances excluded from the content. Three main representation methods in virtual environments are selected to compare for quality of spatial perception and to support for design collaboration, on-screen two-dimensional computer-aided design drawings, on-screen three-dimensional digital mesh models and three-dimensional digital mesh models in immersive virtual reality.

Secondly, communication through virtual environment and its effect for architectural project development is studied. Conventional critique sessions in architectural design studios are based on narrative face-to-face communication between instructors and students. Offered systems for virtual classes are mostly based on peer-to-peer conversation or transferred texts through web-based systems, without getting involved with architectural piece itself. A new method of architectural project evaluation in virtual environments and immersive virtual reality within three-dimensional digital mesh models are introduced to observe effect of communication virtually for architectural design process in design studios.

Another goal of study is to compare spatial perception within immersive virtual reality based on scale of the project. The size of the project varies for each design problem and function demand, because of this reason created volumes require varied sizes. Perceivability of these spaces differs due to motion sickness, the field of view and many other features. Upon the same conditions in virtual environments, use of immersive virtual reality might be advantageous or disadvantageous to understand spaces, facades, interior organizations, and many other aspects in relation with projects' sizes.

1.4. RESEARCH DESIGN

The current study adopeted a so called mixed research design due to the nature of the phenomenon under investigation. Quantitative and qualitative methods were employed in combination to collect and analyze the data required to address the reseach questions postulated in Section 1.3. Conducting a study such as this one, where the outcomes are highly non-tangible, posed significant challenges from the perspective of research design, outlined as follows: (1) To the best of our investigation, there is no consensus on methods in measuring spatial perception. By other words, no standard technique or design of experiments has been agreed as a standard in the literature. Previous works have adopted numerous different approaches in their research designs. The same issue manifest itself in measuring the role of collaboration. (2) Related to the first issue as well as the nature of phenomenon under study, the data to be collected in the current work is either nominal or ordinal scale. This posed significant limitations on the data analysis techniques that can be employed throughout the study. In detail, usage of statistical parametrical tests and plausibility of any results that can be derived from these analyses have been under debate in the literature. Thereof, the analysis were left at the descriptional level, and no further inferential analyses have been made in the current work.

In this mixed approach, first quantitative data was analyzed and results obtained from these analyses were further reinforced from the qualitative data collected. All data collection process was handled through a series of experiments. Each experiment consists of numerous questionnaire surveys, where the numerical responses were either in nominal, or in ordinal – Likert Scale. The questionnaires also contains open-ended inquiries to collect qualitative data which reveals crucial information that cannot be covered by numerical data. This was the key while interpreting and discussing the results.

The experiments were designed to measure spatial perception in different virtual environment setups and architectural feedback sessions through 3D digital models. To these extends, an elective course related with virtual environments in architecture established in Yaşar University, Izmir through the fall semester of 2018-2019 academic year. Since the research team had no intervention in enrollment of the students to the offered elective course, the randomness of the sample is ensured. Although we note that, the elective course was enlisted as the fourth grade elective, and therefore the sample consists students attending forth year, mostly. However, due to regulations of Yaşar University, other students were also free to choose the course. The aim of the course is to provide students insights on how to use virtual environments effectively during their design phase, communication for their projects and presenting their final works. No specific modelling software is introduced in the course; therefore, students were free to use any software they would like to use to create their 3D digital models. After showing the essentials about 3D digital modelling and virtual reality systems, students were subjected to the previously designed experiments throughout the semester.

Digital tools have been used intensively to collect raw data and measurements, throughout the experiments. Communication with students were provided by using “Lectures System” developed by Moodle and administrated by Yaşar University for all the academic personal and the courses. For exchanging data and providing a common ground between different 3D digital modelling applications, another software called “KeplerVR” was proposed and presented to the students where they were able to observe the 3D digital models in OSVE and IVR views as well as leave reviews in the virtual environment as comments on the surfaces. For collecting data from surveys and questionnaires, Google Forms developed by Google have been used.

In total, 4 different experiments were presented to the students. These experiments categorized in two, to measure influence of architectural representation method on understanding different aspects of architectural projects (Experiment 2 and Experiment 3) and other experiments which include a collaborative virtual environment and aims to measure architectural communication by reviews and evaluation of students' projects (Experiment 1 and Experiment 4).

First experiment aimed to establish a validation process about students' skills in virtual environments, to create a 3D digital model, write descriptions to explain them, share it with classmates and evaluate the models. After the qualification of students recognized, they continued with the rest of the experiments.

Second experiment aimed to measure spatial perception of three single family houses in different virtual environment presentation setups. Projects were chosen from actual commercial projects developed by the same architect. Digital orthographic drawings (DOD), on-screen virtual environment (OSVE) view and immersive virtual reality (IVR) view introduced to the students. Since three different projects were chosen, all students looked at those projects in different groups and presentation methods. Later, their spatial perception and what kind of architectural features they understood the most in different setups have been measured by questionnaires.

Third experiment was also similar to the second one. However, instead of using small commercial projects, students observed third year design studio projects. Students were introduced to present their design studio projects with virtual environments and got feedbacks through them. Besides, their spatial perceptions were measured with the digital presentation boards (DPB) and digital walkthrough videos (DWV) against on-screen virtual environment (OSVE) views and immersive virtual reality (IVR) views. Grouping has been done to collect outcomes in relation with contemporary architectural design studio presentation tools and presenting the projects in virtual environments. Later, their spatial perception and key understanding of architectural aspects of the projects were measured by another set of questionnaires.

Last experiment designed as a process of multiple tasks in continuous weeks to respond why architects should use virtual environments during architectural project development for communication through the design itself. Primary aim was to handle this process from distant, which means students did not attend the courses physically. However, each week they assigned to different tasks and evaluated different types of models related with their individual or group work design studio projects. First three experiments created the base knowledge about creating a model in virtual environments, develop an understanding related with the projects in virtual presentation setups and evaluate them. When students were at the satisfactory level for their knowledge related with virtual reality systems, Experiment 4 was presented to them. Students conducted four virtual classes. They asked specified tasks along with the distant courses and the evaluation process handled through a specified software. Different aspects and phases of design process were provided for the experiment. Along with the course and students' design studios, volumetric mass models and planar modelling techniques were expected from them first. Later, they were expected to create the vertical surfaces on their planar models and develop their spaces. Then placeholders and furnishing in the spaces added and students were asked to choose the most important area of their projects. After all, a partial digital model of their volumes has been asked from students. Virtual classes handled through these sets of tasks for four weeks and attendees reviewed each other's projects with randomly generated lists in virtual environments. At the ends of each weeks' tasks, different questionnaires have been used to measure the feedback process among the students.

Descriptive statistics of the experiments indicated the quantitative results of the questionnaires and their impacts for the study aims. After demonstration of each answer sets of questionnaires, discussions handled by the help of visualizations of the data. Even if both quantitative and qualitative data collected from the students related with the experiments, only quantitative data examined widely to generate the outcomes whereas qualitative answers were used to have a deeper understanding of the topics.

1.5. STRUCTURE OF MANUSCRIPT

The current work composes from five different chapters. As the first chapter is introduction, the following content, theoretical background is presented in Chapter 2. In the frame of the literature review, definition of virtual reality, its history and different devices have been introduced first. Following, various uses of virtual reality systems in education have been investigated. Within the scope of this study, architectural education and as its essential, design studios were explained briefly. As the main goals of the study was to measure spatial perception and architectural collaboration, definitions of them and techniques of measuring these phenomena were investigated. At the end, the critical review of the literature was conducted to specify the gaps and the state of the art about virtual environment and its use in architectural practice and education.

In Chapter 3, the methodological approach of the study was presented, exhaustively. First, the opened elective course and data collection tools have been introduced. Second, the initial characteristics of the sample has been presented to create a primary knowledge and lists for the experiments. The influencing factors and the response variables of the study were explained. At the end, questionnaires to measure spatial perception and architectural collaboration, as well as each experiment with the selection of the contents and their processes, were described.

Chapter 4 outlined the results of the study. In this chapter, descriptive statistics of the sample, the students of the course in the content of this study, were illustrated. Results and discussions of each experiment as well as key findings have been presented with the outcomes of each questionnaires. Also, interrelations between the experiments and qualitative commentaries have been presented. Later, comparisons with the previous studies have been conducted in terms of spatial perception and distant collaboration.

In Chapter 5, a summary of the study process and projections for future researches were presented.

CHAPTER TWO
THEORETICAL BACKGROUND

In literature review of the current study, deductive way of reasoning has been used. Based on the keywords a thematic grouping is prepared which include but not limited to history of virtual reality, virtual environment systems, architectural education, spatial perception and architectural collaboration. To narrow down the research field, the study focused on intersection sets between these thematic groups such as use of virtual reality systems in various education fields, use of immersive virtual reality (IVR) and virtual environment (VE) systems in architectural education, how IVR tools enhanced communication and collaboration between parties in design etc. The main target of this section is to review previous studies on use of VE systems in architecture field, how it has been used before, what their findings are and gap in the literature.

In broad terms, the chapter will cover following sections, virtual reality, its history,VR technology and development of its equipment, use of VR systems in education (engineering education, military training, design education etc.), architectural education and its focuses, spatial perception and how to measure it as well as architectural collaboration and how previous studies tried to measure them.

2.1. VIRTUAL REALITY

Virtual reality has been defined in different ways over the years. At first, it was only related with storytelling, however after technological advancements its definition evolved. On observing the evolution of the definition of the two words, namely “virtual” and “reality”, virtual corresponds something that is merely conceptual from physical reality (Beal, 2018). Reality, on the other hand, is a word which clashes with the idea of virtual. While virtual stands for things which does not exist at all, Merriam-Webster (2018) defines reality as “the quality or state of being real” (Merriam-Webster, 2018). Virtual reality, as a word group, implied a computer-generated simulation for environments and graphics which is not real yet can be perceived as real with the help of head mounted displays by users (Portman et al., 2015).

Contrasts among these words and how they have represented meaningful phrase can be explained by its journal throughout history of storytelling. Storytelling created the essentials of virtual reality. Technology made it possible to perceive virtual with our senses. Therefore, following section is allocated to the concept of storytelling and its history. Next, technological advancements for demonstrations of virtual realities are explained. Lastly, principles of virtual reality as known in 21^{st} Century are introduced.

Throughout the history, storytelling has formed in various methods. Storytelling is the activity of telling a real or exaggerated reality or fictional stories (Hyland & Hyland, 2018). While doing so, it differentiates from reality with exaggerating the feelings, situations and senses. The approach is to create a scenery, to make listener to feel what is being told in a more immersive way. Verbal, visual and interactive systems, such as narrative storytelling, cave paintings, printed stories, photography, films, televisions and video games, have been used over the history (Okechukwu & Udoka, 2011b).

Based on anthropological evidence (Selby, 2009), roots of storytelling started around 15000 - 13000 B.C. with the very first known cave drawing story in Lascaux Caves in Pyrenees Mountains (Figure 2.1) in Southern France as it is the very first recorded story in literature (BigFishPresentations, 2012). It is the first evidence of people trying to tell stories by drawings, one to another to experience something different than what happened. Even before that, people were gathering in groups to tell stories to each other to picture themselves in different environments, stories, and situations. After cave paintings and storytelling, first printed story was “the Epic of Gilgamesh” which took place in Mesopotamia and then spread to Europe and Asia. Stories were needed to explain more intimate feelings of events instead of reporting them directly. People told stories about wars, cases, accidents, how they built things, life of important people and daily things. These are all used to demonstrate a picture for people to imagine themselves in different ways, experience what has been said or explained.

Figure 2.1: Cave Paintings at Lascaux Caves

Printing technology is firstly found in Eastern Asia, used for mostly religious texts and important scripts. Carved woods outlined by written papers were used to multiply written texts. The oldest printed work known is a Chinese Buddhist script printed in 868 (Compass Rose Horizons, 2005). With the modern printing technology developed in 1440s by Johannes Gutenberg, printed stories and books were accessible to common folk. It increased the demand as well as supply of fictional and non-fictional stories (New World Encyclopedia, 2015).

Narrative stories, carved stones, paintings and printed books then met with photography invented by a Frenchman, Nicephore Niepce in 1827 (MozTeach, 2010). Heliographs were the first version of photography which have a different creation way than we have in modern times. They were carvings of the light which caused by the sun, on paper. After this technique, technological advancements provided an image with negatives on a celluloid material. This method can capture the exact image of reality. However, all photographs were black and white for another 80 years until autochrome photography introduced in 1907 by Auguste and Louis Lumiere. While storytelling and painting is based on imagination and what artists desire, photography is more related with reality. Therefore, photography gave away the idea of poetry and imagination for the sake of authenticity (Touchette, 2017).

After 50 years of imagery and stand-still views of reality, extended with motion pictures and televisions. Developments in photography started with Eadweard Muybridge, who invented the first motion picture device studied the motion of horses in a series of pictures that demonstrates different phases of horse’s running, in 1877

(MozTeach, 2010) (Figure 2.2). However, it was only series of photos taken by 12 different cameras to show individual photos repetitively for imitating the sense of motion.

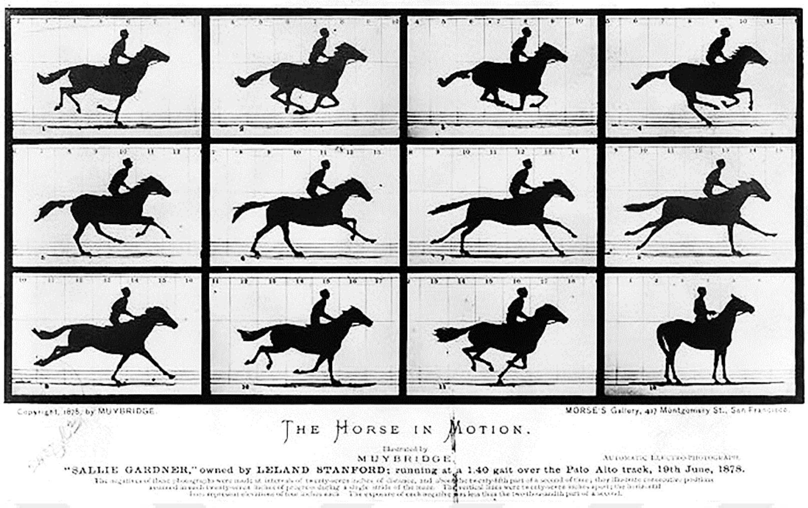


Figure 2.2: Eadweard Muybridge Experiment of Horse Motion

After Muybridge, a French physiologist named Etienne-Jules Marey used a single camera device looks like a rifle to take 12 successful photos (Sklar & Cook, 2018). Despite Muybridge, Marey tried to explore the motion of birds while they are flying (Figure 2.3). Then these pictures printed on glass rotates for a second to demonstrate motion for human perception. Both scientists' methods had 12 frames per second.

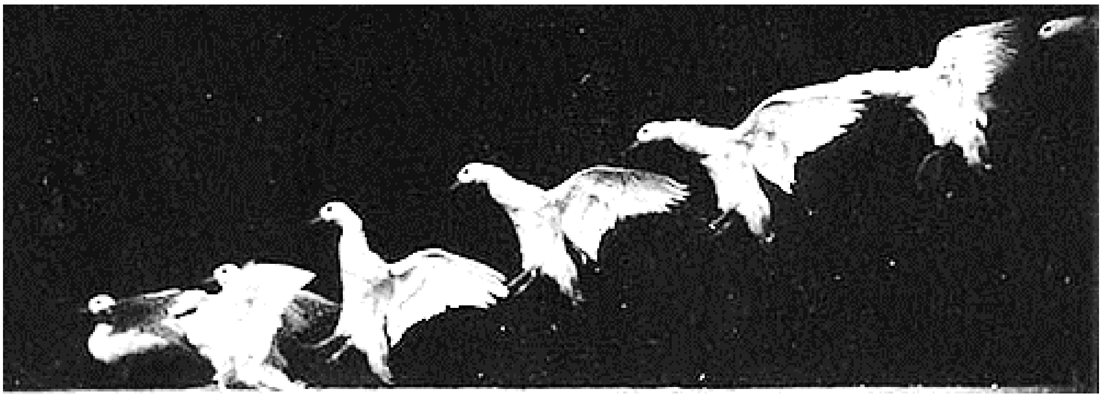


Figure 2.3: Étienne-Jules Marey, Flight of a Bird

These two scientists' works then explored and used for profits by the ones who came after them (Sklar & Cook, 2018). In 1887, after ten years from Muybridge's works, an Episcopalian minister named Hannibal Goodwin developed a device to record longer and more complicated scenes with their motions and created strip film (Sklar & Cook, 2018). However, developments in the motion picture were only used for repetitive movements of people or short clips such as people walking, trains coming to stations, a view of the town centre, etc. The method by Muybridge and Marey, is used to capture motion and Goodwin's strip films, later used by Thomas Alva Edison and Dickson in 1888 to create the most popular home-entertainment device of 19th Century (Rutgerts, 2016). Films created with this method had 40 frames per second. Technological developments in motion pictures enabled artists to manipulate reality, write down stories and scenarios to create virtual realities for viewers, to show them something different than what they have experienced. Cinema industry even today is one of the most significant entertainment sources for society. In 2015, TV and video revenue worldwide reached to the volume of 286 Billion USD; whereas by 2020, estimated revenue is 324 Billion USD (Statista, 2018a). In 21st Century technologies have provided filmmakers new methods to impress viewers with special effects, montage technology, and 3D cinemas.

Stories, books, photos, and movies are mostly generated according to a scenario or script and people had the chance to imagine and experience the embedded fiction as theirs. However, when the fictional story demand of society varied, a new industry born at the 1960s. The very first video game is assumed to be "Spacewar!" developed by Stephen Russell in MIT (Juul, 2008) (Figure 2.4). The game run at a computer so big, it required a room to build at that time. Even if the graphics quality was so primitive, players were still able to get in a fictional space in a fundamental level. However, computer build it requires at those years were not easy to find.

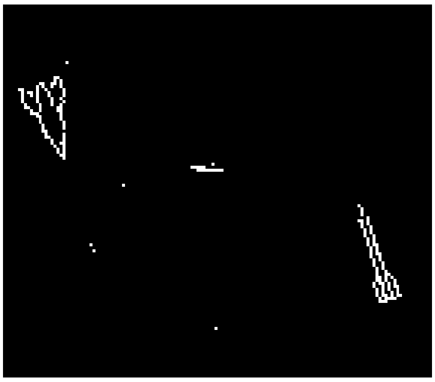


Figure 2.4: Spacewar! The First Computer Game, 1962

Arcade games, which presented dedicated devices in public spaces for people to play certain games and narratives, were preferred more than expensive setups for personal use. The first arcade game to commercialize was "Computer Space" by Nutting Associates in 1971. Right after a year, in 1972, Atari got into the market with Pong which had huge success (Tyson, n.d.). In the same year, Atari introduced the very first home console. It was a massive success for the industry and people to access video games easily. In 1975, Microprocessors, an achievement in circuit boards, were developed that made computer games more robust and made the visuals to be more continuous. In 1979, first handheld gaming devices known as "Microvision" invented, allowing people to play games with a smaller device which was a breakthrough. Similar controllers still being used by many gaming consoles as well as well-known GameBoy in 1989 (Listverse, 2010) (Figure 2.5).

Figure 2.5: Microvision Handheld Gaming Device, 1979

The very first commercial three-dimensional video game 3D Monster Maze was developed in 1981. Realization of realistic environments and allowing players to walk around in perspective enabled areas was a huge breakthrough. Beginning with 3D Monster Maze game, more games focused on creating a whole walkable environment for players. However, it was still using two-dimensional objects in an environment. The first fully three-dimensional commercialized game was developed 15 years after in 1996, Quake (Chikhani, 2015) (Figure 2.6).

Figure 2.6: Quake in Game View

After developing the essentials of gaming and improvements in computer processor units and graphics processor units, games have become more realistic progressively. Offering fully open-world, discoverable, story-based and realistic looking games created fictional environments with stories and challenges attracted more people over the years. Popular examples, such as Grand Theft Auto 5 by Rockstar Games, Minecraft by Microsoft, World of Warcraft by Blizzard, The Elder Scrolls V: Skyrim by Bethesda, were best-selling games of all times in gaming history, with unique stories to explore (Mogi Group International, 2017). Value of the global video games market was 52 Billion USD at 2012, and it is estimated to be 138 Billion USD by the 2021 (Statista, 2018b) (Figure 2.7).

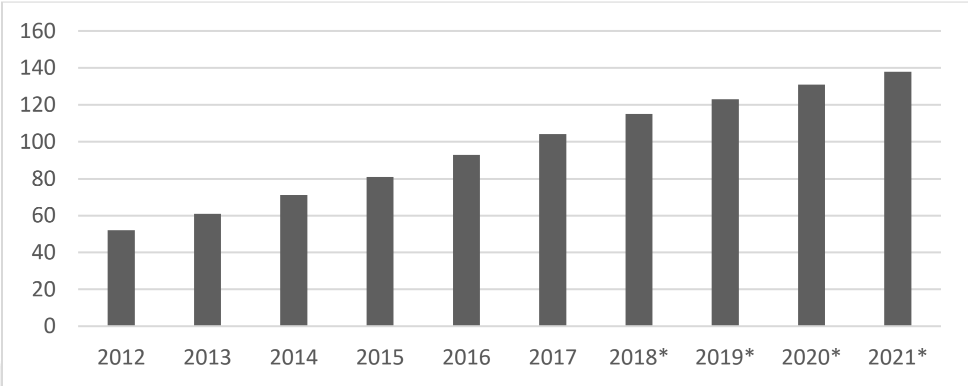


Figure 2.7: Value of the Global Video Games Market from 2012 to 2021 in Billion USD

Growth in the video game and movie industries prove an increasing demand for virtual environments as new methods have been introduced. However, none of these fictional or adapted reality presentation methods disappeared after another one invented. Society did not stop telling stories when photography invented; it evolved into news and verbal presentations for new devices we have. Televisions and movies have continued growing as an industry when video games invented. Instead, video games and movies started to cooperate with their stories and now, society sees movies based on video games and vice versa.

With photography, digital communication, and video games, storytelling represented as a two-dimensional view or narratives to customers. When immersive virtual reality term introduced, all these old methods were just an imitation of realities on papers and screens. Researchers (i.e. REF: Couple of examples) who make their researches on virtual reality started to focus on reality imitations allowing people to perceive as they are in that environment.

2.2. VIRTUAL REALITY DEVICES

By the date 1929, a pioneer Edwin Albert Link introduced LINK trainer also known as Blue Box or Pilot Trainer (Navy Heritage Project, 2008). A device looks like a small plane to train pilots for real events more safely and controllably. The tester is cut off from the reality while using this device. The system was simulating reality with the help of engines. Tester can feel movement and acceleration using the controls in cockpit-on-the-ground. Used for a long time before and during World War II for reducing casualties in training. Blue Box created the fundamentals for modern flight simulators (Figure 2.8). However, at that time, virtual reality as a term still was not used.

Figure 2.8: Link Trainer Instructions. WWII Navy Publications

The pioneer scientist to use the term “virtual reality” was Stanley Grauman Weindaum in 1935 with his publication “Pygmallion’s Spectacles” in Wonder Stories Magazine (Figure 2.9). The main character in the story which is an elfin professor gives a pair of goggles to users which enables them to see a movie giving sight, sound, taste, smell, and touch. The idea was to put users in to the story, users talk with shadows, and they reply. The main idea of the invention is not showing movies on screens. The story was all about the user, and they were living it through their own eyes (History of Information, 2012).

Figure 2.9: Cover of Pygmalion's Spectacles by Stanley G. Weindaum

In the mid-1950s, a cinematographer named Morton Heiling invented a device looks like an arcade gaming machine with integrated stereoscopic films with motion, wind effect, stereo sound, and chemicals to make viewer smell things according to the movie they watch (Cruz-Neira, Fernández, & Portalés, 2018). Later, Sensorama patented in 1962 (3050870, 1962) (Figure 2.10), however, due to its size, financially not feasible structure and content lack it did not last long.

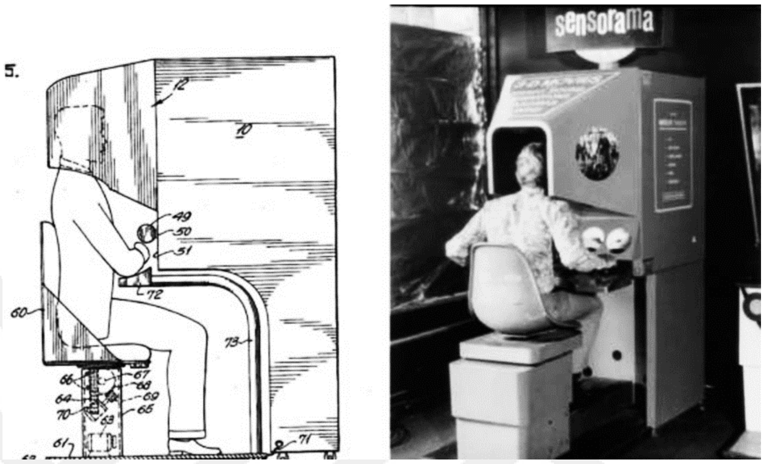


Figure 2.10: Sensorama Simulator Sketch and Picture, 1962

Until the 1960s, virtual reality systems were large and not useful for personal use at homes or offices. They all required a relatively big room to build and time as well as knowledge in computer systems. After Weindaum’s vision, in 1961 first head mounted display (HMD) virtual reality system, “Headsight” introduced to the world. Two employees at Philco Cooperation, Comeau and Bryan, invented the first motion-tracking HMD not for especially virtual reality use but for military use (Figure 2.11). Soldiers and military personals were able to look at dangerous situations and sites within this device (Maeda, Arai, & Tachi, 1992).

Figure 2.11: Headsight: First HMD by Comeau and Bryan

In 1965, four years after first head mounted device, a computer scientist Ivan Sutherland introduced his vision about Ultimate Display (Sutherland, 1965). His idea of HMD is to replicate reality so well; the user would not be able to differentiate reality with virtual. His foresight also includes interaction with objects in virtual environments. The paper he published created the fundamental blueprint of modern VR. Two years after his work, Sutherland and his student Bob Sproull created first virtual reality head-mounted display, “The Sword of Damocles” (Figure 2.12). The invention was considered as the predecessor of modern augmented reality (AR) and virtual reality (VR) displays. The system had its own computer system and head position sensors to display views of vector images according to user movements in changing perspectives (Kostov, 2015). The prototype still was not viable due to its heavy weight and suspension from the ceiling.

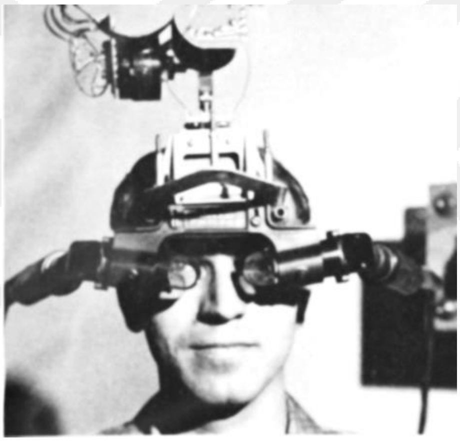


Figure 2.12: The Sword of Damocles by Sutherland and Sproull

In 1975, Videoplace by Myron Krueger showcased at the Milwaukee Art Center, which known as the first interactive VR platform. He used the term artificial reality in his publication. However, instead of using HMD, Krueger used a room-sized black panels with simulated views on them which mimics silhouettes of the user. People were able to get interactions with objects on the screen with the help of their silhouettes. The person next room also has the same system, and they both communicate with each other in a virtual environment. The idea was to create a new communication system for people lives far away in a virtual world even if they are not physically together (Krueger, Fionfriddo, & Hinrichsen, 1988).

Taking people to other places were not only thought by Krueger, in 1977, Aspen Movie Map by MIT used series of photos of Aspen City in Colorado like street views in google to demonstrate a virtual environment for users to feel the city by cars. No HMD had been used. However, it proved virtual realities can transport people to places they desire (Anable, 2012). In 1980, StereoGraphics Company invented stereo vision glasses which was a massive breakthrough for virtual reality world. The idea is to present two offset images for both eyes to enhance depth for the viewer. In 1982, Sayre gloves invented by Sandin and Defanti in a cross-disciplinary research laboratory in Chicago (Sturman & Zeltzer, 1994). An inexpensive, lightweight, wearable glove monitors hand movements of the user and transform them into digital data for computers. Gesture recognition with a wearable was introduced for the first time in the history. Jaron Lanier and Thomas Zimmerman established VPL Research Inc. Company mission was to produce wide range of VR equipment accessible for everyone. All researches have been done until 1985, turned into commercialized items by the company. DataGlove, EyePhone HMD and Audio Sphere were some of these equipment (Thierauf, 1995) (Figure 2.13).

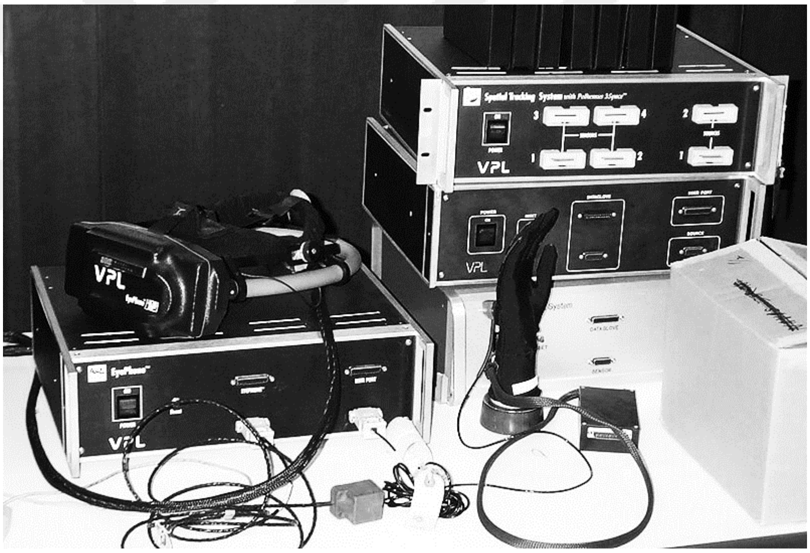


Figure 2.13: EyePhone and DataGlove by VPL Research

After VPL Research Inc. early 1990s NASA and Virtuality invented several machines for both space exploration and exhibitions on different locations. Multiple advancements in VR technology created a foundation to today’s modern virtual world. In 1991 The Virtuality Group introduced VR arcade machines for public use. Virtuality Pods featured head-mounted displays with real-time immersive stereoscopic 3D screens. Another feature was connection of two pods to make very first multiplayer VR game. In short time, successful and well-known games are introduced their VR versions to the market. In the same year, SEGA announced SEGA VR headset. The first commercialized VR headset for public to purchase. But due to company’s concerns about injuring players with their too realistic VR experience as they claim, SEGA VR is never released (Beqiri, 2018). However, this seems not convincing due to limited processing power at that time. In the background, actual reason not to commercialize this invention was difficulties in technical development (Gammage, 2017). In 1994, Apple introduced another realm of virtual reality with QuickTime, not by immersive technologies and head-mounted displays but with 360 photographic panoramas. In the same year, SEGA launched SEGA VR-1 after its failure with SEGA VR. SEGA VR-1 was a motion simulator arcade machine with latest technologies available. In 1995, Nintendo launched first portable console which offers 3D graphics, Virtual Boy. However; it was a marketing failure due to lack of colours in screen and there were no content released for this console after a year. In 1 year time Virtual Boy was off the markets (Beqiri, 2018). In the same year, two different successful headsets hit the market, I-Glasses by Virtual IO and Forte by VFX1 Headgear. In 1997, Georgia Tech and Emory University created a VR environment for war zones as a therapy for veterans with post-traumatic stress disorder, which offered another field for use of virtual reality (Rizo, Difede, Rothbaum, Daughtry, & Reger, 2005) (Figure 2.14).

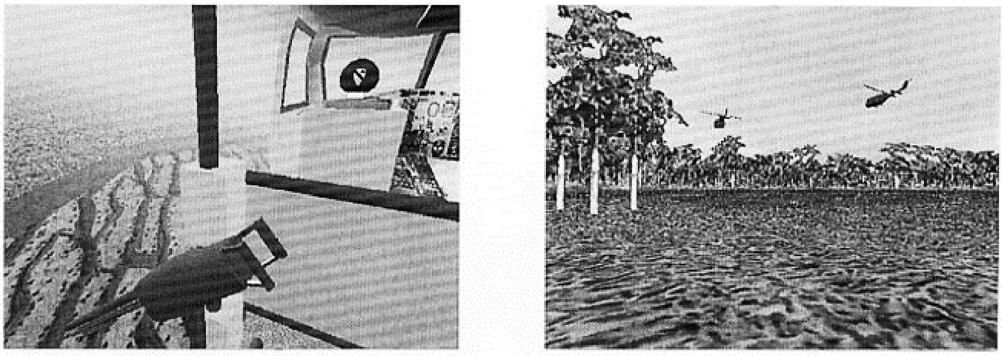


Figure 2.14: VR for PTSD, Helicopter (left) and Open Field Environment (right)

Investments on virtual reality slowed down for a while after 1997, even if research continued, until in 2010 Google introduced a stereoscopic 3D mode for their early release Google Street View in 2007. Users can see anywhere on the Earth on their personal computers as well as their smart phones (Anguelov et al., 2010). Most effective boost in virtual reality world has been done by Palmer Luckey, 18 years old entrepreneur, designed a head mounted display prototype with 90-degree field of vision (FOV) which uses computer’s processing units to receive images (Sterling Academy, 2015). After concept prototype’s success at 2010, in 2012 Luckey started a

Kickstarter campaign for a commercialized Oculus Rift HMD (Figure 2.15). In less than a year, he raised 2.4 million USD.

Figure 2.15: Oculus Rift, 2014

In 2014, after Facebook bought Oculus VR for 2 billion USD, VR researches and industry gained momentum more than it received until that day. Short after, Sony, Google and Samsung, which are the most successful technology companies around the world released their ideas about virtual reality technologies. The biggest hit in the market was do-it-yourself (DIY) stereoscopic viewers which is applicable by any smartphone, designed by Google and distributed as a product or as blueprints online (Figure 2.16). Since them, Google shipped over 10 million of virtual reality head mount (Beqiri, 2018).

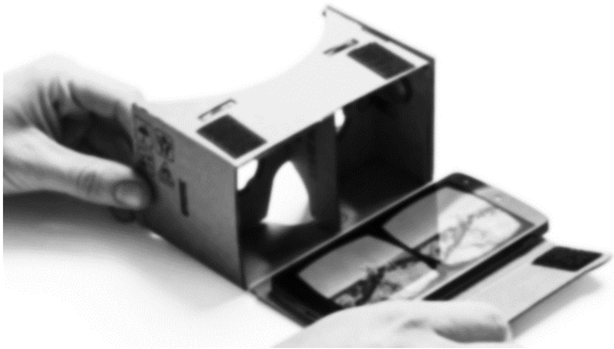


Figure 2.16: Google Cardboard, 2014

All these advancements in virtual reality devices proves it is not only here but it will continue being here for a long time (Gammage, 2017). Even if game industry uses this technology extensively for now, educational simulations, collaborative softwares and application softwares get in market every day. Complex idea behind virtual reality and the situation it is in right now, significant range of software and hardware solutions indicates there is a lot to search for and develop in virtual reality.

2.3. VR IN EDUCATION

VR tools extensively used in many areas such as medical applications, virtual anatomy, surgery training and rehabilitation, education, art, entertainment, military applications for navy, army or air force etc. (Burdea & Coiffet, 2003) Since the very first researches on virtual reality technologies up to today, simulations of real emergencies and critical situations were the main focus of virtual reality in education. Additionally, for the last decade, VR technologies are also used for design related topics such as evaluating designs, virtual prototyping, architectural walkthrough, ergonomic studies and much more (Okechukwu & Udoka, 2011a). However, when educational applications met with virtual reality, it is mostly used as two-dimensional on-screen images or animations, not immersive environments in head-mounted displays (Bell & Fogler, 1995a; Bricken & Winn, 1992; Byrne, 1996a; Eslinger, 1993a).

Educational tools also proved their usefulness against traditional learning methods in engineering departments, immersive environments, created scenarios and visualized data in three-dimensional world were more effective than tables of numbers or lines of texts (Eslinger, 1993b). In 1992, Winn and Bricken used virtual environments to teach their students basics of Algebra (Bricken & Winn, 1992). Despite virtual reality as they call was only three-dimensional graphics, not an immersive environment, they reported VR within the perspective of its significant potential to improve teaching school subjects. Not only mathematical equations but courses for teaching chemical reactions in engineering practices also used virtual environments to enhance their teaching environments (Bell & Fogler, 1995b). Bell and Fogler used a virtual environment named “Vicher” to accommodate educational functions. Questionnaires they made with students concluded contents in virtual environments and representations gave significant boost for understanding the meaning behind the formulas and equations. In 1996, Byrne also made a similar test with chemical engineering students to show chemical reactions in virtual environment, even if it was not so successful as hoped, researcher reports that he witnessed some “a-ha” moments from many of students, indicating they never thought mathematical calculations and operations actually meant the outcomes they saw in virtual environments (Byrne, 1996b). Kaufmann, Schmalstieg and Wagner also used VR tools to teach mathematics and geometry (Kaufmann, Schmalstieg, & Wagner, 2000). Researchers developed an application named Construct3D to teach students mathematics and geometry education in high schools and universities. Their pilot studies proved HMD supported virtual environments also eased experimentations with geometric constructions, enhanced students' spatial abilities. In 2007, researchers tried a whole virtual laboratory experiments in several universities, their findings indicates online laboratories offers unique advantages and can become an alternative to physical laboratories (Balamuralithara & Woods, 2009). Also, in civil engineering education which seems more suitable for virtual reality has been used (A. Z. Sampaio & Henriques, 2007). Sampaio and Henriques developed series of virtual reality teaching models to teach students about field experiences, time management etc. In 2007, they reported virtual reality method is useful for first-degree courses in civil engineering. However, in their future experiments along with technological advancements in virtual reality systems, they concluded that the introduction of CAD and VR systems improve students' understanding of the professional applications and prepare them for their future professional practices (A.Z. Sampaio, Henriques, & Martins, 2010; Alcínia Z. Sampaio & Martins, 2014; Alcinia Z Sampaio et al., 2013).

To sum up, teaching engineering in virtual environments due to content preparation is limited with online laboratories or data visualization most of the time. As mentioned examples demonstrated, virtual reality is highly confused with virtual two-dimensional environments in engineering practices. Virtual environments provide a whole experience for students to enhance their learning abilities, yet they are narrowed down to what pre-made contents can offer.

In 1995 a significant work by Satavara claims medical uses of virtual reality emerged around 1990s. Researcher later categorized medical applications of such systems as surgical simulators, telepresence surgery, database visualization and rehabilitation (Satava, 1995). In the first years of exploration of VR in medical field, lack of technological implementations for such complex cases directed researchers to use gaming devices for virtual reality. DataGlove and head-mounted display devices by VPL Research Inc. Company are used for training students in the same research. Use of such systems with three-dimensional cameras and sensors, improved immersive feedback of systems for enhance students' hand-eye coordination. Flying inside and outside of interior organs of human anatomy showed new perspectives for students to explore their professions.

As computing power gets better every day, graphics quality of medical simulations in virtual environments also improved. Especially rapid change in communication through partners with internet provided interactive and instantaneous access of such life-saving information (Gorman, Meier, & Krummel, 1999). Researches show information management on a regular day takes 80% to 90% of a physician's workload (Satava, 1998). Cooperation with new technologies are important for both enhancing process and patient safety (Gorman et al., 1999). In 1999, a virtual model for medical operations developed by MusculoGraphics Inc., Evanston, Illinois. Researchers found out improvements in 12-minute exercises for IV catheter insertions. Furthermore, their results also include approximately 83% of students enjoyed virtual reality education in the project, 66% of students said VR environments improved confidence in real-life situations and 68% of students indicated they would like to try VR tools for learning other invasive skills (Prystowsky et al., 1999). Traditional training method consisted "see one, do one, teach one" approach since 1890s (Kotsis & Chung, 2013). However, with virtual reality education systems and improved quality in surgical simulations this training method gradually turns into "see one, then simulate, simulate and simulate, before doing one" (Mariani & Pêgo-fernandes, 2011).

After Word Trade Centre attack of 9th November 2001, civilians exposed to traumatic events and imaginal memories. Researchers then created VR therapies to overcome these post-traumatic stress disorder (Difede & Hoffman, 2002). Difede and Hoffman reports measurements are done by Beck Depression Inventory and the Clinician Administered PTSD Scale about depression and PTSD symptoms of subjects. VR therapy concluded with 83% reduction in depression and 90% reduction in PTSD symptoms. Specific phobias such as accident phobia also is a subject to VR therapy. Accident phobia can be seen in 18-38% of all car accidents. Computer games and virtual reality seems to be a useful way to cure such physiological problems. In 2003, a research indicates half of patients completed the program and immersed with driving environments in such systems successfully overcome their traumatic situations (Walshe, Lewis, Kim, O'Sullivan, & Wiederhold, 2003). Another use of VR applications is to reduce pain during physical therapy. In a trauma centre Hoffman, Patterson and Carrougher made an experiment with 12 patients (Hoffman, Patterson, & Carrougher, 2000). All patients reported reduction in their pains when they are distracted by VR systems. Results prove VR can be useful as a nonpharmacologic pain reduction technique. Later Hoffman observed dozens of studies and concluded virtual reality has matured enough to help people overcome fears and traumatic memories as well as control their pain (Hoffman, 2004).

Since very first use of virtual reality flight simulation device Link Trainer (or Blue Box) in 1929 by Edwin Link, virtual reality systems and virtual environments are used extensively for such extreme cases (Myers, Starr, & Mullins, 2018). A report done by Wilson indicates VR technology which offers effective and cost-efficient solutions for military personal training to handle dynamic and potentially dangerous situations from equipment use, social counters, immediate decision making to various extends (Wilson, 2008).

In the Wilson's report, advantages of VR in military trainings are listed. Firstly, importance of repetitive pattern for gaining a skill set is highly valuable. Virtual environments can be restarted in case anything happens such as an error in the process or a variable change in scenario. Military personal can re-play every scenario easily with different settings. Continuity of training can be maintained during different sessions as VR offers a software-based training. Secondly, reducing the risks of worst-case scenarios and emergency situations was considered as a highly useful outcome of such systems. Jordaan and Schwellnus reports over 9 weeks of military trainings, participants' injury rate is 31% (Jordaan & Schwellnus, 1994). However, environments or accessible places for medical personal to operate. Finally, he mentioned not requiring any military equipment or just replications of them is a cost-effective side of using virtual reality. Fuel and maintenance also eliminated completely since it does not require any physical interaction. Wilson claims, VR is gradually seen as a useful tool to adequately train military personal for real-life situations (Wilson, 2008). In contrast, because military and real-life simulators are requiring significant computational power and user motivation, Myers, Starr, and Mullins indicate disadvantages of VR systems in such cases as simulator sickness, adaptation, and compensatory skills, lack of motivation, complexity of software architecture, over-regulation and high-costs for setting up advanced simulation systems (Myers et al., 2018).

Design education requires a significant collaboration, decision making along with conceptual thinking and creativity (Page et al., 2007). A most common use of virtual reality learning environments (VRLE) is architecture education, product, and industrial design education, urban planning education, interior design, and landscape design education. These disciplines require a certain amount of communication between parties to continue the design process of a project. Virtual environments are used to create a communication ground for students and instructors as well as a tool to design conceptual elements.

In 2005, Dvorak et al., used virtual reality systems to boost up architectural design education (Dvořák, Hamata, Skácilík, & Beneš, 2005) (Figure 2.17). Their results showed that virtual reality systems significantly helped students for understanding the fundamentals of architectural design and their instructors to understand students' projects better. Instructors indicated that VR systems allowed them to investigate students' projects with all details further. Their findings prove students' three-dimensional perception of architectural models improved. They also claim that "Architecture is a perfect application area for VR." However, the main problems they faced were inadequate computer graphics, the conversation of three-dimensional models to virtual reality scenes and equipment prices with accessibility. Problems remain the same within many works done by other researchers over the years (Donath & Regenbrecht, 1996; Fonseca, Villagrasa, Martí, Redondo, & Sánchez, 2013).

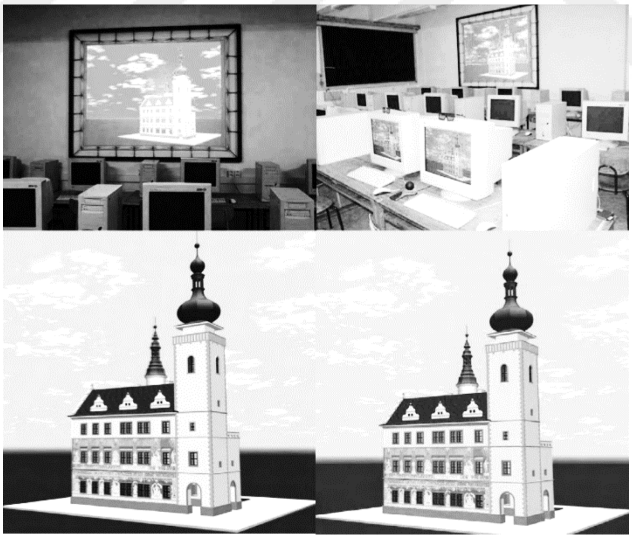


Figure 2.17: Architectural Models to Explore by Students and Instructors, 2005

Potential of virtual reality design environments and web-based collaboration tools are investigated by Kan, Duffy, and Su in 2001. Researchers firstly focused on the needs of the industry to come up with a viable system to eliminate current problems. Later they designed a web-based virtual design environment for clients and designers to use together over a server. Even if VR technologies were not advanced at that time, web-based structure proved demonstrating initial ideas and creating conceptual models were easy and effective with such systems as well as showcasing the end product to clients (Kan et al., 2001). Ye, Campbell, Page and Badni discussed about human and computer interface (HCI) benefits product design students to evaluate their conceptual design according to outcomes of user tests (Ye, Campbell, Page, & Badni, 2006). In the same year, Pappas, Karabatsou, Mavrikios and Chryssolouris developed a web-based collaboration platform for product designers, DiCoDEv Platform (Figure 2.18). Virtual reality environment for design evaluation bases on two-dimensional graphics on screen. However, their findings indicates multiple users in same environment decreases the time required for design process and improves team productivity due to communication possibilities with parties overseas and real-time revisions on projects (Pappas, Karabatsou, Mavrikios, & Chryssolouris, 2006). Same findings are also reported by other product design and collaborative virtual design environment researches (Ong & Shen, 2009; Park, Lim, Seo, Jung, & Lee, 2015; Shen, Ong, & Nee, 2010; L. Wang et al., 2002).

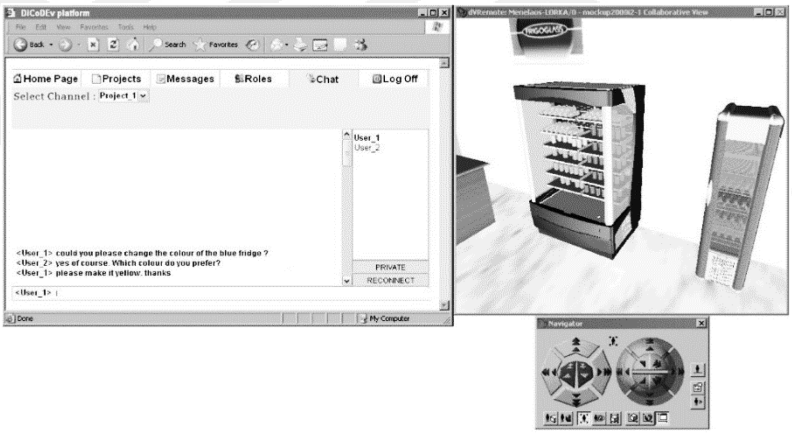


Figure 2.18: DiCoDEv Platform by Pappas et al, 2006

In the recent studies based on augmented reality (AR) technologies done by Mourtzis, Zogopoulos and Vlachou in 2018, researchers applied advanced visualization technologies to teach product design, improve interaction and evaluate the designs to improve them (Figure 2.19). They proposed a design flaw detection and redesign cycle for product manufacturing with augmented reality evaluation process. More than 100 students involved into case study within small groups. Each group expected to design a product via proposed AR system. Results show 12% reduction of the errors in students' designs to be corrected for assembly. Also, because students had the improved perspective about final product, assembly of it performed 10% quicker. However, they also mention for future developments cost-efficient methods to perform

VR or AR technologies would be a better option due to lack of investments. Furthermore, a platform which can be connected by multiple designers to evaluate would be beneficial for design process (Mourtzis, Zogopoulos, & Vlachou, 2018).

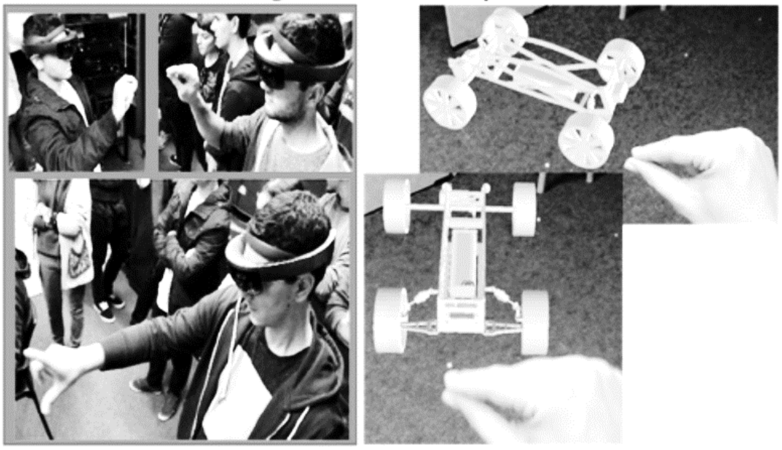


Figure 2.19: Augmented Reality Supported Product Design Evaluation, 2018

2.4. VR IN ARCHITECTURAL EDUCATION

Over the years, architecture had different working domains as well as different definitions for each one of them. In 1995, Salama mentioned that there are four different practices in architecture, academic architect, the craftsman (builder), the civil engineer and social scientist (Salama, 1995). However, in today's situation, architecture as a profession requires different interdisciplinary actions to be undertaken. Cambridge Dictionary describes architect as "a person whose job is to design new buildings and make certain that they are built correctly" (Cambridge Advanced Learner's Dictionary & Thesaurus, 2018). Due to this definition and working fields, architectural education aims to give knowledge for designing of complex systems, environments, structures for living, working, playing and learning; including concerns related with engineering, architecture, urban planning, functional analysis and their integration (Bissonnaise, 2001). According to Bissonnaise, because of these various extends of architecture education, curriculums became the compositions of sets of different courses including architectural design, building construction, history of architecture, structures, materials, equipment, professional code, professional practice, art and even more (Muschenheim, 1964). Lawson however, defines architecture as the most central field in spectrum of design (B. Lawson, 1980). Since definition of architect and architecture is not absolute, how to educate, train architects and teach architecture became even more uncertain over the last decades as discussed in

Programs and Manifestoes on 20th Century Architecture in 1970 and there are many thoughts about what should be included or excluded from architectural education, what should categorizations be like, how architecture education should be handled through the history (The MIT Press, 1971). Despite this situation, architecture education just like any other design discipline education has mainly a studio-based learning model (Büyükkeçeci, 2017).

Design studios emerged in 1819 within classical atelier systems in France at Ecole Des Beaux-Arts, which is not only for artistic developments but also analytical and structural thinking skills (Drexler, 1984). However, in Beaux-Arts school there are two main goals of the system, formal and practical. While students learn crafting and materials in practical education, formal side of the curriculum included problem-solving based on architectural forms through creative thinking as well as an introduction to colours, space, structure and model making (Balamir, 1985). Later, a new architectural education method is created in The Weimar Bauhaus School founded by Walter Gropious in 1918 (Pasin, 2017). Comparison between Beaux-Arts School and Bauhaus School indicates that while Beaux-Arts School focuses more on two-dimensional learning and compositional approach, Bauhaus implements three-dimensional thinking with extensive use of creativity, imagination and personal expression (Balamir, 1985). The curriculum of Bauhaus model consists three main sections; introductory courses teach basics of form and composition, general courses based on space, surface and construction, and architectural courses introducing structural systems (Roters, 1969). Over the years architecture schools prepared their curriculums based on these two different approaches, main differentiation of design studios varied between the more abstract vision of built environment or directly focusing on it (Pasin, 2017). In both approaches and various others, design studios include creative, innovative, participatory process which can be achieved by critical teaching and learning methods that support versatile thinking (Durmus, 2015).

Design studio process handled in various ways depending on the institutions' visions since 1819, yet creativity, three-dimensional thinking and collaboration remains the same (Soliman, 2017). However, no matter the approach of design education, there are fundamentals of architectural professional practices today, defined as predesign, schematic design, design development, and documentation of design (Collidge, 2013). For students to embrace such process they learn by doing it instead of studying or analysing (B. Lawson, 2005). According to Lawson, physical environment of design studios imitates professional architectural offices which is a collaborative working place by students under supervisions of the instructors. There are different approaches to establish a design studio in universities, such as panel reviews, face to face critiques with instructors, group or individual works etc. (Dizdar, 2015). Design studios aim to shape students' architectural sensitivities, develop communicative abilities and spatial and general problem solving skills (Tokman & Yamaçlı, 2007). Architects and students use various methods for representing their works from two-dimensional documents to three-dimensional models. Spaces and forms shape along with creation of these documents, models. Dorta and Lalande introduce representation methods used by architects through history, changing schemes have different advantages and disadvantages. However, they also mention obstacles to perceive three-dimensional spaces architects and architects-to-be created, abstraction of projects in drawings, field of vision of perspectives, different characteristics of representations and communication of information on paper (Dorta & Lalande, 1998). These problems are highly related with traditional methods of representing architectural works. With the last technological advancements, spatial perception and design collaboration tools started to change (Davidson & Campbell, 1996).

As a three-dimensional representation technique, architectural models are defined as a representation of reality that exists, have existed or may exist (Echenique, 1970). Models have been used as a common communication ground by many disciplines, however, the way design education uses it differs from others (Gürsoy, 2010). Physical models simplify complex realities and make them comprehensible and workable. Throughout the years architecture learning environments used physical models in different ways. Generally, early in the design cycle, physical models appear as working models to quickly answer creativity in three-dimensional methods.

Later in the design cycle, more carefully prepared detailed models are created to explain projects to instructors and clients as well (Janke, 1968). Technological advancements in computer-aided design tools provided three-dimensional digital modeling to help architects and students to represent their works better, but, physical models are still a valid form of developing projects by hands and they are highly being used as a final representation tool (Gibson, Kvan, & Ming, 2002). However, model-making always considered as a second option as a representation tool in architecture, instead sketching and drawing got more attention as a research topic through history than physical appearances of the scaled models (Burry, Ostwald, Downton, & Mina, 2007). Despite this situation, when digital went beyond virtual with new systems, digital representations renewed interest along with modeling in practice and academia (Cannaerts, 2009). Both physical and digital models are crucial for understanding architectural projects as they are the actual form of space to perceive rather than two-dimensional representation techniques (Gürsoy, 2010).

Collaboration in between close or distant parties are one of the key features of architectural practice and education (Bråthen, 2015). Especially group projects require constructive collaboration to share their ideas and visions to achieve singe goal for the sake of projects (Idi & Khaidzir, 2018). Design as a process is highly cognitive and consists of continuous feedback process between designers and stakeholders which also supports integrated framing, reflecting, critical mobbing, behaviour and reasoning between parties (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013). Traditional methods of collaboration such as sharing drawings, sketching and brain-storming are still being used in early stages of design, yet new methods started to emerge to overcome difficulties of complex detailing and advanced spatial creation and exploration (Froese, 2010). Tools of nowadays digital age offer more user-friendly digital design environments for flexible and digital-supported collaboration (Jonson, 2005).

Many researchers conducted a series of case studies to find out problems of current architectural representation and communication tools and new methods for representing architectural designs, design studio communication between students as well as between students and instructors. As technology improves for design and construction built environment and how design evolves by itself, spatial perception and design collaboration are also needed to be updated (Hardin & McCool, 2015; Kasali & Nersessian, 2015; Mazlan, Sui, & Jano, 2015; Preece, Rogers, & Sharp, 2015; Vaishnavi & Kuechler, 2015). Studies also show that modern design and construction method highly focuses on multi-disciplinary approach, higher level of technology use, communication between parties, sharing of detailed information, error detection and speed of handling the process (Bryde, Broquetas, & Volm, 2013; Grilo & Jardim-Goncalves, 2010; Isikdag & Underwood, 2010; Mitcham, 1995; Olatunji, 2011; Succar, 2009).

2.5. SPATIAL PERCEPTION

The primary goal of architecture and interior architecture discipline is to create three-dimensional volumes according to given programs, problems and situations while considering aesthetics, human behaviour, safety, and many other aspects which effect human life and interaction in those volumes (Gabrielli & Gardner, 2016). Three essential qualities of decent architecture are defined as firmness, utility, and beauty (Vitruvius Pollio & Morgan, 1960). To achieve such goals while creating architectural spaces; problem-solving, creative thinking and collaboration play an essential role in architects' approaches to design problems (Runco, 2004). Spatial perception is crucial both in design process to produce meaningful spaces and to explore those architectural pieces (N. Cross, 1990). In this section, definition and physiological explanations of spatial perception, how architects used representation methods to perceive spaces in design process throughout history and measurement methods of spatial perception will be explored.

2.5.1. PERCEPTION

Throughout the history of the built environment, many designers including architects, interior architects, urban planners, industrial designers and many others discussed much about how their creations were being perceived by the stakeholders (Hegzi & Abdel-Fatah, 2017). Descartes explores spatial perception with different sensations, secondary quality sensations such as colour, sound, smells, light, etc. and internal sensations which rely on feelings such as pain, tickle, anger, hunger, etc. Additionally, Malebranche indicates the difference between two different processes of perception as primary and secondary qualities of spatial perception and adds, primary qualities include sensory perception which represents properties which can really exist, perceived in the material world. However, secondary qualities of spatial perception represent non-existing qualities of our world, such as feelings, needs, what space around us reflects to our body (Simmons, 2003). Other definitions of perception include a process of environmental stimulants' interpretation and organization (Dittrich & Atkinson, 2008), the process of interpreting sensation and making them meaningful (Morgan, King, Weisz, & Schopler, 1986), the name given to the process of giving meaning to the objects and events around us by organizing and interpreting the sensory data (Cuceloglu, 1972) and many others.

While philosophical discussions continued with qualitative researches on spatial perception which is a cognitive ability defined as the capability of awareness of individuals' relationships with the environment around them (exteroceptive processes) and within themselves (interoceptive processes) (Cognifit, 2018). According to Johnson, “Where am I? Where am I going? How do I get there?” are the most commonly asked questions in the minds of researchers working on perception (Johnson, 2011). While those questions refer spatial ability to create volumes in architectural design discipline, for each specific work in an individual site, responses change (Stecker, 2005).

Spatial ability is seen as one of the critical elements of nearly all architectural courses because of its importance in both psychological theory and architectural education, especially ability to represent three-dimensional volumes on flat paper and in a three-dimensional environment (Stringer, 1971). Maintaining understanding of spaces between designers is crucial to proceed further in the development of the project, particularly in architecture discipline this need of communication goes through understanding the imagined space before anything else. For such need in architectural design and design education, various documentation and presentation methods generated to perceive imaginary spaces (Oxman, 2002).

2.5.2. ARCHITECTURAL REPRESENTATION METHODS

Spatial perception in an imaginary project which is in design process yet differs from being in a space. To understand spaces while in design process, architects and designers use two-dimensional or three-dimensional representations of ideas, designed elements to be able to perceive those spaces (McKim, 1972). Different dimensions of visualization, representation methods such as drawings, physical models, renderings, diagrams, and many others are the proven method for maintaining an understanding of imaginary spaces through spatial perception in design phase between parties (Kozhevnikov, Kozhevnikov, Yu, & Blazhenkova, 2013).

Farrelly, in his book presents architectural representation methods as conceptual sketches, analytical sketches, observational sketches, orthographic projections such as plans, sections, elevations, details; three-dimensional perspective, axonometric, isometric drawings, photomontage, collage, physical modeling, CAD models, fly-through, layout presentations, oral presentations, story boards and portfolios. He also said architectural ideas emerge as buildings at the end, process goes as ideas to concepts, concepts to sketches, sketches into physical models and at the end set of scale drawings to be investigated in detail. Categorization of all these representation methods are grouped as sketch, orthographic projection, three-dimensional images, modeling, eventually layout and presentation in different scales to answer specific needs during design phase and construction phase of the project (Farrelly, 2008). Such methods are being used for representing imaginary spaces during design phase in architectural project development (Klanten, 2010).

Sketch is a quick, loose and open-ended drawing which puts speed and abstract explanation of idea in its core. Sketches have a various range of use which includes visual note-taking, observing conditions and situations in real world or producing analytical drawings which ends up categorizing them as conceptual, analysis and observation sketches (Farrelly, 2008). While sketches are representing initial ideas of architectural design process, they define a space to be explored and method to create them is mostly drawing via pen, pencils, markers etc. on a flat paper (Figure 2.20). With technological advancements, three-dimensional sketching also is a tool to be used to generate digital spaces to experience (Oosterhuis, 1995). However, while sketching requires a certain knowledge and effort to prepare, its communicative benefits can never be underestimated for design collaboration and speed in creative thinking (Guidera & MacPherson, 2008).

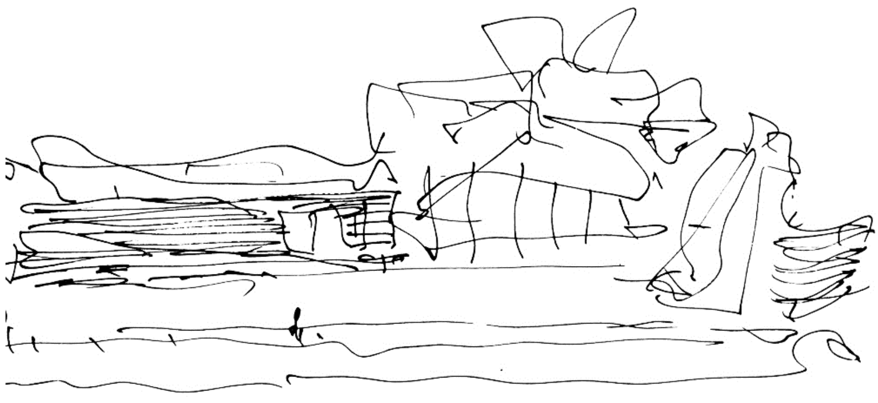


Figure 2.20: Guggenheim Museum, Bilbao, Sketch by Frank Gehry (Pollack, 2005)

Architects used a coded system of drawings to represent their designs since the time of ancient Egyptians (Kostof & Cuff, 1977). Orthographic projection is an interesting challenge of displaying a proposed piece of architecture, which uses a set of two-dimensional views to be interpreted and read as a three-dimensional building or space. This representation method shapes with interrelated horizontal cross section of building (plans) (Figure 2.21), vertical cut sections of building (sections) (Figure 2.22), views from all sides of the structure (Figure 2.23) and other additional details which are needed in the construction site. The purpose of such effort is to describe how to realize conceptual idea in physical terms (Farrelly, 2008, p. 75). This method is the most conventional and used method to represent architectural projects throughout the history (Kostof & Cuff, 1977). While in the history architects and designers were handling the process via hand-drawn plans, sections and elevations, technological advancements in computer-aided design tools allowed architects to generate drawings in different layers to automate such process (Coons, 1966; Farrelly, 2008, p. 80). Many researches proved using CAD software during design period significantly improved students ability to understand spaces they create, fasten and improved the quality of the critique sessions (Banz, 1985; Coons, 1967; Guidera, 2002; Guidera & MacPherson, 2008; Mack, 1995; Samsudin, Rafi, & Hanif, 2011; Vriesendorp et al., 2016).

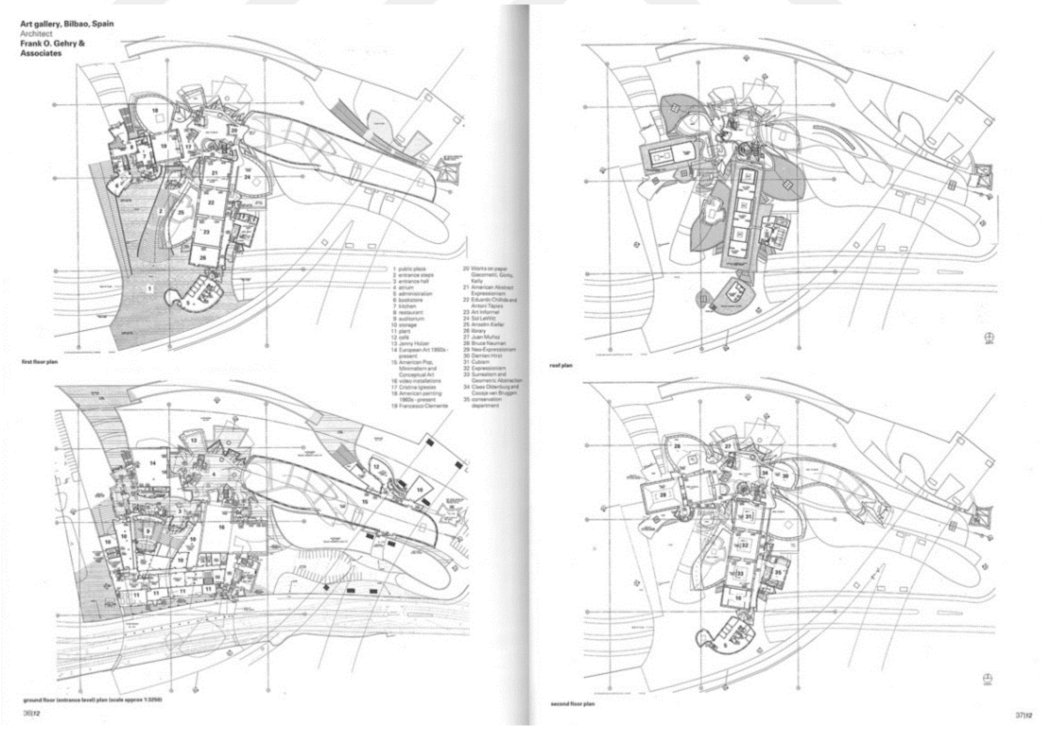


Figure 2.21: Guggenheim Museum, Bilbao, Plans by Frank Gehry

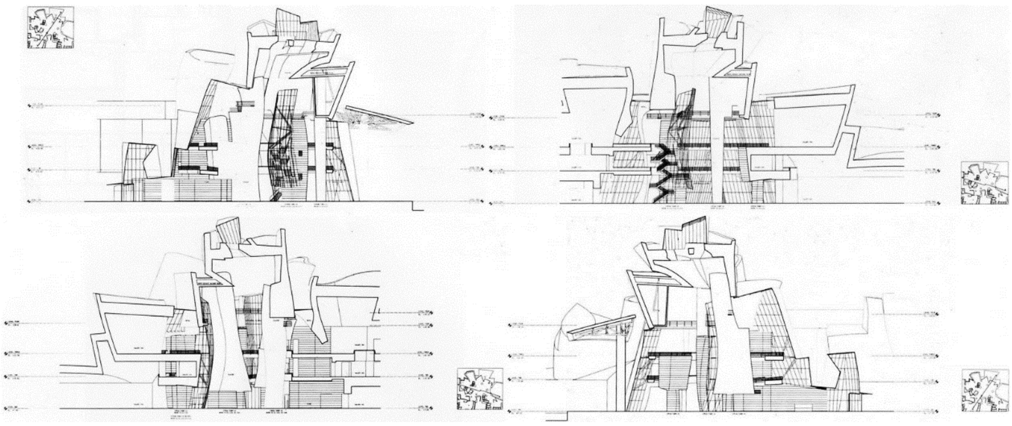


Figure 2.22: Guggenheim Museum, Bilbao, Sections by Frank Gehry

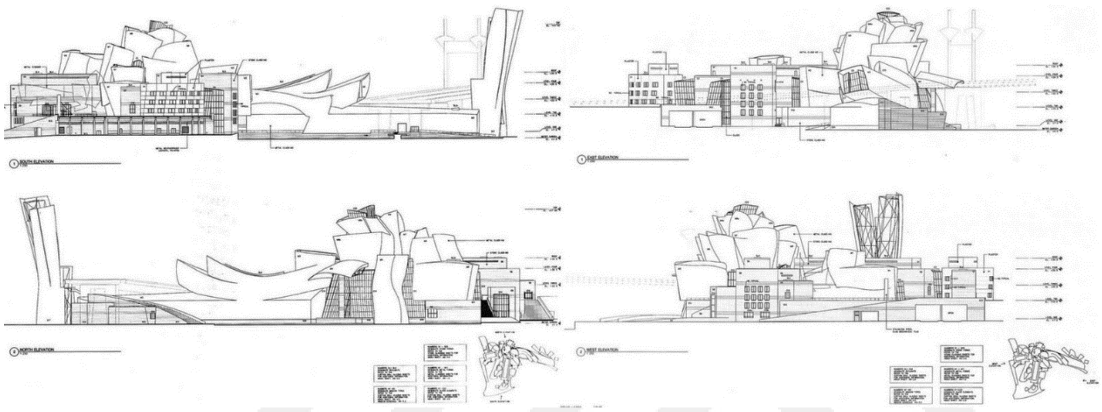


Figure 2.23: Guggenheim Museum, Bilbao, Elevations by Frank Gehry

Sometimes it appears difficult to understand orthographic drawings as they are kind of a specialized code in architectural practice and profession. Two-dimensional representation of three-dimensional environments is not an easy task to undertake under certain conditions such as complex creations, unfinished design decisions etc. Various methods of three-dimensional drawings such as perspectives (Figure 2.24), axonometric and isometric interpretations of spaces, make appearance of buildings much easier for both designers and non-educated eyes and they also make architectural pieces immediately accessible (Farrelly, 2008, p. 94). Easiest method to create quick three-dimensional drawings from drawn plans is to use axonometric drawings which are also known as plan oblique drawings, advantage of such representation method is to give educated-eyes an understanding of both plans and internal or external three-dimensional space (Farrelly, 2008, p. 99). However for non-educated eyes, perspectives provide true impression of a space even if they are distorted views of designs which make the impossible appear possible (Farrelly, 2008, p. 95). All these drawings can be rendered via hand-drawing techniques or snapshots of digitally generated three-dimensional models (Figure 2.25) as well as a mixture of both.

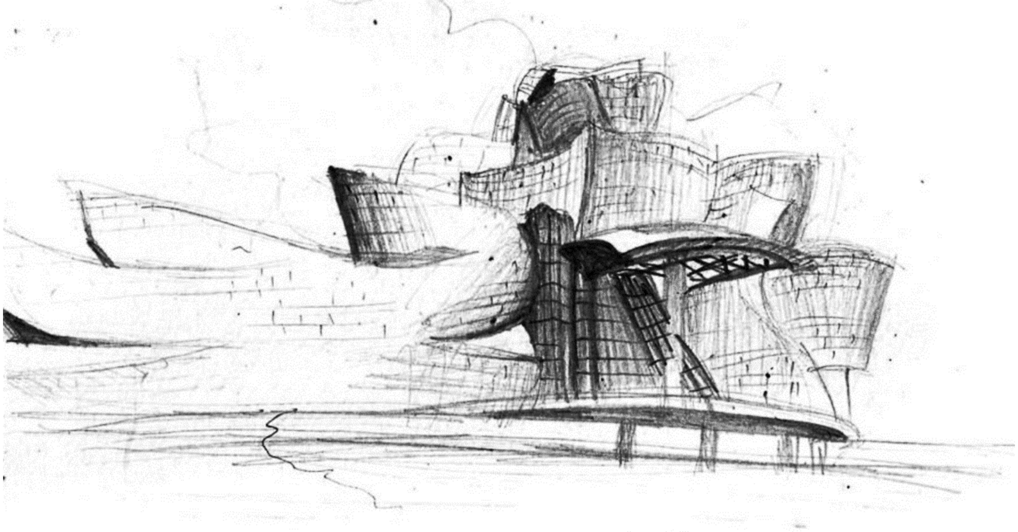


Figure 2.24: Guggenheim Museum, Bilbao, Hand-drawn Perspective Rendering

Figure 2.25: Guggenheim Museum, Bilbao, Computer-Generated Perspective Rendering

Since Renaissance period (early 15th Century – 17th Century, different locations in Europe), modeling has been used as a popular method among designers to describe architectural idea (Wiscombe, 2006). Drawings became the primary method of delivering architectural ideas and projects during the Beaux-Arts period, later in mid 1990s, architects once again started to use models extensively as a representation method for their ideas to audiences, colleagues, instructors and clients (Farrelly, 2008, p. 117). Modeling allows the designers to explore their ideas in three-dimensions and evaluate their projects in an accessible, fast and effective way. Physical (Figure 2.26) and digital models (Figure 2.27) can answer specific needs of designers in different phases of design. CAD models generally offer more realistic and in-depth informative data to architects for complex forms and shapes (Farrelly, 2008, p. 134).

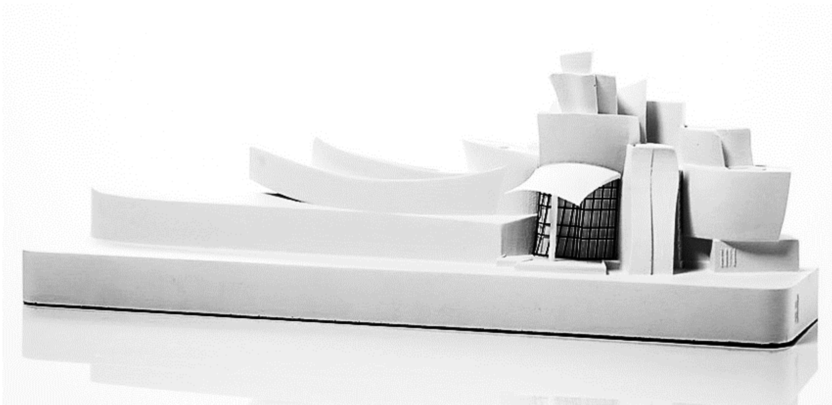


Figure 2.26: Guggenheim Museum, Bilbao, Physical Model

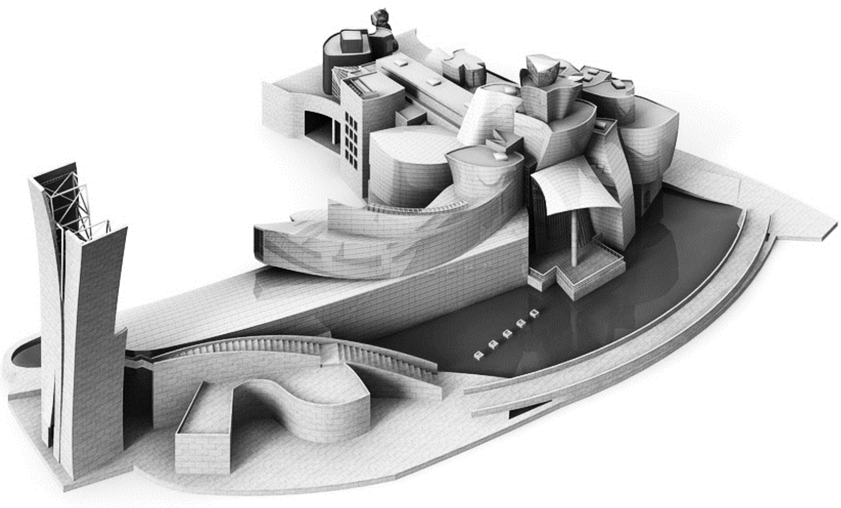


Figure 2.27: Guggenheim Museum, Bilbao, CAD Model

All these representation methods in architectural practice and education offer unique aspects of design and focus on various qualities of projects. Based on which phase the project is, each method has advantages and disadvantages along with the way of using them. Mostly these drawings presented on presentation boards or on paper during face-to-face critique sessions. However, CAD drawings and models can also be seen on computer screens. When architecture design education and practice meant, understanding the creation through spatial perception is important in all these representation models.

2.5.3. MEASURING SPATIAL ABILITIES

In different professional fields such as military, architecture, firefighting, elementary school education, psychological experiments, etc., measurements of spatial perception (or presence, spatial ability, navigation through, etc.) handled within different methods, questionnaires, comparisons, interviews etc. (Bliss, Tidwell, & Guest, 1997; D. Henry & Furness, 2002; Loomis & Philbeck, 2008; National Academies Press, 2015; Witmer & Singer, 1998; Yılmaz, 2009). When measurement techniques in architectural education and practice are investigated, primary way of measuring perception in a built space or an imaginary space is questionnaires prepared with quantitative data related with projects, spaces etc.; sensory data, distance, orientation of shapes, errors in spaces or architectural terms and more (Cognifit, 2018; Dizdar, 2015; Daniel Henry, 1992; Johnson, 2011; Loomis & Philbeck, 2008; Rizo et al., 2005; Simmons, 2003; Stringer, 1971; Sun et al., 2014).

Many studies on virtual environments in practice created various ways of measuring perception of three-dimensional space. However, many researchers troubled to conclude their findings due to subjectivity of presence questions and lack of measurements in open-ended questions statistical validation (Gooch & Willemsen, 2002; Interrante, Ries, & Anderson, 2006). One of the key findings of literature reviewers on spatial perception measurement is that the most common cognitive measurement method is comparative studies with quantitative data (Paes, Arantes, & Irizarry, 2017). Franz et al. conducted an experiment in 2005 with 16 participants (50% male, 50% female), asked them to rate eight different rooms in eight experimental categories based on pleasure, interestingness, beauty, normality, calm, spaciousness, brightness, openness. Experiment is done with 360 degrees panoramic images of the rooms (Figure 2.28). Their findings proved five out of those eight experimental categories are useful in terms of describing observed space (Franz, von der Heyde, & Bülthoff, 2005).

Figure 2.28: Rooms to Evaluate in Virtual Environments, by Franz et al., 2005

Perception diversified between physical and digital models is also explored with questions like "Which building is higher? How long that building is?" and also participants' response time (Sun et al., 2014). Pioneers of spatial perception researchers distributed first presence questionnaires to participants related with control, sensory, distraction and realism aspects in virtual environments (Witmer & Singer, 1998). Many works after their researches have conducted similar questionnaires (Castronovo, Nigolic, Liu, & Messner, 2013; Kalisperis, Muramoto, Balakrishnan, Nigolic, & Zidic, 2006; Ruschel, Fracaroli, & Silva, 2005). Later, to measure cross-media presence, another questionnaire based on sense of physical space, ecological validity, engagement and negative effects. Not only perceiving spaces but also effectiveness of creativity in virtual environments is measured by Schnabel and Kvan with questions related with form-finding, collaboration and creativity (Schnabel & Kvan, 2003). In 2018 a detailed questionnaire is introduced to measure effects of augmented reality systems into building information modeling. Their questions included gender, years of expertise, age, knowledge about technology, navigation difficulty, putting tasks in order related with their importance and open-ended questions for participants to further comment (Chu, Matthews, & Love, 2018).

2.6. ARCHITECTURAL DESIGN COLLABORATION

Even if architecture is a sophisticated profession by itself, stakeholders in modern times require more complex and demanding solutions for their designs. This demand causes architects to combine different perspectives, types of knowledge as well as integration of various parameters (Nilsson, 2014, p. 41). Design process is not only about purely creativity but also imagination and communication (Nelson & Stolterman, 2012). Ability of associating elements, practices and actions as well as reading situations to communicate through narratives or on various platforms is in the centre of design disciplines (Nelson & Stolterman, 2012). Therefore along with current developments in industry, just like other design disciplines, architectural practice and education considered as an extremely cognitive profession which requires certain communicative skills while designing, presenting or experiencing created spaces (Dorst, 2011; Goel, 1994; B. R. Lawson, 1979; Valkenburg & Dorst, 1998). Non-verbal communication through objects, reading and writing about them is also a primary ability for architectural challenges (Nigel Cross, 1982). Most of the time, architects must work within interdisciplinary approach, not only this but communication between architects and stakeholders of the projects require significant collaborative work. This need for collaboration discussed under different names such as “participatory design”, “transdisciplinary design”, “co-production”, “integrative design”, “user innovation” etc. Discussions on collaboration emerged questions related with awareness of the expertise of fields among parties. Founders of the discussions concluded having an identity in individual’s disciplinary knowledge is crucial to have multi-disciplinary collaboration with other professionals and researchers on different fields (Baber et al., 1995; Klein et al., 2001; Nowotny, Scott, & Gibbons, 2001).

2.6.1. COLLABORATIVE PLATFORMS

Throughout the history, design collaboration handled as a narrative process between individuals or groups, within the help of technological advancements, virtual studios and distant communication started to emerge (Nilsson, 2014, p. 42). In early 1990s, a collaborative work done by Hong Kong University, University of British Columbia, Harvard University, Harvard Graduate School of Design, Escola Tecnica Superior d’Arquitecture de Barcelona and Massachusetts Institute of Technology, academicians started a virtual design studio project bringing distant places around the world together for two weeks of project. However, due to technological situation of those times, their communication through virtual environments based on e-mails, internet videos, conference calls, exchange of native CAD files, images and animations made their research results focus more on technical specifications and reports rather than discussing collaborative design process (Wojtowicz, 1995). Later instructors and participants categorized collaboration methods in architectural design as universal computer networking, digital video, communication of video and computation, and handheld wireless communication (Mitchell, 1995). They established the foundation of hardware technologies for current design collaboration tools, such as collaborative computer-aided design files employing few of those technologies. However their finding also proved scheduling, file organization and high bandwidth between parties are crucial for distant collaboration in design projects, which concludes the experiment as these technologies cannot handle design collaboration by themselves but with careful design of collaboration, such as indexing changes, filing certain elements, revision lists, versioning, establishing turn-taking etc. (Gross et al., 1997).

A recent study in 2018 explored a hundred of researches on design collaboration and concluded new category setup for design collaboration, building information modeling (BIM), teamwork activities in collaborative design (TDA), evidence-based design (EBD), and modality supported collaboration design (MSCD). Their findings also demonstrated use of those collaborative methods in terms of design activity, design management process, conceptual design stage and detail design stage (Table 2.1) (Idi & Khaidzir, 2018). Another perspective to this table can prove model creation in collaborative design can improve design activity in creativity sense. However, their collaborative environments in architectural design practice excluded immersive virtual environments.

Table 2.1: Use of Collaborative Methods, (adopted from Idi & Khaidzir, 2018)

	Design Activity	*Management*	*Concept Design*	*Detail Design*
BIM	-	10	1	9
TDA	27	-	11	16
EBD	-	2	2	-
MSCD	49	-	9	40

Latest improvements in immersive virtual environments provided collaboration in thinking the way architectural design activity occurs as well as communication in the spatial presence through virtual reality (Abdelhameed, 2013). When individuals get involved with imaginary environments in immersive virtual environments, narrative communication between designers is verified as a method to critique spatial quality of architectural pieces (Cogné et al., 2017).

2.6.2. MEASURING COLLABORATION EFECTIVENESS

To understand how to measure collaboration in design process, studies are done to understand what the main issues in this field are. For this purpose, researchers tried to summarize main problems with current collaborative methods in design, observed limitations and constrains of such experiments. While doing so, researchers considered all data which is exchanged and discussed on, produced correctly and other parties understood the data (Creese, 2007; Romito, Probert, & Farrukh, 2007). Under such conditions, measurements are mostly done considering two parameters, accessibility of the data (technical aspect), clarity and usefulness of the data for designers (semantic aspect). After sufficient data is evaluated by the researchers, the main task is defined by researchers as possibility to measure collaborative performance quantitatively, actors' behaviours for elements of collaborative data (Pirayesh Neghab, Etienne, Kleiner, & Roucoules, 2015). These questions have been demonstrated to be effective for developing end-product, in architectural case, designed architectural piece (Bassetto & Siadat, 2009).

Design performance metrics have been used by many researchers to demonstrate a common ground for understanding effectiveness of collaboration (Chiesa, Frattini, Lazzarotti, & Manzini, 2009). More than eighty publications on research and design project collaboration measurement techniques are evaluated by researchers. Later they came up with a list of metrics to measure effectiveness and they sorted them from most important to less important metrics. Most significant metrics to evaluate collaborative process in design are efficiency of collaborative method, delivering the brief between parties, clarity of design goals and objectives, decision making hierarchy, and eventually personal initiation (Hwang & Hu, 2013).

2.7. CRITICAL REVIEW

Architectural design process is a cognitive practice, requiring creativity, collaboration, communication and certain level of three-dimensional thinking (e.g. D. Henry & Furness, 2002). Technological advancement in design and representation methods such as building information modelling (e.g. Bråthen, 2015; Bryde et al., 2013; Campbell & Wells, 1994; Chu et al., 2018; Du, Zou, Shi, & Zhao, 2018; Edwards, Li, & Wang, 2015; Grilo & Jardim-Goncalves, 2010; Hardin & McCool, 2015; Leigh, Johnson, Vasilakis, & DeFanti, 1996; Migilinskas et al., 2013; Olatunji, 2011; J. Wang,

Wang, Shou, & Xu, 2014; Whyte, Bouchlaghem, Thorpe, & McCaffer, 2000), three-dimensional mesh modelling (e.g. Guidera, 2002; Guidera & MacPherson, 2008; Heydarian et al., 2015; Alcinia Z Sampaio et al., 2013), virtual reality (e.g. Bell & Fogler, 1995b; Cruz-Neira et al., 2018; Davidson & Campbell, 1996; Dorta & Lalande, 1998; Frost & Warren, 2000; Kan et al., 2001; Kaufmann et al., 2000; Okechukwu & Udoka, 2011a; Rahimian & Ibrahim, 2011; A.Z. Sampaio et al., 2010; Whyte et al., 2000), augmented reality (e.g. Broll et al., 2004; Chi, Kang, & Wang, 2013; Cirulis & Brigmanis, 2013; Fazel & Izadi, 2018; Fonseca et al., 2013; Huang, Chen, & Chou, 2016; Mesárošová, Hernandez, & Mesároš, 2015; Meža, Turk, & Dolenc, 2015; Mourtzis et al., 2018; Pan, Cheok, Yang, Zhu, & Shi, 2006; Park et al., 2015; Shen et al., 2010; Turkan, Radkowski, Karabulut-Ilgu, Behzadan, & Chen, 2017; X. Wang, 2009; Younes et al., 2017), network supported collaboration (e.g. Balamuralithara & Woods, 2009; Davidson & Campbell, 1996; Kan et al., 2001; Kvan, Maher, Cheng, & Schmitt, 2000; Pappas et al., 2006; L. Wang et al., 2002), blog based communication (e.g. Bâldea, Maier, & Simionescu, 2015), data exchange in computer-aided design files (e.g. Campbell & Wells, 1994; Frost & Warren, 2000; Gibson et al., 2002; Tidafi & Iordanova, 2006), and many others for architecture and other design discipline practice and education shown as a useful tools over the years within various metrics and experiments. Findings demonstrate the use of such technologies for specific purposes such as creative thinking, understanding of projects, evaluation and critique process, studio management, collaboration, have different advantages and disadvantages. However, these experiments and studies addressed the issue individually within a specified setup and research design. Therefore, results obtained from these studies implied certain limitations.

In the following two sections, critical review of the previous studies is conducted. The aims of such critical review are to demonstrate the state of spatial perception researches and design collaboration studies, also their current problems related with spatial perception of architectural projects in immersive virtual environments and collaborative communication using three-dimensional models in virtual environments through a web-based platform.

2.7.1. SPATIAL COMMUNICATION

Perception is individual's ability to understand environment by their senses and interpreting them to create a meaning for themselves. However, perception most of the time is confused with spatial perception in architecture. Those educated in design disciplines and non-educated individuals have different perspectives and set of minds to perceive spaces. While designers and architects are able to interpret two-dimensional drawings to turn them into three-dimensional volumes in their minds, freshmen in design education and non-designer individuals troubling to understand such data (Nigel Cross, 1982). Two-dimensional perspective drawings of architectural pieces on paper or on screen help non-designer individuals to understand the volume to a certain level as well as three-dimensional walk-throughs (Farrelly, 2008). Physical models also proven to be a viable method to demonstrate projects for non-designer individuals to understand the basics of it as well as instructors and professionals to evaluate the project (Fahmi, Aziz, & Ahmend, 2012).

Academicians used virtual reality systems as a presentation tool for graduate projects due to technology state of CAD systems which has had little impact on the earlier phase of design. Researchers claim that students require a significant mental leap from sketches and conceptual models to CAD environments. VR has been proposed to architecture students to design and go for further developments, also to define the problems, shortcomings and benefits of such systems in design process through semester. Proposed system investigation includes; user interface, abstraction level in three-dimensional environment, VR as a design tool in early phases of design, fly-through and representation of the design. Feedbacks from jury members were better than expected, they found VR walkthroughs useful as a presentation tool. However, pre-determined routes criticized by them, they demanded a free-walk in 3D environment which would be more suitable to experience the design in depth. One of the problems of system was asking students to manually re-design and re-model their graduation projects in a certain way to showcase in virtual reality (Campbell & Wells, 1994). However, the main problem with the study was non-immersive virtual reality as researchers also pointed out, virtual reality handled as a walkthrough video instead of immersive environment to experience the design. Same situation also occurred in many other experiments through years by defining renderings, CAD data and mainly 3D models on screens as virtual reality (e.g. Davidson & Campbell, 1996; Edwards et al., 2015; Frost & Warren, 2000; Ismail, Mahmud, & Hassan, 2012; Jiménez Fernández-Palacios, Morabito, & Remondino, 2017; Kan et al., 2001; Leigh et al., 1996; Mesárošová et al., 2015; Pan et al., 2006; Whyte et al., 2000)

The use of virtual reality, which is in the core of this study, seen as an innovative and effective way of understanding architectural works (Campbell & Wells, 1994). Despite its usefulness, the main issue with virtual reality stands by its definition. Any computer-generated model, perspective, drawing etc. considered as virtual reality no matter if it is on screen orthographic drawing, perspective or isometric digital drawing, computer-aided design data, building information modelling data, an able-to-explore three-dimensional virtual model on screen, or a three-dimensional model which is in augmented reality, immersive virtual reality or mixed reality. All these different architectural representation methods mentioned as virtual reality data in previous studies even though virtual reality stands for immersive virtual environments which requires head-mounted displays to involve participant into space itself for a whole spatial experience (e.g. Gammage, 2017). Therefore, any view, drawing, 3D data or walkthrough on computer screens etc. which is non-immersive considered as 2D representational media in this study, rather than virtual reality material. Spatial communication through different types of representation methods will be investigated to understand which method is more useful in which phase of the design and how.

Advancements in virtual reality technologies made it possible to run on desktops through years. High-end computer systems are financially not viable and requires a lot of professional attention from information technology departments to maintain its working status. Also, students and instructors often have problem with having more than few of those setups (Kan et al., 2001). With technological improvements, immersive virtual reality systems can finally be used with certain amount of computational power reduction on daily use smart phones of students. However, no experiment with accessibility of mobile immersive virtual reality system have ever been done before in literature.

Furthermore, experiments are done under different research designs. Especially comparative studies prepared with multiple participants and projects to observe in various representation methods. Experiments are mostly done by defining a control group and an experimental group, requesting them to look at different types of data to evaluate, the project (e.g. Heydarian et al., 2015; Samsudin et al., 2011; Tidafi &

Iordanova, 2006). However, depending on individuals' professional ability and projects properties this method may change the actual solutions of experiments. Other approach as a comparison based experiment is to show different representation methods related with specific projects to all participants and try to evaluate results accordingly their answers (e.g. Cannaerts, 2009; Fonseca, Martí, Redondo, Navarro, & Sánchez, 2014; Sun et al., 2014). However, this experiment design may cause familiarity of the project for all participants, therefore results can show biased results.

2.7.2. ARCHITECTURAL COLLABORATION

As many professionals and academics indicated that architecture practice require specialists work together on complex projects with unique demands, as well as a working group including multiple designers and engineers, therefore interdisciplinary action is crucial (e.g. Nilsson, 2014, p. 41). Towards achieving a collaborative platform in architectural project design process, mail-based feedback (e.g. Davidson & Campbell, 1996), pin-up systems (e.g. Gross et al., 1997), narrative communication and sketching which are most commonly used ones (Hyland & Hyland, 2018), text-based networks (e.g. Balamuralithara & Woods, 2009), blog based communication platforms (e.g. Bâldea et al., 2015), video-call between distant parties (e.g. Gül & Maher, 2009) etc. have been employed. De Freitas and Rusched (2013) also reported number of researches and experiments on architectural collaboration in virtual environments reduced in the last few years.

When architectural collaboration is mentioned, understanding of how collaboration occurs and on what topic an architect tries to collaborate with another colleague is highly important. Evaluation of the projects have higher importance in collaborative design between parties. While group members work individually on the project and later parties bring design ideas and/or documentation together. Sessions of group work handled by evaluating individuals personal creations and coming up with a collaborative design solution (Koutsabasis et al., 2012). Therefore, enabling a system for designers to evaluate different aspects of their or someone else's project is crucial to maintain collaboration in parties.

To serve the purpose of this study, works which used innovative three-dimensional virtual environments to evaluate projects for collaborative reasons are observed in depth to point out their advantages and disadvantages. Therefore, data exchange systems, information transfer by building information modelling and critique sessions within emails or other text-based systems excluded. Experiments within the scope of this study mostly used series of 3D sketching or 3D modelling within virtual reality technologies along with students' or professionals' collaborative works.

Sketching is one of the primary skills every designer uses in their professional life. When researchers used this traditional thinking, discussing and creating method in three-dimensional virtual environments, ideally, participants of design collaboration in distant or together, got in virtual world and with the help of hand movement monitoring systems, they started discussions on shapes, ideas and brainstorming in three-dimensional sketching environments (e.g. Donath & Regenbrecht, 1996; Rahimian & Ibrahim, 2011). Even if such systems have positive effects on problem-solving in three-dimensional environments as well as quick action taking in design process, 3D sketching in virtual environments mostly found hard to learn as well as hard to get used to it in shorter terms. These systems mostly provided by immersive environments with advanced computer systems and head-mounted displays. On the other hand, hardware cost and required spaces for such systems found not feasible for design collaboration. Finally, level of sketching ability and detailed design capability for in-depth communication while decision-making in design is reduced due to limited hand gestures (Figure 2.29).

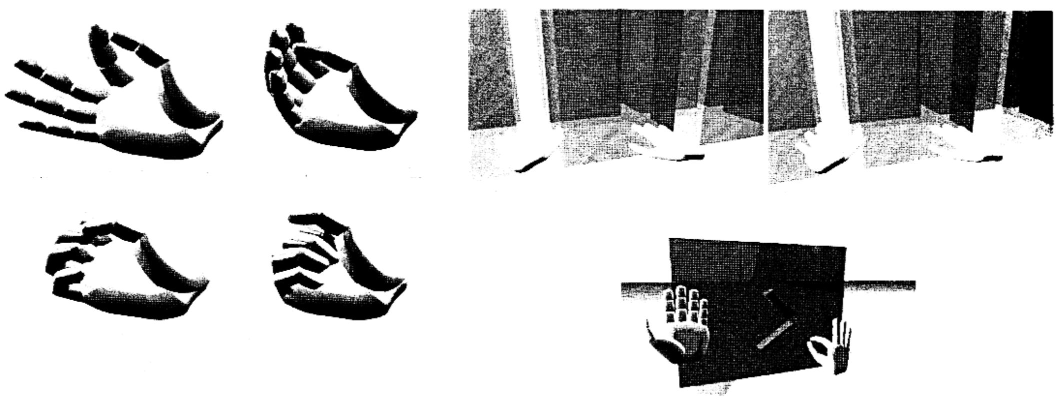


Figure 2.29: Hand Gestures for 3D Sketching (Left) and View in Immersive Virtual Environment (Right) (adopted from Donath & Regenbrecht, 1996)

Another approach to cooperative design process is shared three-dimensional working spaces which students, instructors and professionals can all contribute to design itself within virtual environment. The main purpose of such platform is to bring distant members into same environment to evaluate and design. Experiments to go through collaborative design process gave every participant a problem to solve in groups and observe their experiences through virtual environments (e.g. Davidson & Campbell, 1996; Fröst, 2002; Frost & Warren, 2000; Kan et al., 2001). Such systems usually provide on-screen three-dimensional modelling environments where individuals indicated as avatars and can see each other's while they explore virtual design models. Due to designers' familiarity with such systems, compare to 3D sketching environments a sharable modelling environment answers needs of parties better than virtual sketching softwares. However, lack of spatial awareness due to non-immersive virtual reality systems reduce the spatial communication.

CHAPTER THREE
METHODOLOGY

Architects face with several phases throughout the design process in professional practice. These phases are defined as conceptual design, schematic design, and design development, then construction documentation, and bidding, later construction administration (Faatz, 2009). Use of virtual environments are not classified as a standardized method, yet architects and architecture students follow a non-clear path through their processes. Especially while generating imaginary spaces in their minds, they often face with problems by considering the representation of those spaces to their instructors and other group members in case of a group work. As current state of literature indicates problems related with perception of non-physical environments, for project development process not only perceiving such elements is important but also being able to communicate through them. Therefore, the current research focused on answering three main questions. (1) How digital architectural representation methods influence architects' perception of space? (2) How can distant collaboration between architects in virtual environments effect the project development process?

In design studios, due to limited time and resource as well as aims of the studios, tasks are simplified as conceptual design, schematic design, design development and presentation of design proposal. Within the scope of this research, to define influence of representation methods in architectural design process, these tasks in design studios investigated. To collaborate with design studios to gather data, experiments were designed within the content of a designated class which aims to teach students how to use virtual environments. Besides, by the submissions of the course, specified tasks for measuring their spatial perception and architectural collaboration were requested from the enrolled students. These tasks related with generating OSVE of their projects and IVR scenes which they can observe, evaluate and review. Furthermore, different representation methods of specified projects are shared with students to evaluate their spatial perception process and measure the influence of the method. For data collection method, digital tools are highly used to ease the comparison process.

3.1. COURSE DESIGN: ARCH 4151

The experiments were conducted within an elective course named "Arch 4151 – Virtual Environments in Architecture" in Izmir Yaşar University in 2018 – 2019 fall semester which prolonged for 14 weeks. The aim of the course is to teach students how to use virtual environments effectively during their design phase, communication for their projects and presenting their final works. No specific modelling software is introduced in the course; therefore, students were free to use any software they would like to use to create their 3D digital models. During the course students are expected to generate models to explore and to explain spaces in virtual environments. Series of lectures are given within this course, related with three-dimensional modelling techniques, history of virtual reality, and how to use virtual environments to solve and to evaluate design problems as well as developing architectural projects. At first, students are introduced to the course content and a brief history of architectural representation techniques. Traditional, contemporary, and innovative approaches in architectural representation methods are explained to students (Figure 3.1).

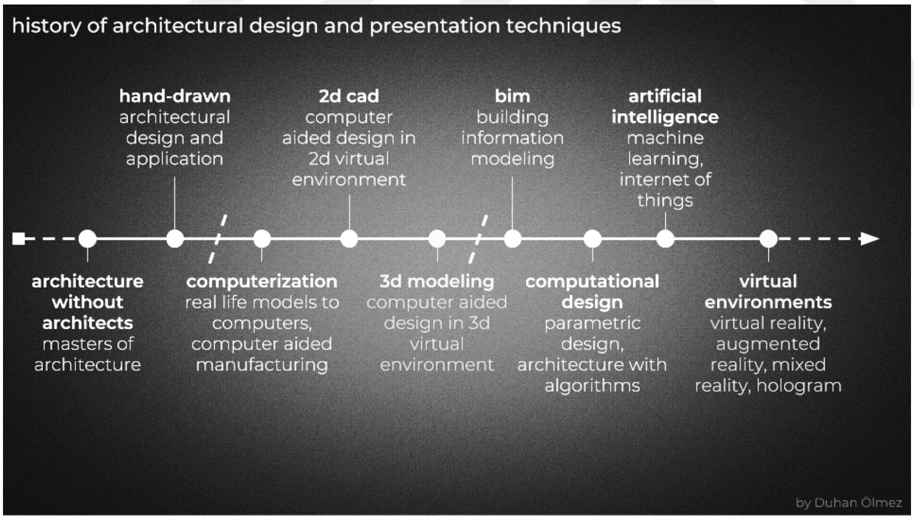


Figure 3.1: Course Material, Architectural Representation Techniques

Following week, the definition of virtual reality with its history and different approaches as well as professional architectural project delivery process (Figure 3.2) and how students can imply such procedure in their design studios are taught to students. In Yaşar University's architectural design studio courses, students highly use digital modelling tools. However, the process regularly includes feasibility study, schematic design and design development. Construction documentation, bidding and construction administration parts of the projects are excluded from design studio course syllabuses. Additionally, other compulsory and elective courses aim to teach students those skills and knowledge. Flow of three-dimensional visualization and modelling techniques in feasibility and schematic design process are introduced to students to use these methods along with their design studio courses and this study (Figure 3.3).

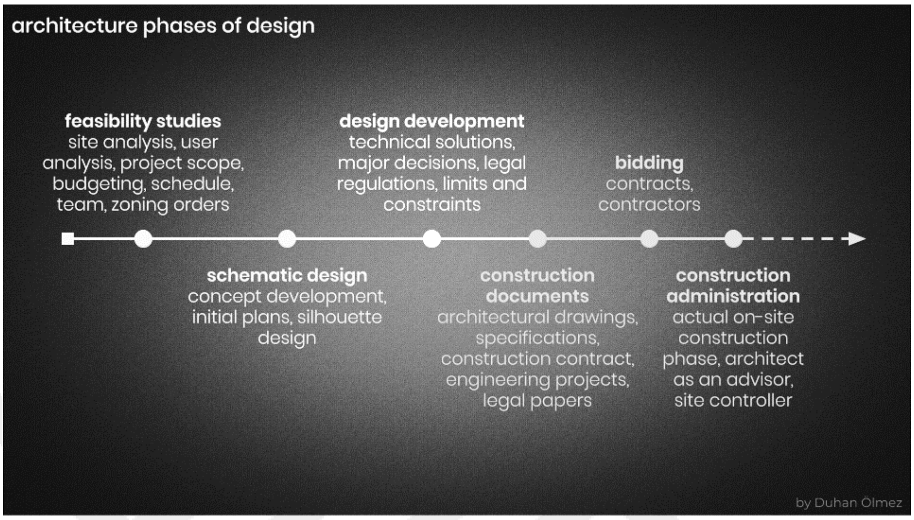


Figure 3.2: Course Material, Architectural Project Delivery Method

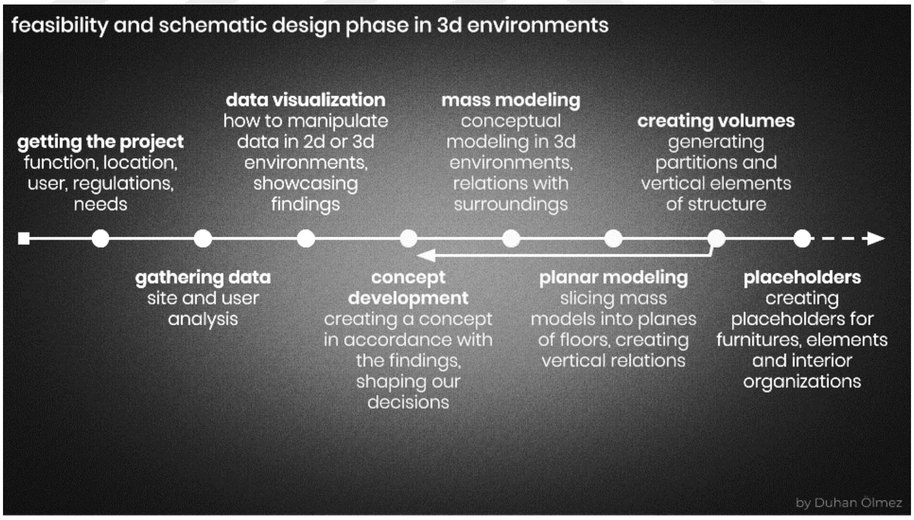


Figure 3.3: Course Material, Feasibility and Schematic Design Flow in 3D Environment

In the third week of the class, technical aspects of immersive virtual reality systems are explained to students. Also, three-dimensional modelling types, how to model in NURBS (non-uniform rational basis spline) and polygons are explained (Figure 3.5). Differences in wireframe, surface and solid objects also introduced to create a basic understanding of how transformation from one state to another can be handled and how collusion works in virtual environments (Figure 3.5). These three states of three-dimensional digital models are discussed to create a foundation for students about modelling advantages and disadvantages in terms of which architectural platform uses them and how.

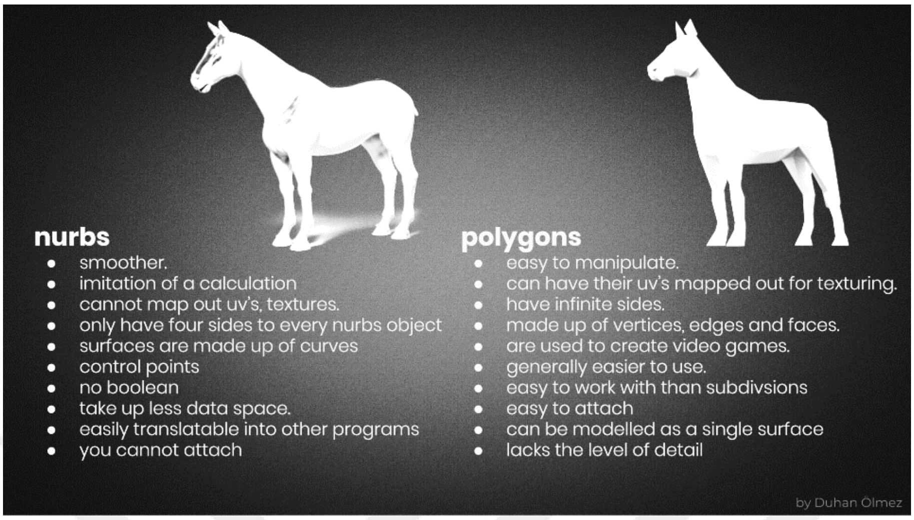


Figure 3.4: Course Material, Differences between NURBS and Polygons

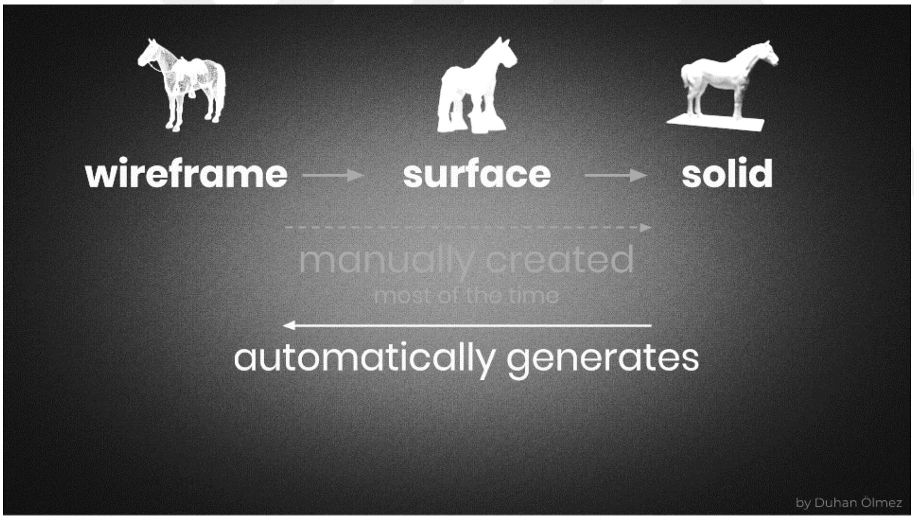


Figure 3.5: Course Material, Wireframe, Surface, and Solid Data Flow

With the given lectures, students are considered as they know what virtual reality is, how 3D environments and models work, what are their uses for architectural practice, and key aspects of using 3D models in immersive virtual reality systems. In the following weeks, different modelling techniques are presented to students to continue their design studio tasks such as 3D digital mass modelling, 3D digital planar modelling, vertical surfaces in virtual environments and placeholders for low-poly interior solutions. Additionally, specified tasks are given to students for both measuring their spatial perception and architectural collaboration as well as to develop their designs and use the process for the experiment. Throughout the semester five different experiments are applied by students for different purposes.

For experiments, communication with students are provided by using “Lectures System” prepared by Moodle and obliged by Yaşar University for all academic personal and courses. For exchanging data and providing a common ground between different 3D digital modelling applications, another software called “KeplerVR” is prepared and presented to the students. For collecting data from surveys and questionnaires, Google Forms have been used provided by Google.

3.2. DATA COLLECTION TOOLS

3.2.1. LECTURES PAGE

A collaborative platform, which is developed by Moodle and provided by Yaşar University to all academic personal as well as to students, has been used throughout the semester to provide a base communication between instructors and students. In total 14 weeks tabs and an announcement segment had been prepared within the web-page (Figure 3.6). Each week, course materials and presentations are shared with students using Lectures Page. Specified tasks are also presented to students here during the course and as homework. Questionnaires are embedded into the web-page using embed snippets. Students are expected to fill in these questionnaires while they are in the class or from distant related with the specified situation. Announcement feature in system is used to establish e-mail communication with students. Lectures assignments are also used to collect raw data which students created for further investigations. However due to limited upload size for students is only twenty megabytes, as students’ models get more detailed every week, different cloud-based storage systems are also used such as Google Drive, Dropbox, and OneDrive etc.

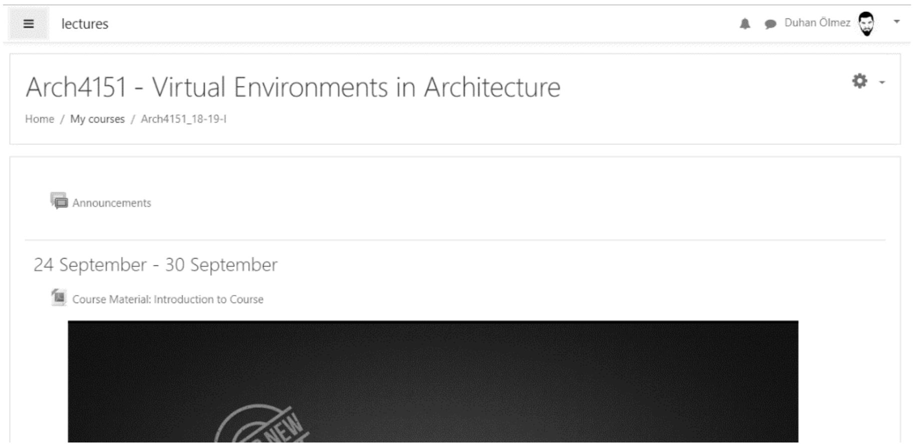


Figure 3.6: View from Lectures Page

3.2.2. GOOGLE FORMS

Free to use questionnaire and survey system provided by Google has been used to collect experiment results from students (Figure 3.7). Google Forms is a system which works collaboratively with Google Drive. Students initiated these forms within Lectures Page, answered questionnaires for specified tasks. In the system qualitative and quantitative questions can be prepared. Within the aim of this study short answers and paragraph answers are used as qualitative open-ended questions. Additionally, multiple choice, checkboxes, dropdowns and linear scale question types are used as quantitative data collection methods through surveys. Survey attendees had the choice to either fill questionnaires on their computers or mobile devices. Google Forms also provided data visualizations based on collected data. However, instead of using those exported spreadsheets have been used to visualize data and analyse them.

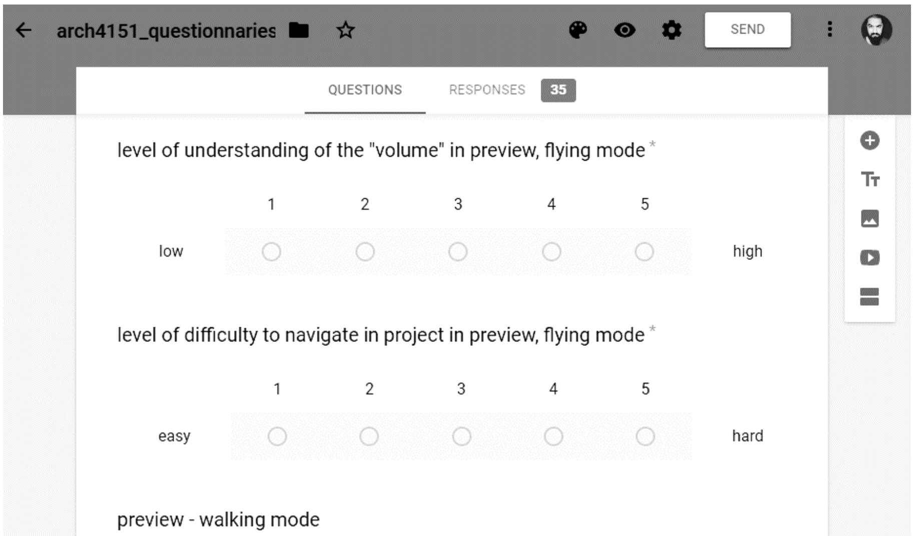


Figure 3.7: View from Google Forms

3.2.3. KEPLERVR

While students use range of software to create their 3D digital models in virtual environments, none of that software provide neither built-in immersive virtual reality (IVR) system nor a common control in on-screen virtual environment (OSVE). Since study is aiming to measure spatial perception in these 3D digital models as well as communication through them, a specific platform was needed. To this extend, KeplerVR which is a cross-platform virtual reality software has been chosen and used. The application works on every computer and mobile device users had such as Windows PC, iMac Laptops, Android Smartphone, iOS iPhone etc. Most significant features of the application are data exchange through OBJ format, creating models with description and model name, sharing these models between users, viewing 3D digital models in OSVE with walking or flying mode as well as in IVR by the help of VR-Boxes, leaving text or voice reviews in models on surfaces. Along with all these features, application offers an easy-to-use interface for users where they can upload 3D data, share them, view them etc.

3.2.3.1. DATA EXCHANGE AND CREATING A MODEL

As mentioned before, students were free to use the software they would like to use during the course and experiments. Most commonly used softwares were ArchiCAD, AutoCAD, Revit, SketchUp etc. All these software work by using their own native file formats like PLN, DWG, RVT, SKP and many others. Data change between all these softwares were crucial since all students were expected to present their works in the same way (Figure 3.8). Therefore, as a common ground, OBJ file format has been used to maintain 3D data between parties which known as wavefront file created by Wavefront Technologies to store geometric objects in virtual environments. OBJ files contain lines, polygons and free-form curves and surfaces, additionally they can hold colour information of surfaces (Chakravorty, 2018). However, any texture data which includes custom pictures does not included into the content of OBJ files. An automated generation system along with OBJ export algorithm can generate MTL files and a texture file. All the softwares students use to develop their architectural design can export OBJ, MTL and texture files easily as a product of their design development.

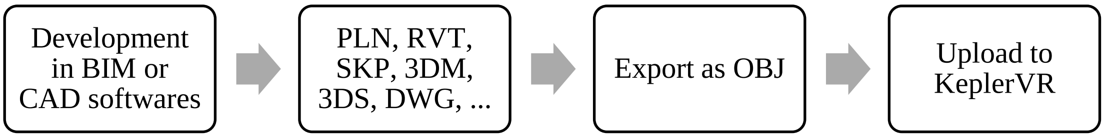


Figure 3.8: 3D Digital Data Flow

After OBJ, MTL and texture files created, in KeplerVR interface students were able to generate OSVE and IVR scenes using their exports. The flow of generation goes through an importing, adjusting and publishing process (Figure 3.9). Since the software already supports OBJ file as a base to generate scenes, uploading only OBJ files is enough to generate a model concluding models to be "white-model" which means there will be no texture applied on surfaces. By using "Create a Model" action in the dashboard interface (Figure 3.10), upload screen appears. By providing necessary information into the panels, users are able to generate scenes, scale them to correct size, rotate all 3D geometry, write a description, give a name and finish uploading the geometry etc (Figure 3.11). Most importantly, they can publish their models in the HUB, which is a common platform for everyone to see all published models (Figure 3.12).

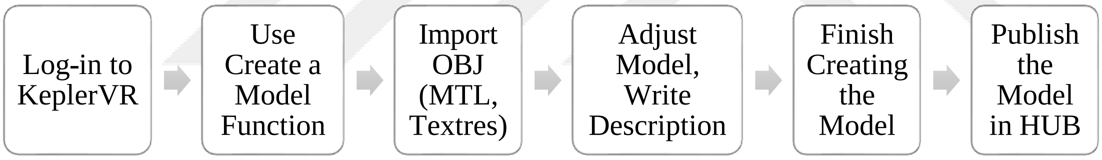


Figure 3.9: Model Creation in KeplerVR

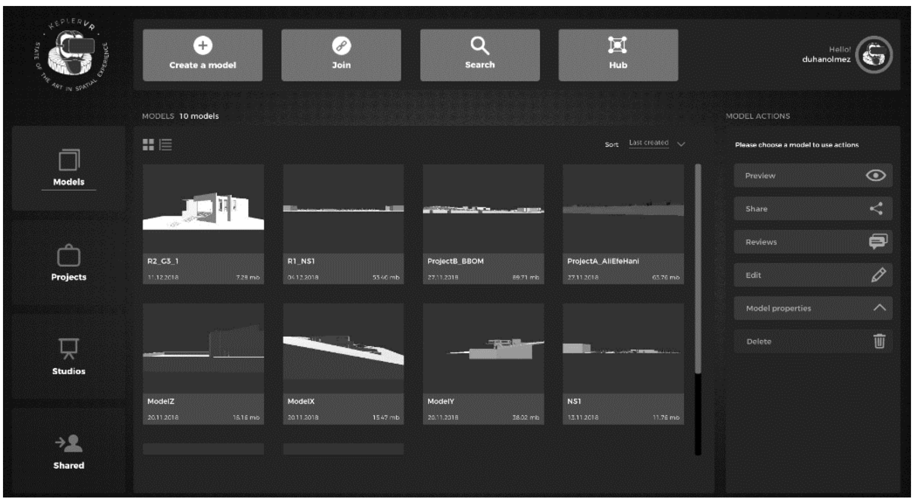


Figure 3.10: View from KeplerVR, Dashboard

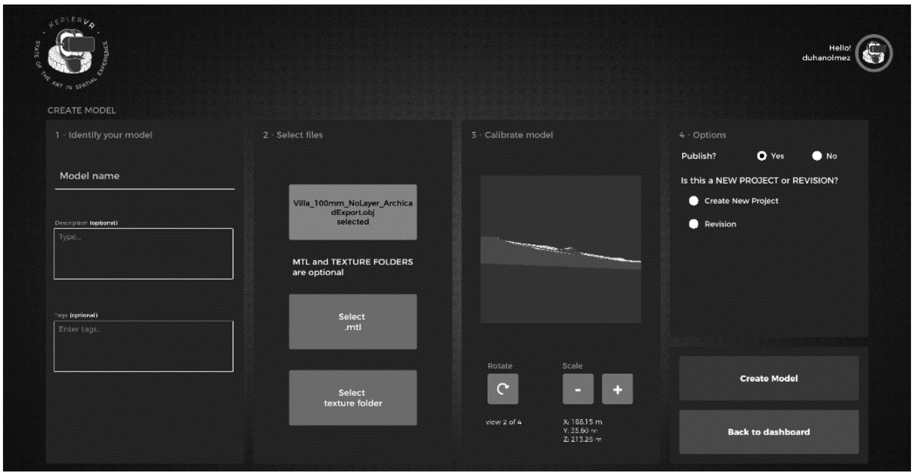


Figure 3.11: View from KeplerVR, Create a Model

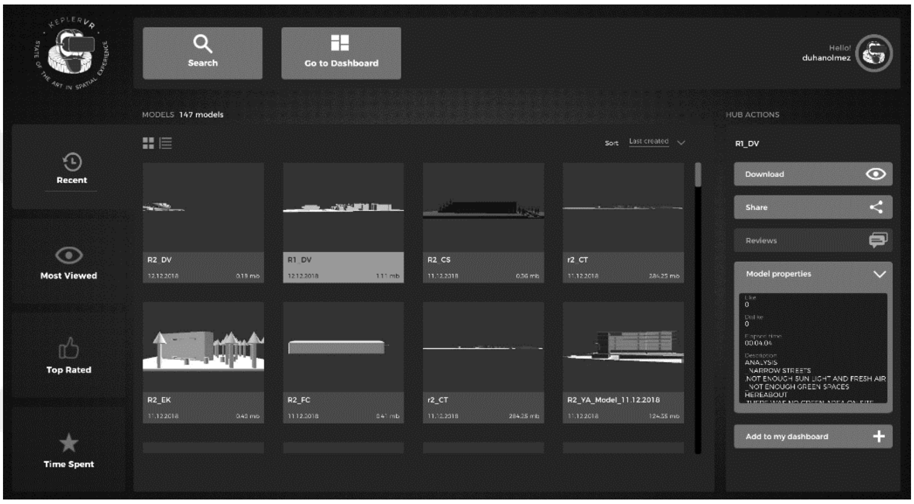


Figure 3.12: View from KeplerVR, The HUB Dashboard

3.2.3.2. OSVE AND IVR VIEWS

After generating the models in the software, users can see 3D digital models using different methods. The software provides two different viewing options including seeing 3D digital data on-screen virtual environment (OSVE) and immersive virtual environment (IVR). For OSVE view, two movement method is defined, flying mode and walking mode. By using flying mode, no collusion on surfaces applies to users, which means users are free to move in 3D virtual environment with no obstacle, can go through surfaces. On the other hand, walking mode generates collusion to able users to walk on surfaces. Both OSVE and IVR views provides walking mode. The camera stands on the offset of the ground by 1.65 meters which is an average human eye location from the ground. Users can move on the surfaces, go on stairs, get through openings on vertical surfaces etc. While OSVE view can be used in both computers

(Figure 3.13, Figure 3.15) and smartphones (Figure 3.14, Figure 3.16). IVR view can only be used by a smartphone using cost efficient VR-Box (Figure 3.17). On computers, for walking and flying mode users use keyboard and mouse inputs to navigate in 3D digital models. On smartphones in OSVE view, users can navigate through joysticks both in walking and flying mode, one for moving the camera and the other one is for changing camera angle. However, in IVR mode using VR-Boxes, users can only navigate through looking at the walking icon on the ground for a second (Figure 3.18), after walking is toggled, user moves in the direction of camera angle on the surface. To stop walking, users must toggle stop icon on the ground again. All these navigation options are applicable with any model users generate.

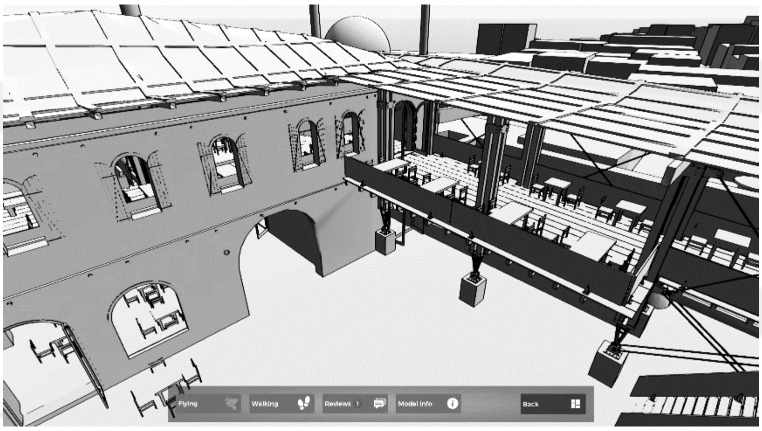


Figure 3.13: OSVE View on Computer, Flying Mode

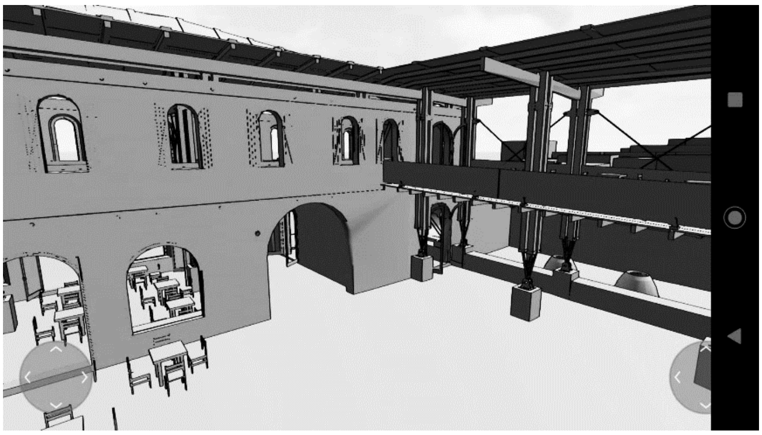


Figure 3.14: OSVE View on Smartphone, Flying Mode

Figure 3.15: OSVE View on Computer, Walking Mode

Figure 3.16: OSVE View on Smartphone, Flying Mode

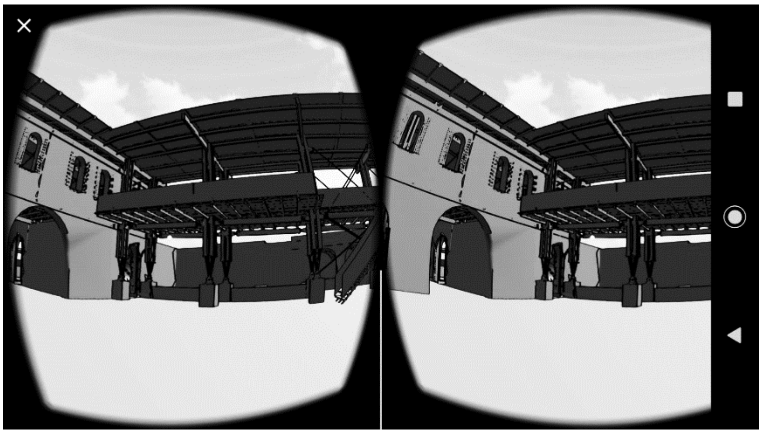


Figure 3.17: IVR View on Smartphone

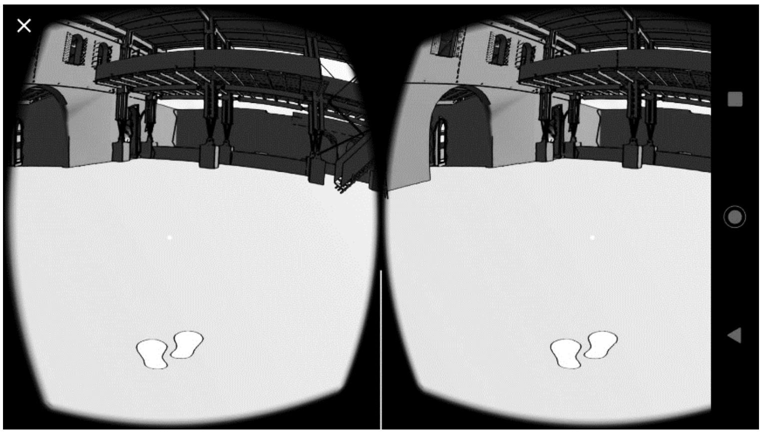


Figure 3.18: IVR View on Smartphone, Walking Toggle Icon

3.2.3.3. REVIEWS IN VIRTUAL ENVIRONMENT

For architectural communication and collaboration through design is a must in architectural project development. One of the key features KeplerVR offers is highly suitable for the study. In the recent studies designers were handling review, feedback and communication via speaking and/or text-based emails. However, by the "Review" system KeplerVR supports, users can put specified notes, feedbacks, request for changes etc. in the model, on 3D digital models' surfaces. Multiple reviews can be set by the users. Whenever a review generated, the software automatically notifies the model owner and creates a red sphere object along with text-based or voice-based context including comments (Figure 3.19). Reviews can be accessed both in dashboard (Figure 3.20) as well as in the virtual environment (Figure 3.21) along with the 3D digital data of the project. Later, model owner can evaluate the reviews and answer them through system. This conversation can be stored in the same review segment within the 3D data. However, the system only shows and allows people to give reviews in OSVE view on computers and/or smartphones.

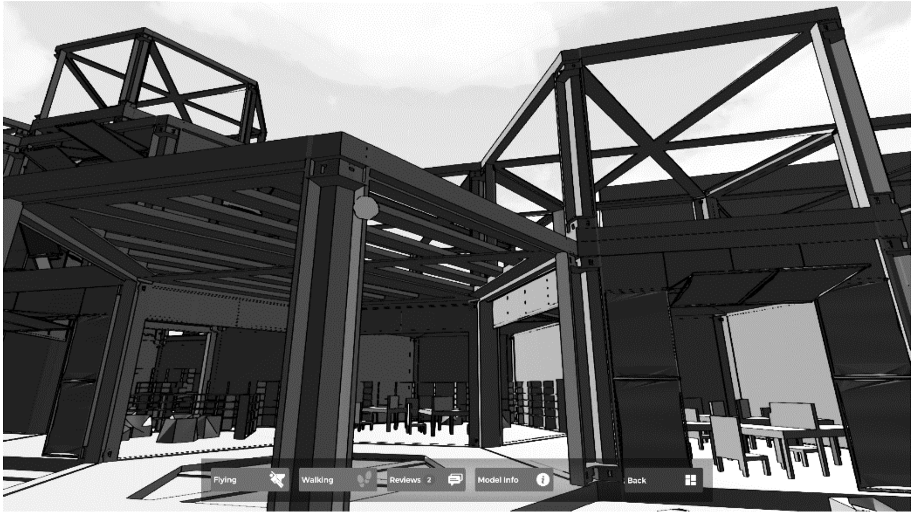


Figure 3.19: Review Indicator in OSVE View

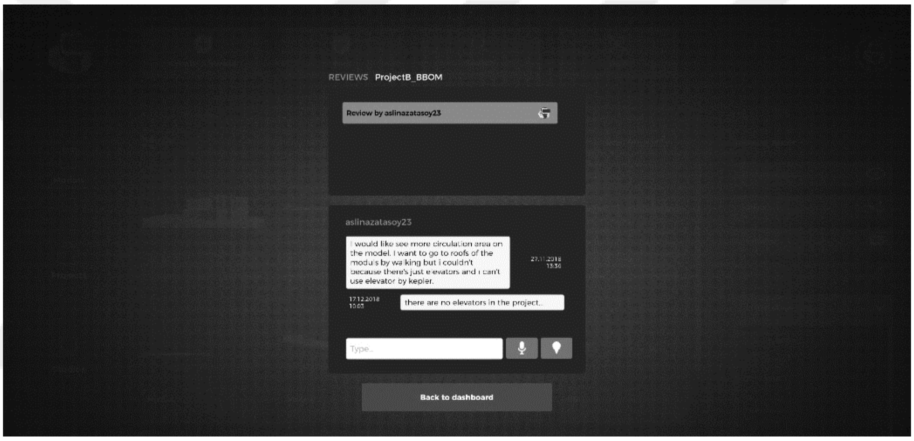


Figure 3.20: Review Panel in Dashboard

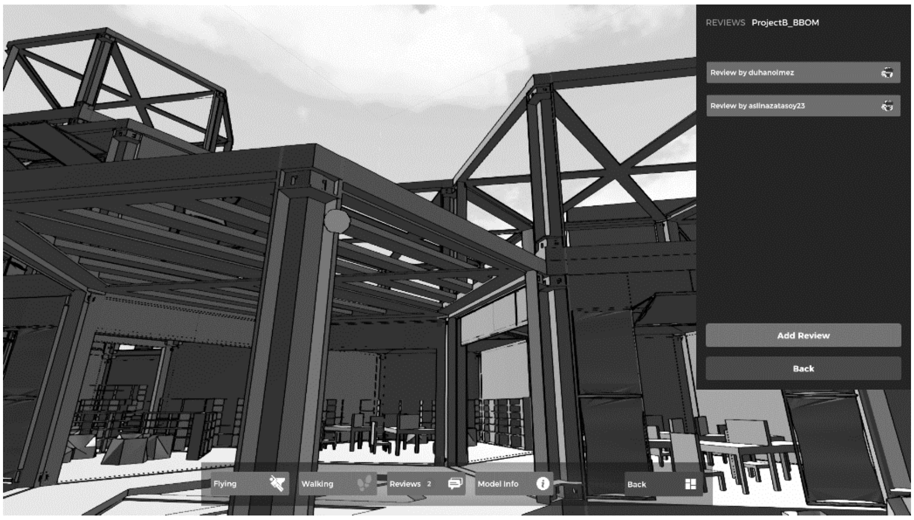


Figure 3.21: Review List in OSVE View

3.3. SAMPLE

Students who enrolled Arch 4151 – Virtual Environments in Architecture elective course in 2018 – 2019 Fall Semester in Yaşar University formed the sample of the current study. Therefore, each individual student corresponded to an independent observation unit in the sample. Since submission to the course was not restricted, the sampling method was random. That is, the research team has no influence on the observation units contributed to the current research. At the beginning of the experiments, a questionnaire was applied to students to generate descriptive statistics of the sample.

Due to university regulations, students were free to choose whatever elective they want, and sample acquired by students' appetite for such course. In total forty-six students selected the course at the beginning of the semester and their number remained the same throughout all semester (Table 3.1). However, because attendance required for such applied courses is 80%, students also had the chance to not attend few courses. For some experiments, students answered same questionnaire multiple times for different projects and representation methods. While twenty-two students worked individually (IW) for their design studios, there were three different three-member group-work and six different two-member group-works (GW). Also, five students had no design studio class in the same semester, therefore they assigned to be reviewers (RV), which means they did not develop any model; however, these reviewed more projects than the others. For different experiments project tags and personal tags of each individual has been used to indicate which student is going to evaluate whose project. This procedure handled randomly, therefore every week students were expected to observe and evaluate different projects.

Table 3.1: Study Units: Arch 4151 Student List, Roles and Tags

Student ID	*Role*	*GW / IW*	*GW Members*	*Project Tag*	*Personal Tag*
16080004167	Designer	IW	-	AKO	AKO
16080004168	Designer	IW	-	ANO	ANO
15080004021	Designer	IW	-	AO	AO
16080004234	Designer	IW	-	BO	BO
14080004024	Designer	IW	-	CO	CO
14080004005	Designer	IW	-	CS	CS
16080004102	Designer	IW	-	CT	CT

Student ID	*Role*	*GW / IW*	*GW Members*	*Project Tag*	*Personal Tag*
16080004231	Designer	IW	-	DV	DV
14080004063	Designer	IW	-	EK	EK
14080004049	Designer	IW	-	EO	EO
16080004248	Designer	IW	-	FB	FB
16080004287	Designer	IW	-	FC	FC
14080004031	Designer	GW	3	G1	G1_1
14080004035	Designer	GW	3	G1	G1_2
14080004046	Designer	GW	3	G1	G1_3
14080004001	Designer	GW	3	G2	G2_1
14080004025	Designer	GW	3	G2	G2_2
15080004016	Designer	GW	3	G2	G2_3
15080004027	Designer	GW	2	G3	G3_1
15080004045	Designer	GW	2	G3	G3_2
15080004048	Designer	GW	2	G4	G4_1
15080004056	Designer	GW	2	G4	G4_2
14080004015	Designer	GW	3	G5	G5_1
14080004033	Designer	GW	3	G5	G5_2
14080004045	Designer	GW	3	G5	G5_3
16080004085	Designer	GW	2	G6	G6_1
16080004227	Designer	GW	2	G6	G6_2
14080004026	Designer	GW	2	G7	G7_1
14080004066	Designer	GW	2	G7	G7_2
14080004040	Designer	GW	2	G8	G8_1
15080004028	Designer	GW	2	G8	G8_2
13080004017	Designer	IW	-	GA	GA
14080004047	Designer	IW	-	MCK	MCK
16080004283	Designer	IW	-	MM	MM
17080004087	Designer	IW	-	MS	MS
17080004083	Designer	IW	-	NNU	NNU
09080004074	Designer	IW	-	NS1	NS1
16080004279	Designer	IW	-	NS2	NS2
13080004042	Designer	IW	-	OD	OD
16080004221	Designer	IW	-	RA	RA
16080004209	Designer	IW	-	YA	YA

Student ID	*Role*	*GW / IW*	*GW Members*	*Project Tag*	*Personal Tag*
14080004108	Reviewer	-	-	-	RV_1
16080004307	Reviewer	-	-	-	RV_2
16080004311	Reviewer	-	-	-	RV_3
17400003008	Reviewer	-	-	-	RV_4
18300017002	Reviewer	-	-	-	RV_5

Such information as descriptive statistics of the sample can be found in Chapter 4, Table 4.1 with more detail.

3.4. VARIABLES

3.4.1. LIMITATIONS

Within the aim of current study, various situations and attribute can affect virtual environments in architectural design process and its efficiency. Questionnaires handled by a group of students who selected Arch 4151 elective course in 2017 – 2018 academic year, fall semester, in İzmir Yaşar University. Students who selected the course are mostly 4th year students. Therefore, most significant assumption can be the students with an initial interest in virtual environments selected the course.

Another variable that might affected the study was level of expertise in three-dimensional digital modelling. While students used different 3D modelling applications to develop their designs such as ArchiCAD, SketchUp, Rhinoceros, Revit, 3D Studio Max, AutoCAD etc., their knowledge of those platforms are also important for the aim of the study. However, they all took primary knowledge of what is a 3D digital model, their types and how to work with them in the course.

Used devices can also affect the process for research. As students use smartphones to demonstrate immersive virtual environments, operating systems observed have been mostly Android for Samsung, Huawei, Sony, etc. and iOS for apple smartphone iPhones. On the other hand, to generate models, students use their personal computers. Its operating systems as well as computers' technical specifications such as processors, graphic cards, RAM capacity, operating system, hard-drive setup etc. fastens or slows down the process of generating 3D models and receiving them to evaluate from their friends.

Students' familiarity with brand new video games can also be a factor to improve their ability to understand 3D digital data in virtual environments. Scoresby (2011) indicates video games effects perception and three-dimensional thinking on virtual environments. While students explore 3D games and their contents, their ability to hand-eye coordination and 3D thinking improve. Therefore, those students who play video games frequently expected to have better spatial understanding and navigate in virtual environments easier.

Even if education language in Yaşar University is officially English and all students were obliged to take the language preparation school education, all students' native languages were different than English, including foreign students. Lack of communication in English may have also affected the experiment process. However, level of English spoken in the class was adequate. Therefore, questionnaires and experiments done in English.

Also, some experiments required students to develop their own projects. Due to diversity of design studios, some students were working in groups while others developed their projects individually. Development process and designer collaboration also is a variable that effects the process. However, distribution of group and individual working was homogenous.

Students' ability to design, develop an architectural project and handle design studio has a major effect on their spatial perception and architectural collaboration. Critique sessions were open for all students, therefore no exception has been made between students and architectural collaboration measures might consist insufficient results related with students' skillsets for architectural project development. Therefore, students' critiques for other students' projects are used as a base to measure architectural collaboration.

Which grade students are also an attribute to affect the results. Upon initial analysis, participants consist fourth- and third-year students mostly. Their design studios were different due to level difference. They all expected to develop their projects using virtual environments. However, scale difference between projects they assigned for may cause inequality.

Students' attendance status may cause different level of knowledge throughout the experiment. However, all documentations, slides, and course materials as well as models and assignments uploaded to a common webpage which students who could not attend the course can follow.

Last, gender of participants effects the understanding of virtual 3D data. As Dorta et al. (1998) and many others (e.g. Samsudin et al., 2011) also indicated, male participants have significant advantage on understanding three-dimensional environments in virtual reality systems. Generating 3D data and navigating through immersive virtual environments might be easier for male students.

3.4.2. RESPONSES

Primary goal of experiments is to measure spatial perception in virtual environments, their differences when compared with each other's, and effectiveness of distant communication for architectural collaboration. For these extends, sets of questionnaires prepared for participants to answer in accordance with their experiences and understanding.

Different experiment setups have been used to demonstrate distinct aspects of spatial communication and architectural collaboration. Also, experiment materials, 3D digital models and used methods varied during the study, which caused use of different questionnaires. However, comparable questions and measures have been used in different sets of questionnaires to provide a common ground to compare multiple results and cross check aspects of results. Both quantitative and qualitative questions presented to participants to investigate the topic further. However, quantitative results had been focused to demonstrate results of the study and qualitative results used as an indicator for further researches.

For spatial perception questions related with understanding project definition, 3D model adequateness, mass organization, plan organization, human scale, volumes' relations, circulation paths with corridors, stairs, rooms etc., interior-exterior relations, openings on surfaces, solid-void relations, furniture organization, vertical slab relations and how all these aspects perceived in virtual environments asked to participants in different settings. Also, for other experiments to see efficiency of representation method on understanding several aspects of the design, they asked to compare different representation tools by the same questionnaires or similar ones.

Architectural collaboration is measured in two separate ways. Students completed two questionnaires in two distinct roles as reviewers and project owners. Each week, they asked to evaluate their friends' projects in virtual environments. All students evaluated projects and gave comments to their friends as well as their friends gave comments to their projects in immersive or on-screen virtual reality. This mutual relation between students measured by questions like if they were able to give reasonable reviews, offer new circulations, new interior solutions, plan organizations etc. and if the model was adequate to give reviews, or not. The reviews they got were measured by questions related with validity of those questionnaires and their efficiency to develop their projects further.

3.5. QUESTIONNAIRES

Measuring spatial perception is highly varied in previous studies, most common use of measurement is to create questionnaires for participants. Questions have large range of types. Distinction between surveys occurs related with the aimed group. While non-designers are not qualified to understand the elements of volumes but they are mostly focuses on use and its appearance, designers and especially architects which are in the core of this study, more focus on elements of the volume, their creation, effects for the interior, different organization methods, functions, their viability and many other aspects which effects design and appearance of the volume significantly. Therefore, questionnaires prepared by considering students who took an architectural elective course, which they assumed to know the basics related with the volume. On the other hand, no specified nor proved method had been used in literature to measure participatory actions in design process. While collaborative platforms such as CAD, BIM etc. is highly used to demonstrate such function, their measurements mostly considered construction documentation for further development in design process. While designing volumetric creations, no measurement technique has been established to understand influences of the tools for such process. For this case particularly, questionnaires prepared to get an insight about influence of virtual environments in design phase and feedback effectiveness. Spatial perception is measured by comparing different virtual environment and presentation setups. In contrast, no comparative analysis had been conducted for collaborative works. Students only used virtual environments to maintain communication through them. Therefore, measurements for collaboration only indicates effectiveness of the virtual environments in feedback and critique process.

Throughout the semester students expected to fill in various questionnaires depending on experiments. To create a categorization between all those questions, they handled differently. Yet specified questions remained same in every experiment to support comparison between different cases. Questionnaires focused on measuring two aspects of the study, level spatial perception and feedback process which enhances architectural collaboration. Closed-ended and open-ended questions are given to students. While close-ended questions had been used to create quantitative results to compare and analyse the outcomes of the research, qualitative questions only handled for proceeding in-depth investigation.

All experiments handled by different sets of questionnaires. However, to explain questions in broader sense, most of the questions asked can be seen in Table 3.2. To understand students' ability, behaviours and habits related with virtual environments, initial questionnaire presented to them. Questions mostly focused on their experiences and the way they use 3D digital environment as well as personal questions to define independent variables like their gender, whether they play computer games or not, in which phase they use virtual environments and 3D digital modeling in their design process, their age, if they will use computer applications to develop their projects, which design studio they are taking, for how long they are using CAD systems, what software they are using to create 3D digital models, etc. Some additional questions also presented to students depending on the experiment and various aspects of the study. Further explanations of questions will be held in following section.

Table 3.2: Questions That Were Commonly Employed

Question	*Method*	*Type*	*Response*	*Var. Type*
What is your gender?	Quantitative	Multiple Choice	Male, Female, Other	Independent Variable
How old are you	Quantitative	Multiple Choice	Values	Independent Variable
Do you play video games?	Quantitative	Multiple Choice	Yes, No	Independent Variable
Which design studio are you taking right now?	Quantitative	Multiple Choice	Design Studio List	Independent Variable
Are you working individually or with a group?	Quantitative	Multiple Choice	Individual, Group Work	Independent Variable

Question	*Method*	*Type*	*Response*	*Var. Type*
If you work in a group, how many members are you?	Quantitative	Multiple Choice	Values	Independent Variable
What is the topic of design studio you are taking?	Qualitative	Open-ended Answers	Open-ended Answers	Independent Variable
What are your initial ideas about the project?	Qualitative	Open-ended Answers	Open-ended Answers	Independent Variable
Do you use CAD or BIM softwares?	Quantitative	Multiple Choice	Yes, No	Independent Variable
Which software are you using for designing your project?	Quantitative	Multiple Choice	List of Softwares	Independent Variable
For how long you are using BIM or CAD softwares?	Quantitative	Multiple Choice	Year ranges	Independent Variable
In which phase of design process do you use virtual environments?	Quantitative	Checkboxes	Different Phases of Design Process	Independent Variable
"I understood…"	Quantitative	Multiple Choice	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest…"	Quantitative	Multiple Choice	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I figured out…"	Quantitative	Multiple Choice	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was…"	Quantitative	Multiple Choice	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The reviews I gave were mostly about…"	Quantitative	Multiple Choice	List of Architectural Design Aspects	Dependent Variable, Feedback Process
Describe your project/volume.	Qualitative	Open-ended Answers	Text	Dependent Variable, Feedback Process

Question	*Method*	*Type*	*Response*	*Var. Type*
Describe the project/volume you reviewed.	Qualitative	Open-ended Answers	Text	Dependent Variable, Spatial Perception
Write down the critiques and revision requests for the project/volume.	Qualitative	Open-ended Answers	Text	Dependent Variable, Feedback Process
Which one was more effective to understand…?	Quantitative	Multiple Choice	Different Representation Methods	Dependent Variable, Spatial Perception
Level of understanding of the project/volume in…	Quantitative	Likert Scale	Values	Dependent Variable, Spatial Perception
Level of navigation difficulty in…	Quantitative	Likert Scale	Values	Dependent Variable
Level of communication in…	Quantitative	Linear Scale	Values	Dependent Variable, Feedback Process

3.6. EXPERIMENTS

Different sets of experiments applied to students within the course (Table 3.3). These experiments categorized in two, to measure influence of architectural representation method on understanding different aspects of architectural projects (Experiment 2 and Experiment 3) and other experiments which include a collaborative virtual environment and aims to measure architectural communication by reviews and evaluation of students' projects (Experiment 1 and Experiment 4).

Table 3.3: List of Experiments

Experiment	*Name*	*Date*	*Week*	*Importance*
Experiment 1	Installation	October 16, 2018	4th Week	First Encounter with Virtual Environments
Experiment 2	DOD, OSVE, IVR Comparison	October 23, 2018	5th Week	Comparing Presentation Methods, Spatial Perception
Experiment 3	DPB-DWV, OSVE-IVR Comparison	November 27, 2018	10th Week	Comparing Presentation Methods, Spatial Perception

Experiment	*Name*	*Date*	*Week*	*Importance*
Experiment 4	Distant Collaboration	November 13, 2018 December 18, 2018	8th Week 13th Week	Spatial Perception, Virtual Project, Distant Feedback Process
Experiment 4.1	Initial Mass Models	November 13, 2018	8th Week	Virtual Project Development, Distant Feedback Process
Experiment 4.2	All Project Models	December 4, 2018	11th Week	Virtual Project Development, Spatial Perception, Distant Feedback Process
Experiment 4.3	Partial Space Models	December 11, 2018	12th Week	Spatial Perception, Distant Feedback Process
Experiment 4.4	Review Session	December 18, 2018	13th Week	Distant Feedback Process

Since the experiment handled through an elective course, students have informed about their responses in the questionnaires will not affect their grades. To ensure this situation and enhance the viability of the results, at the end of each experiment they graded their friends' works to generate their final grade at the end of the semester.

After theoretical part of the course is finished, students expected to create a basic 15-meter to 15-meter closed volume with some geometrical installations inside by using low-poly modelling techniques. This assignment created the base for the first experiment where students met the virtual environment with their own creations for the first time. Their ability to model, navigation in virtual environments and how they use those platforms are measured.

Second experiment handled by evaluating three different housing projects by students. Technical drawings, 3D digital model and immersive virtual environments explored by students. Their reactions recorded, and understanding level of the space, overall project etc. measured.

As third experiment, students observed mid-scale projects which are bigger than the housing projects in second experiment. Students evaluated projects with on-screen walkthrough and presentation boards also immersive virtual environments. Another aim of this experiment was effects of projects' sizes in virtual environments to understand projects.

Following week, in relation with their own design studio tasks, volume-based and surface-based mass model technique introduced to students. Rapid modelling technique presented to improve their digital mass modelling ability. At the end, they expected to model their own design studio proposals as digital 3D mass models. Forth experiment handled within courses midterm assignment by students evaluating each other's mass models. Another questionnaire presented for students to measure architectural collaboration. Last weeks of the course and the final week of semester designed as a set of studies where students evaluated their schematic designs and got into details through their friends' reviews, critiques, and ideas. First, vertical surfaces, what they are and how to model them introduced to students and they expected to create those geometries for their projects. Later, placeholders as interior furniture organization and furnishings taught to them and they presented interior volumes to their friends. Course handled as virtual studio for 4 weeks, students did not physically attend the course, however scheduled tasks given to them for demonstrating critique session. Different sets of questionnaires applied to students to measure collaboration and perception.

3.6.1. INSTALLATION (EXPERIMENT 1)

After lectures throughout the semester related with representation methods, 3D digital modelling techniques and how they work, VR systems and use of them, students expected to be aware of such systems and able to use them for their own benefits. To measure if they can do so, Experiment 1 presented to the students. For the experiment, students created a 15-meter to 15-meter slab with an installation on top of it. Vertical surfaces and what to put inside left to them. Installations they created is collected within Lectures Page and their design criteria defined as 15-meter to 15-meter slab, minimum 120cm exterior walls, something important for them to demonstrate, 3D abstraction of installation, no materials, low-poly digital models and they had to work individually for this experiment. Their projects collected by using Lectures Page and KeplerVR. In total 42 students uploaded their OBJ files to Lectures Page. Also, they expected to create their IVR and OSVE within KeplerVR using their created OBJ files. When their modelling and creation phase is over, they expected to get into KeplerVR and evaluate three other students' installations according to the list provided in Table 3.4.

Table 3.4: Experiment 1, List of Students

Personal Tag	*Review1*	*Review2*	*Review3*	*Extra1*	*Extra2*
AKO	CT	G6_2	ANO	G3_1	NNU
ANO	AKO	AO	G5_2	G1_2	G4_2

Personal Tag	*Review1*	*Review2*	*Review3*	*Extra1*	*Extra2*
AO	G2_1	G1_2	G7_1	NS2	MS
BO	GA	AO	NS1	G5_3	NS1
CO	CS	BO	MCK	AKO	G6_1
CS	MS	NS1	CO	G4_2	GA
CT	EO	G7_1	AO	G2_1	YA
DV	G8_2	ANO	G6_1	CT	CS
EK	CS	G8_2	CT	FC	DV
EO	MCK	G7_2	G2_3	NS1	DV
FB	MM	G4_1	G5_1	BO	EO
FC	G2_2	G5_2	YA	G1_3	CT
G1_1	G5_2	YA	AKO	MS	OD
G1_2	ANO	EK	G2_1	G5_1	G4_1
G1_3	G5_3	G3_1	FB	G6_2	FC
G2_1	FB	BO	G6_2	EK	G5_1
G2_2	BO	G5_3	DV	G7_1	EO
G2_3	NS1	FB	EO	G5_2	G1_2
G3_1	CO	G2_3	FB	GA	G1_3
G3_2	RA	NS2	RA	AO	G3_1
G4_1	G3_1	G6_1	G3_2	G1_1	G2_1
G4_2	G4_2	CO	FC	NNU	ANO
G5_1	EK	G1_1	G3_1	YA	G1_1
G5_2	G6_2	MS	MM	EO	RA
G5_3	OD	AKO	G8_2	G4_1	G5_3
G6_1	NS2	CS	G2_2	G1_2	G7_1
G6_2	FC	G5_1	ANO	MM	G2_2
G7_1	G2_3	G2_1	BO	G2_2	CO
G7_2	G4_1	CT	G5_3	G2_3	AO
G8_1	G5_1	OD	G8_1	G3_2	AKO
G8_2	G7_2	RA	G1_2	OD	G1_3
GA	G3_1	NNU	G1_1	G3_2	G3_2
MCK	G3_2	G2_2	NS2	G8_1	EK
MM	YA	G2_1	CO	DV	G4_1
MS	G4_2	G4_2	G4_2	G2_2	G8_2
NNU	G1_3	FC	G4_1	RA	MCK
NS1	G1_1	G3_2	G7_2	CO	MM
NS2	G7_1	EO	NNU	G7_2	G2_3
OD	G1_2	G1_3	CS	MCK	NS2
RA	AKO	MM	GA	G5_1	FB
YA	AO	GA	CT	G2_3	G7_2
RV_1	NNU	DV	G5_2	CS	G6_2
RV_2	G5_3	G1_1	OD	ANO	G8_1
RV_3	DV	G8_1	EK	G8_2	BO
RV_4	G8_1	MCK	MS	G6_1	G5_2
RV_5	G6_1	EK	G1_3	FB	FC

On November 16, 2018 attendees in the class of Arch 4151 started the evaluation process. To evaluate each project students had approximately twenty minutes. They were obliged to review assigned projects in the list with Review1, Review2 and Review3, in case some of the models were missing or crashing, they had the chance to continue with Extra1 and Extra2. Since students assigned as reviewers did not generate any model, they were expected to review Extra1 and Extra2 assigned to them. To observe, evaluate and review the projects, students used their computers and smartphones. KeplerVR application provided OSVE in both computers and smartphones and IVR in their mobile devices. While OSVE system provides walking and flying mode, in IVR students were only able to navigate on slabs, walking. Students were free to use whatever they want, if they use both at least once. Later, students expected to fill in two separate questionnaires. One of them for understanding what they saw, understood and felt in the assigned installations, another one to understand their ability to navigate and perceive projects in OSVE and IVR. Questionnaire 1 was given to students and questions were the personal tags of each project and what they saw in model, in overall, volumetrically, ideally and how those models made them feel (Table 3.5). Questionnaire 2 included questions categorized in three, for OSVE flying mode, OSVE walking mode, IVR mode and communication. For different movement and preview modes, level of understanding of the overall project, level of understanding the volume and level of difficulty to navigate in project using that mode is asked (Table 3.6). For communication and feedback process and its effects on the development, asked questions were level of communication by speaking with other person, by text-based reviews, level of difficulty to give reviews, level of finding made reviews to their projects, and level of understanding the reviews designers received. All questions' answers were based on a linear scale from easy to hard or low to high.

Table 3.5: Questionnaire 1

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
What is the first model owners name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Please explain the installation in the first model, what did you see in overall,	Qualitative	Open-ended Answers	Text	Dependent Variable,

Question	*Method*	*Type*	*Response*	*Aim*
volumetrically, how it made you feel like.				Spatial Perception
What is the second model owners name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Please explain the installation in the second model, what did you see in overall, volumetrically, how it made you feel like.	Qualitative	Open-ended Answers	Text	Dependent Variable, Spatial Perception
What is the third model owners name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Please explain the installation in the third model, what did you see in overall, volumetrically, how it made you feel like.	Qualitative	Open-ended Answers	Text	Dependent Variable, Spatial Perception

Table 3.6: Questionnaire 2

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Level of understanding of the overall installation in OSVE view, flying mode?	Quantitative	Likert Scale	Low to High	Dependent Variable, Spatial Perception
Level of understanding of the volume in OSVE view, flying mode?	Quantitative	Likert Scale	Low to High	Dependent Variable, Spatial Perception
Level of difficulty to navigate in OSVE view, flying mode?	Quantitative	Likert Scale	Easy to Hard	Dependent Variable, Spatial Perception
Level of understanding of the overall installation in OSVE view, walking mode?	Quantitative	Likert Scale	Low to High	Dependent Variable, Spatial Perception
Level of understanding of the volume in OSVE view, walking mode?	Quantitative	Likert Scale	Low to High	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
Level of difficulty to navigate in OSVE view, walking mode?	Quantitative	Likert Scale	Easy to Hard	Dependent Variable, Spatial Perception
Level of understanding of the overall installation in IVR view?	Quantitative	Likert Scale	Low to High	Dependent Variable, Spatial Perception
Level of understanding of the volume in IVR view?	Quantitative	Likert Scale	Low to High	Dependent Variable, Spatial Perception
Level of difficulty to navigate in IVR view?	Quantitative	Likert Scale	Easy to Hard	Dependent Variable
Level of communication via speaking with other person while in IVR view?	Quantitative	Likert Scale	Low to High	Dependent Variable, Feedback Process
Level of communication via text-based reviews on surfaces in OSVE view?	Quantitative	Likert Scale	Low to High	Dependent Variable, Feedback Process
Level of difficulty to put reviews in OSVE view?	Quantitative	Likert Scale	Easy to Hard	Dependent Variable, Feedback Process
Level of difficulty to find reviews' locations in OSVE view?	Quantitative	Likert Scale	Easy to Hard	Dependent Variable, Feedback Process
Level of understanding of reviews you got to your installations?	Quantitative	Likert Scale	Low to High	Dependent Variable, Feedback Process

3.6.2. DOD, OSVE AND IVR VIEWS (EXPERIMENT 2)

Each architectural presentation method indicates different aspects of the design. In previous studies, physical and digital models have been used extensively to demonstrate advantages and disadvantages of both presentation methods. Results indicate physical models have a significant value in architectural project development and presentation process. However, no research has been conducted to demonstrate influences of different virtual environment systems for understanding architectural projects. Within the content of this study, Experiment 2 designed to demonstrate spatial understanding of different aspects of the architectural projects in three different digital representation method which are orthographic drawings, on-screen virtual environment view, and immersive virtual reality view. Since all these methods are virtual, and no physical appearance of the projects are provided to students, no comparison between physical and digital methods have been aimed. In total 46 students attended the experiments. Since they already submitted previous experiment, they all assumed to know how to navigate in virtual environment on both OSVE and IVR views. Also, they are third- and fourth-year students, which also means they know how to read orthographic drawings. For experiment, model selection, dividing the students' groups and collecting information was crucial.

3.6.2.1. PROJECT SELECTION

Three different commercial projects selected for the experiment. All of them around same square meter and characteristics. They defined as Model X, Model Y and Model Z which are all villa projects with two or three stories and included volumes are almost the same with a living room, kitchen, dining area, toilet, two regular and one master bedrooms, restroom, and additional open spaces. Model X is 120 square meters with two stories. Model Y is 180 square meters with three stories, a basement, ground floor and first floor. Both Model X and Model Y are commercial villa projects in Güllük, Milas, Muğla in Turkey. On the other hand, Model Z is 150 square meters with three stories including basement, ground, and first floor. It is also a commercial villa project in Kemalpaşa, İzmir in Turkey. All three projects are for a single family, individual housing projects. None of the projects has any surrounding, therefore no contextual data is provided within them but only the structures and their sites. Orthographic drawings in PDF and DWG files are provided to students at the beginning of the experiment including plans (Figure 3.22, Figure 3.24, Figure 3.26), sections and elevations (Figure 3.23, Figure 3.25, Figure 3.27) in the Lectures Page.

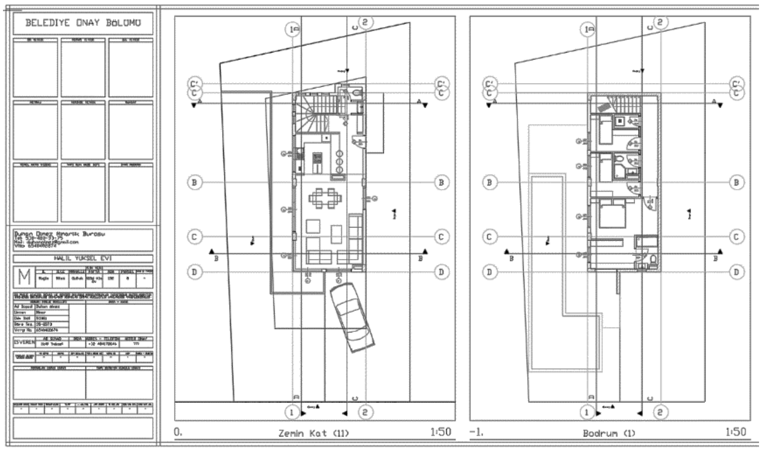


Figure 3.22: Model X, Orthographic Plans

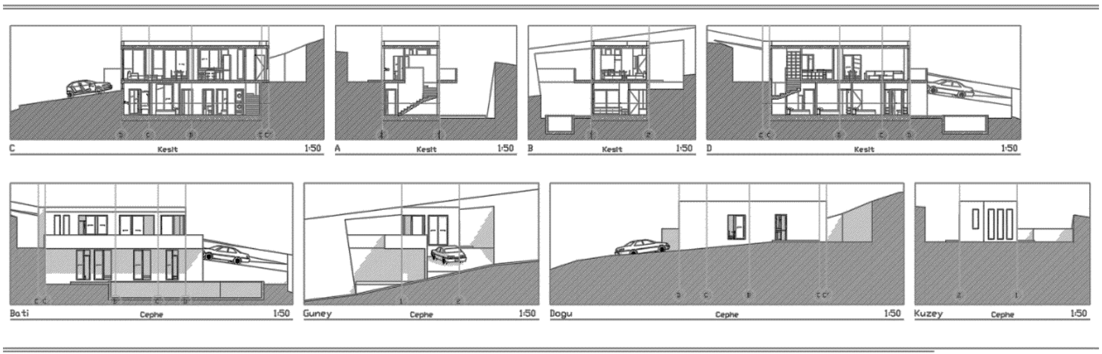


Figure 3.23: Model X, Orthographic Sections and Elevations

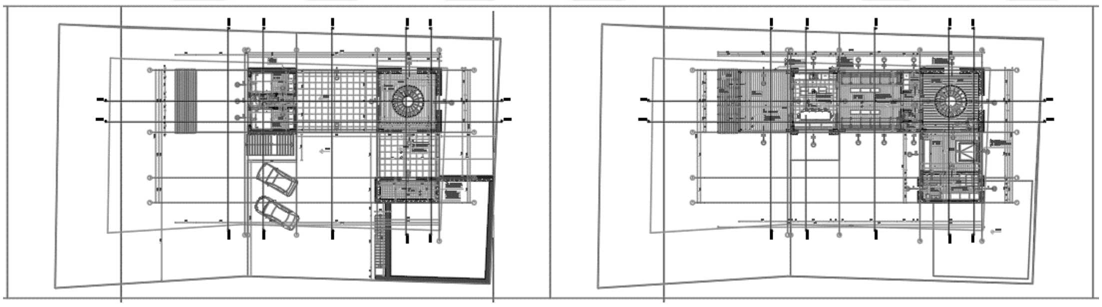


Figure 3.24: Model Y: Orthographic Plans

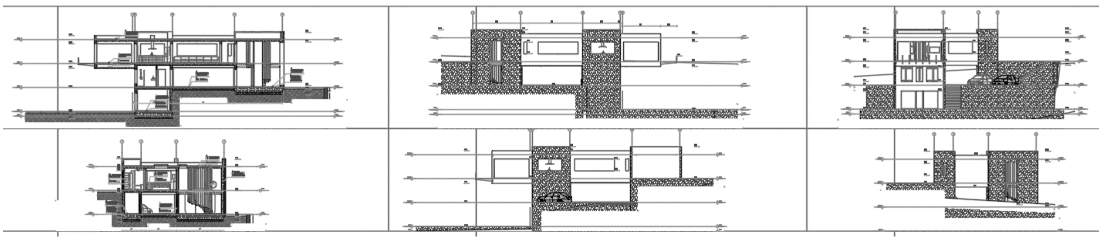


Figure 3.25: Model Y, Orthographic Sections and Elevations

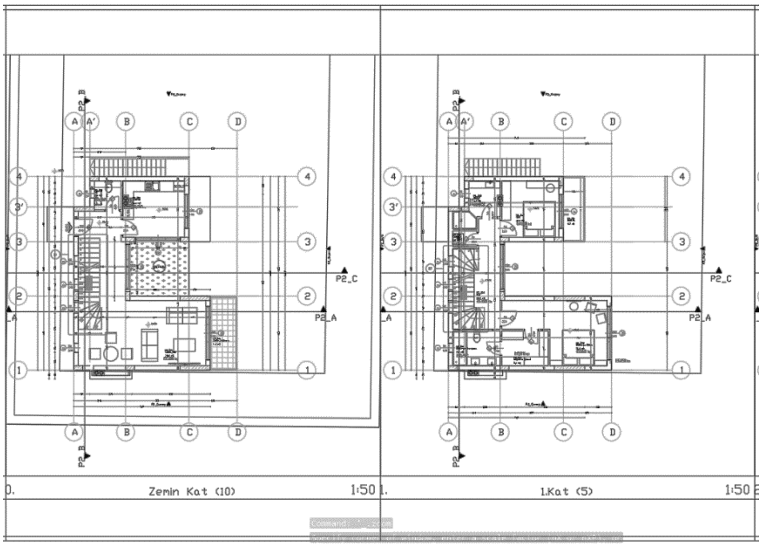


Figure 3.26: Model Z, Orthographic Plans

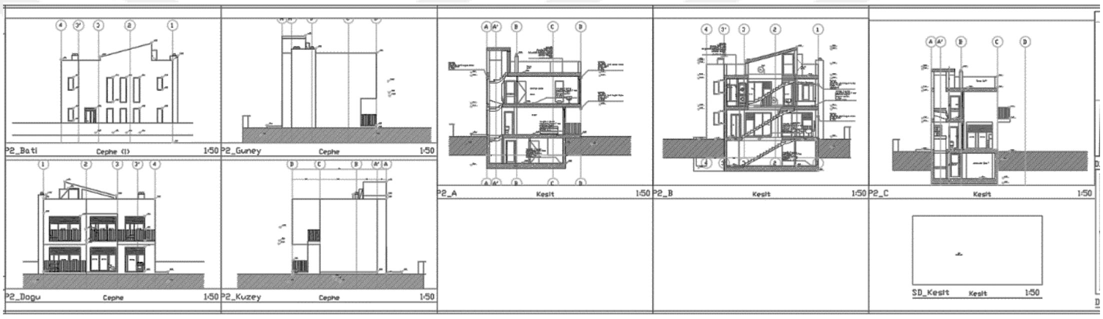


Figure 3.27: Model Z, Orthographic Sections and Elevations

Along with the shared orthographic drawings, generated pin numbers for Model X (Figure 3.28), Model Y (Figure 3.29), and Model Z (Figure 3.30) in KeplerVR shared with students. They were able to use the “Join” action with the given pin in application to access OSVE and IVR views in virtual environments. Since they were expected to navigate through digital models, 3D geometries created via openings on the surfaces. Students were fully able to get in and out every volume available in the virtual models. Models included horizontal surfaces such as site, slabs and roof; vertical surfaces which are walls, doors, façade elements and railings; also, placeholders, furnishings and frames of the glazing elements. None of the models had any textures or colours to manipulate the viewers, therefore all three models were white-models.

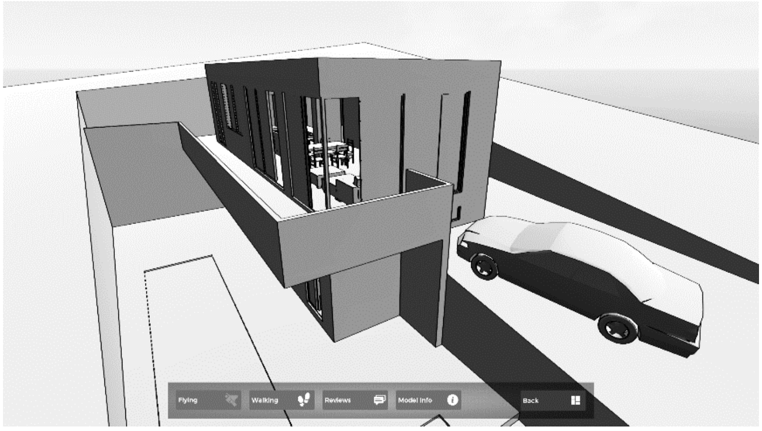


Figure 3.28: Model X in KeplerVR

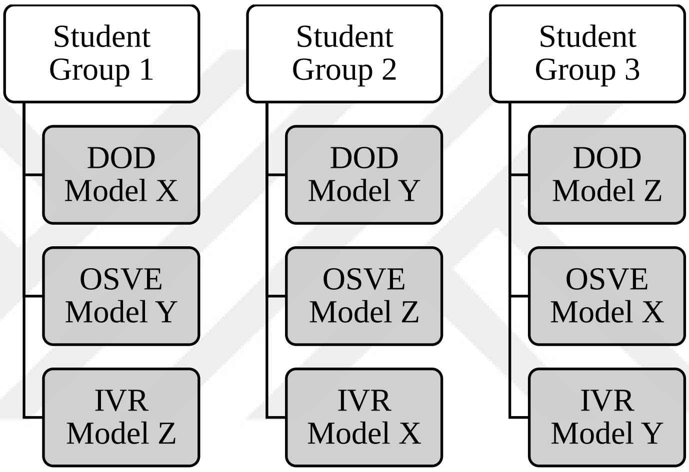
Figure 3.29: Model Y in KeplerVR

Figure 3.30: Model Z in KeplerVR

3.6.2.2. EXPERIMENT APPLICATION

In the literature, comparative studies based on representation methods mostly being used with a control and experiment groups. While test group examines the object using one representation method, experiment group examines the object using the other representation method. This method may cause error in the results due to characteristics, skills and personal attributes of two separate groups. Another example of such studies is showing the same model or project to every participant within an order to measure perception differentiations. However, this method creates a familiarity with the model, therefore showing the same model to the sample causes bias which may affect the results. Also, some researchers use different models to show every participant in different setups to measure their perceptions, however differentiations in different models and projects may cause diversity in the results. Since these experiment setups do not seem viable, a new approach has been assembled to measure spatial perception (Figure 3.31).

Figure 3.31: Experiment 2, Student Groups, Projects, Representation Methods



As seen in Table 3.7, all models have been looked at via orthographic drawings, OSVE views and IVR views, by every student. All students assigned to different models within different representation methods. E.g. Student 1 perceived Model X via digital orthographic drawings (DOD), Model Y by OSVE view, Model Z by IVR view, while Student 2 perceived Model Z via DOD, Model X by OSVE view, Model Y by IVR view. In total, every model looked 46 times, and each one of them looked from orthographic drawings, ISVE and IVR views at least 15 times. Everyone looked at different models in different representation methods. Since every student looked at different projects in different representation methods, no familiarity or distinction between students or projects affected the results. Later, every student filled in four different questionnaires.

Table 3.7: Experiment 2, List of Students

Name Tag	*Orthographic Drawing (DOD)*	*On-screen Virtual Environment View (OSVE)*	*Immersive Virtual Reality View (IVR)*
AKO	Model Y	Model Z	Model X
ANO	Model Z	Model X	Model Y
AO	Model Y	Model Z	Model X
BO	Model Y	Model Z	Model X
CO	Model X	Model Y	Model Z
CS	Model Y	Model Z	Model X
CT	Model X	Model Y	Model Z
DV	Model X	Model Y	Model Z
EK	Model X	Model Y	Model Z
EO	Model Y	Model Z	Model X
FB	Model Z	Model X	Model Y
FC	Model Z	Model X	Model Y
G1_1	Model X	Model Y	Model Z
G1_2	Model Z	Model X	Model Y
G1_3	Model Z	Model X	Model Y
G2_1	Model X	Model Y	Model Z
G2_2	Model Y	Model Z	Model X
G2_3	Model X	Model Y	Model Z
G3_1	Model Z	Model X	Model Y
G3_2	Model Y	Model Z	Model X
G4_1	Model Z	Model X	Model Y
G4_2	Model X	Model Y	Model Z
G5_1	Model Z	Model X	Model Y
G5_2	Model Y	Model Z	Model X
G5_3	Model Y	Model Z	Model X
G6_1	Model Y	Model Z	Model X
G6_2	Model Z	Model X	Model Y
G7_1	Model Z	Model X	Model Y
G7_2	Model Y	Model Z	Model X
G8_1	Model X	Model Y	Model Z
G8_2	Model X	Model Y	Model Z
GA	Model Y	Model Z	Model X
MCK	Model X	Model Y	Model Z
MM	Model Y	Model Z	Model X
MS	Model X	Model Y	Model Z
NNU	Model Z	Model X	Model Y
NS1	Model X	Model Y	Model Z
NS2	Model X	Model Y	Model Z
OD	Model Z	Model X	Model Y
RA	Model Y	Model Z	Model X

Name Tag	*Orthographic Drawing (DOD)*	*On-screen Virtual Environment View (OSVE)*	*Immersive Virtual Reality View (IVR)*
RV_1	Model Z	Model X	Model Y
RV_2	Model X	Model Y	Model Z
RV_3	Model Y	Model Z	Model X
RV_4	Model Y	Model Z	Model X
RV_5	Model X	Model Y	Model Z
YA	Model X	Model Y	Model Z

After list of projects, orthographic drawings for DOD view through Lectures Page, 3D digital model for OSVE and IVR view through KeplerVR provided for students, Experiment 2 began in 23 October 2018 within the given course. At first, each student informed about downloading the digital orthographic drawings, they had 15 minutes to observe the assigned projects through DOD (Figure 3.32). Later, they asked to close all opened windows such as PDF viewers and DWG viewers. Related questionnaire (Table 3.8) applied to them. After all of them finished the first cycle, they informed to login KeplerVR, download second assigned projects for OSVE view. For 15 minutes, they observed the assigned projects with the help of their computers and mobile devices, explored the projects in OSVE view. When the time was up, they again asked to shut down the application and fill in the related questionnaire (Table 3.8). At the end, student informed to download the last project which are assigned to them and explore the projects using IVR view in KeplerVR with the help of VR-Boxes (Figure 3.34). After time was up, they asked to take out their head-mounted displays and fill in the related questionnaire (Table 3.8). When all three cycles were done, another questionnaire (Table 3.9) applied to students to conclude the experiment.

Figure 3.32: Students Observing Projects with DOD

Figure 3.33: Students Observing Projects with OSVE View

Figure 3.34: Students Observing Projects with IVR View

3.6.2.3. DATA COLLECTION

To measure spatial perception in DOD, OSVE and IVR views for different projects from all students, four questionnaires presented to them. First three questionnaires were duplications with same measures and questions for different representation methods (Table 3.8). However, the last questionnaire was a comparative survey for students to indicate which system was better to understand which aspect of the project (Table 3.9). To create a quantitative basis to compare these representation methods, a linear scale has been used for answers in most of the questions. Two questions prepared to understand quantitative characteristics of the projects from the students as well as open-ended qualitative based questions to have a deeper understanding of the experiment.

Table 3.8: Questionnaire 3, 4, 5 (for different representation methods)

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier

Question	*Method*	*Type*	*Response*	*Aim*
Which model did you look at?	Quantitative	Dropdown	Model X, Model Y, Model Z	Identifier
"I understood the plan organization of the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the human scale and how big the structure is."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the rooms and their relations with each other's."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the circulation between corridors, stairs, rooms, etc."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood interior and exterior space relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical elements such as walls, cladding, and façade elements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood openings and their impacts for interior."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood solid/void relation of the façade."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the interior design and the furniture organization."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the volume, how it feels, how would it be like to live inside that environment."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
"I figured out overall problems related with the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out problems with narrow areas and small volumes."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out wrong furniture placements in the interior areas."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest a new layout for overall room relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I can suggest a new circulation for the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest new solutions for the interior furniture placements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
To the best of our judgement, what is the square meter of total closed area of the project?	Quantitative	Multiple Choice	List of Square Meter Ranges	Dependent Variable, Spatial Perception
How many volumes are there?	Quantitative	Multiple Choice	List of Volume Amount Range	Dependent Variable, Spatial Perception
Please write a description about the project.	Qualitative	Open-ended Answer	Text	Dependent Variable, Spatial Perception
Please write a critique, request for a change about the project.	Qualitative	Open-ended Answer	Text	Dependent Variable, Feedback Process

Table 3.9: Questionnaire 6

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Which one is more effective to understand plan organization of the project?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand human scale and how big the building is?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the rooms and their relations with each other's?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the circulation between corridors, stairs, rooms, etc.	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand interior and exterior space relations?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand vertical elements such as walls, cladding, and façade elements?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand openings and their impacts for interior?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand solid/void relation of the façade?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the interior design and the furniture organization?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand vertical relations between balconies,	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
stairs, slab overlaps, etc.				
Which one is more effective to understand the volume, how it feels, how would it be like to live inside that environment.	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand overall problems related with the project.	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand problems with narrow areas and small volumes?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand wrong furniture placements in the interior areas?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is more effective to evaluate the project and suggest a new layout for overall room relations?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Feedback Process
Which one is more effective to evaluate the project and suggest a new circulation for the project?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Feedback Process
Which one is more effective to evaluate the project and suggest new solutions for the interior furniture placements?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Feedback Process
Which one eases to understand the square meter of total closed area of the project?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one eases to understand how many volumes are there?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
Which one is easier to navigate for understanding the overall project?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Which one is easier to navigate for understanding the interior areas and impact of them?	Quantitative	Multiple Choice	DOD, OSVE, IVR	Dependent Variable, Spatial Perception
Please explain your opinions about differentiations related with understanding the project between perceiving it via DOD, OSVE or IVR views.	Qualitative	Open-ended Answer	Text	Dependent Variable

3.6.3. DPB-DWV AND OSVE-IVR (EXPERIMENT 3)

After Experiment 2, same methodology applied again but with larger scaled projects using digital presentation boards (DPB) with digital walkthroughs videos (DWV) and virtual environments including OSVE and IVR together. Since representation boards and walkthroughs are most used methods to present architectural projects in design education, its comparison with virtual environments (VE) has been conducted. While representation boards are crucial elements which shows both progress, diagrams, explanations in detail, virtual models gives the perception of space and immerse viewers with the environment and designed spaces themselves. To overcome this gap, walkthrough videos along with the representation boards have been provided to students. To this extend, same steps as Experiment 2 had been used, selection of projects, experiment application and data collection .

3.6.3.1. PROJECT SELECTION

Experiment 3 conducted with two different design studio projects. Both projects are almost at the same square meters, however their functions, plan organizations and volumes are completely different. However, spatial design and expectations are almost the same due to being design studio projects in fifth and sixth semester architectural project course. Project A, which is designed as sixth semester architectural design studio project individually by Duhan Ölmez in 2014 – 2015 spring semester in Yaşar University, is a re-functionalization project in a historical building in Tire, İzmir, Turkey. Historical “Ali Efe Hanı” an old trading post had been worked on to transform into a gastronomy centre along with a restaurant, kitchen, social areas, coffee house, accommodation, management and wet spaces. In total 40 various sized spaces spread in the project. Due to using an old structure as a base for renovation, structural strengthening applied with some newly designed structural details. On the other hand, Project B is designed within a group project by Duhan Ölmez, Damla Gül Begüm Keke and Engin Akkan in 2014 – 2015 fall semester as a fifth semester design studio project in Yaşar University. The project located in Örnekköy, İzmir, Turkey, has a hexagon modular system for two different functions including a kindergarten, elementary school along with a post-disaster emergency management office in case of an emergency. Modular structure provides daily, weekly or monthly changes in accordance with user needs. While it is a school, additional modules stored on top of the used ones. In total 50 various sized spaces spread in the project area including classrooms, wet spaces, kindergarten, kitchen, canteen, social area, library, teachers' room, semi-open areas. Two different representation sets had been used for both projects. First set includes web-sites containing digital presentation boards for Project A (Figure 3.36, Figure 3.37) and Project B (Figure 3.39, Figure 3.40), orthographic drawings, diagrams, perspectives, details and explanations with walkthrough videos for both Project A (Figure 3.35) and Project B (Figure 3.38). On the other hand, second set contains a virtual model of the Project A (Figure 3.41) and Project B (Figure 3.42) with a definition in KeplerVR where students can observe OSVE and IVR view in the application to evaluate the project. All 3D digital models are white-models meaning no texture or colour had been used on the surfaces.

Figure 3.35: Project A, Digital Walkthrough Video

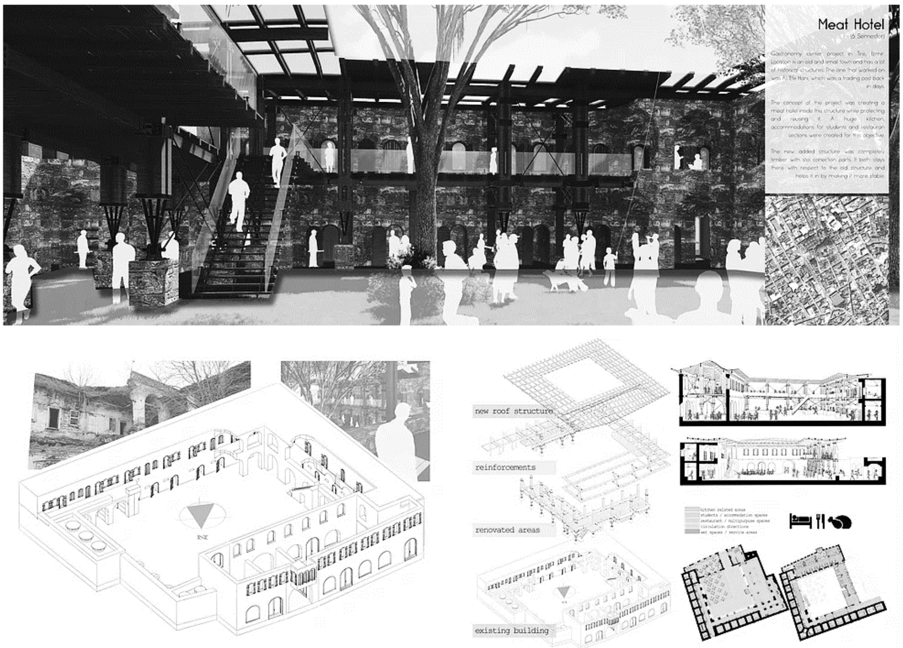


Figure 3.36: Project A, Digital Presentation Board 1

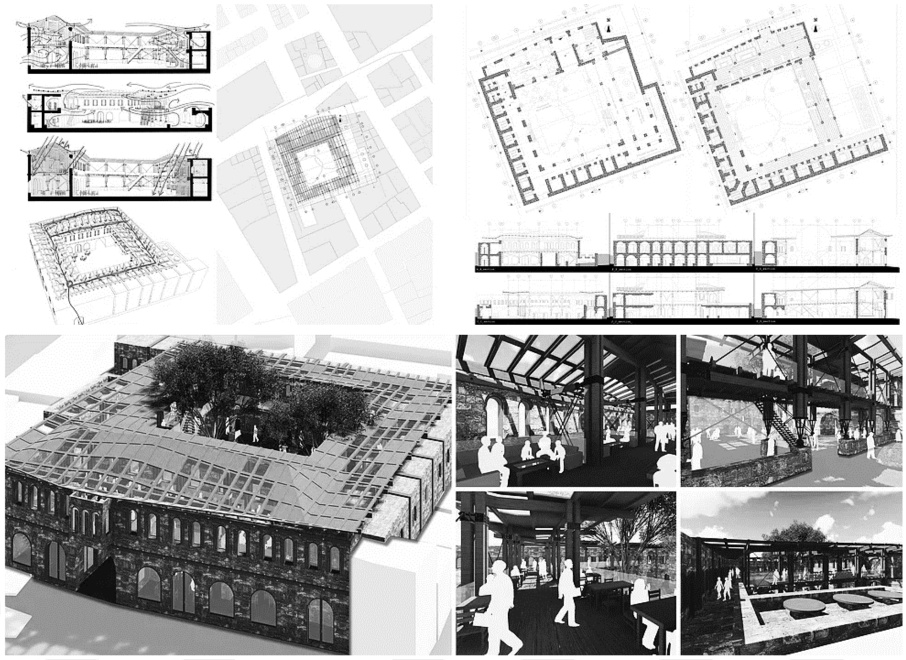


Figure 3.37: Project A, Digital Presentation Board 2

Figure 3.38: Project B, Digital Walkthrough Video

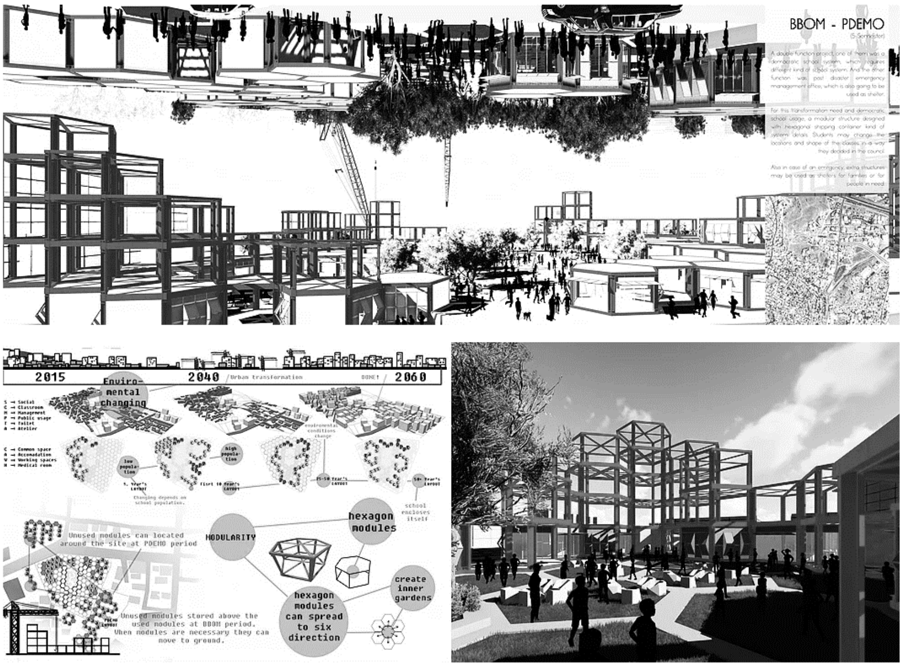


Figure 3.39: Project B, Digital Presentation Board 1

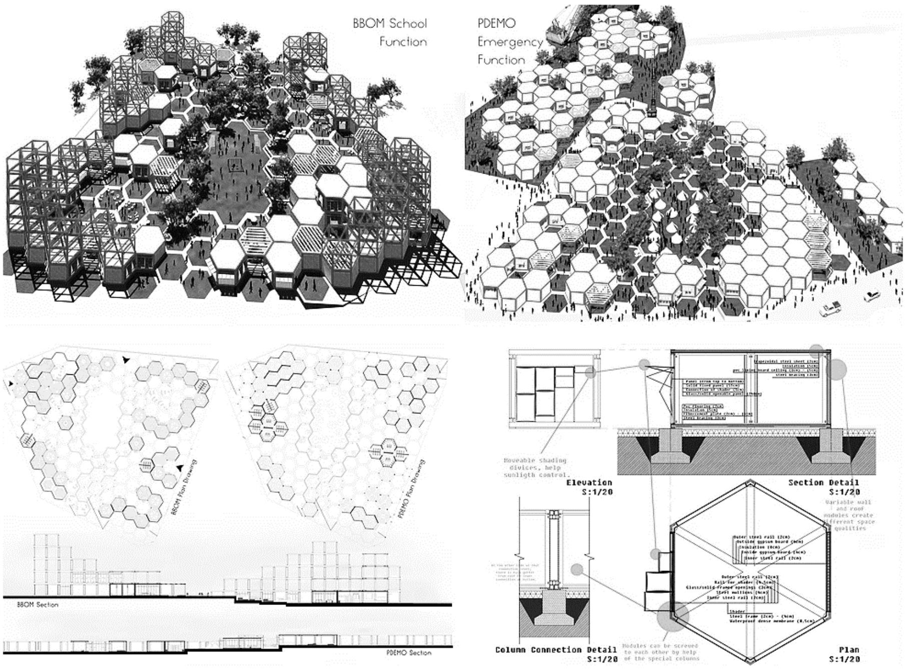


Figure 3.40: Project B, Digital Presentation Board 2

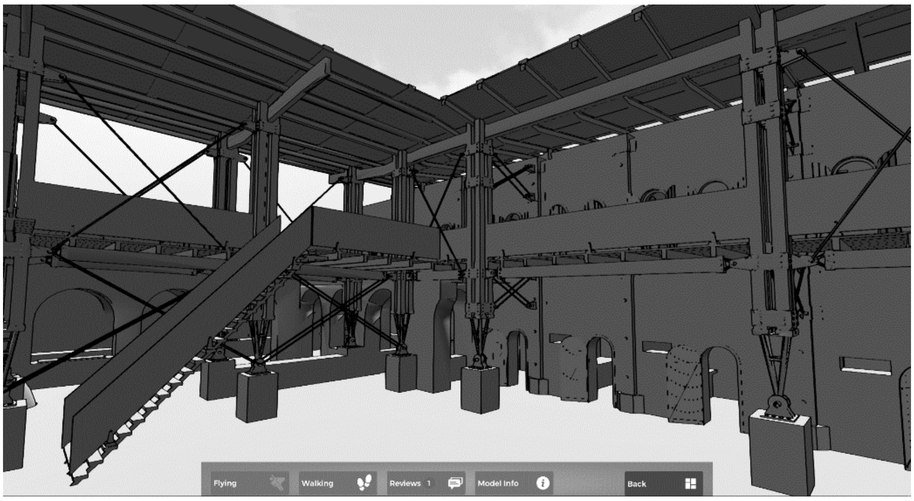


Figure 3.41: Project A in KeplerVR

Figure 3.42: Project B in KeplerVR

3.6.3.2. EXPERIMENT APPLICATION

Because of the same reasons in the previous study, both models shown to all students within an order according to student order. To avoid any familiarity, skill or project bias, each model has been looked in both DPB-DWV views and OSVE-IVR views (Figure 3.43). E.g. while Student 1 is looking at Project A in DPB-DWV view, Student 2 is looking at OSVE-IVR view, later Student 1 is looking at Project B in OSVE-IVR view and Student 2 looks at Project A in DPB-DWV view. This method has been applied to every student with a random list (Table 3.10). In total both Project A and Project B looked at for 46 times, 23 times in DPB-DWV views and 23 times in OSVE-IVR views.

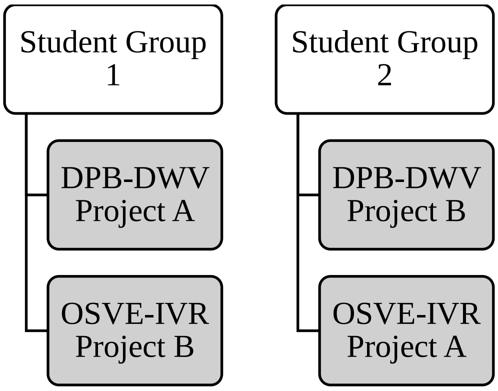


Figure 3.43: Experiment 3, Student Groups, Projects, Representation Methods

Table 3.10: Experiment 3, List of Students

Name Tag	*Digital Presentation Board, Digital Walkthrough Video (DPB-DWV)*	*On-screen Virtual Environment, Immersive Virtual Reality (OSVE-IVR)*
AKO	Project B	Project A
ANO	Project B	Project A
AO	Project A	Project B
BO	Project A	Project B
CO	Project B	Project A
CS	Project B	Project A
CT	Project A	Project B
DV	Project A	Project B
EK	Project A	Project B
EO	Project A	Project B
FB	Project A	Project B
FC	Project B	Project A
G1_1	Project B	Project A
G1_2	Project A	Project B
G1_3	Project A	Project B
G2_1	Project A	Project B
G2_2	Project A	Project B
G2_3	Project B	Project A
G3_1	Project B	Project A
G3_2	Project B	Project A
G4_1	Project A	Project B
G4_2	Project B	Project A
G5_1	Project B	Project A
G5_2	Project B	Project A
G5_3	Project B	Project A
G6_1	Project A	Project B
G6_2	Project A	Project B
G7_1	Project B	Project A
G7_2	Project A	Project B

Name Tag	*Digital Presentation Board, Digital Walkthrough Video (DPB-DWV)*	*On-screen Virtual Environment, Immersive Virtual Reality (OSVE-IVR)*
G8_1	Project A	Project B
G8_2	Project A	Project B
GA	Project A	Project B
MCK	Project B	Project A
MM	Project B	Project A
MS	Project B	Project A
NNU	Project B	Project A
NS1	Project A	Project B
NS2	Project B	Project A
OD	Project B	Project A
RA	Project A	Project B
RV_1	Project B	Project A
RV_2	Project B	Project A
RV_3	Project A	Project B
RV_4	Project A	Project B
RV_5	Project B	Project A
YA	Project A	Project B

Experiment conducted in 27 November 2018, along with Arch 4151 – Virtual Environments in Architecture course. Web-site links which includes both projects' DPB-DWV contents shared through Lectures Page. 3D digital models for students to explore the projects in OSVE-IVR views also prepared and generated PIN number saved to share with them. The student list with projects also shared with them through Lectures Page. When the experiment started, students informed about getting in the assigned projects web-sites to observe the project via DPB and DWV views (Figure 3.44). They had 30 minutes to look at them in the detail. After the time was up, they asked to close the web-site and fill in the related questionnaire. When they finished the questionnaire, students asked to log-in KeplerVR both with their computers and mobile devices. Generated PIN number for the Project A and Project B provided to them. They had 30 minutes to observe the assigned projects in both OSVE (Figure 3.45) and IVR (Figure 3.46) views. How much they looked at the projects from which view did not measured. However, they used both systems as they wished. After time was up, they logged off from KeplerVR and started filling in the questionnaire. When second cycle was done, a comparative survey also presented them to fill in.

Figure 3.44: Students Observing Projects with DPB and DWV

Figure 3.45: Students Observing Projects with OSVE View

Figure 3.46: Students Observing Projects with IVR View

3.6.3.3. DATA COLLECTION

To measure spatial perception in DPB-DVW and OSVE-IVR for different projects from all students, three questionnaires presented to them. First two questionnaires were duplications with same measures and questions for different representation methods (Table 3.11). However, the last questionnaire was a comparative survey for students to indicate which system was better to understand which aspect of the project (Table 3.12). To create a quantitative basis to compare these representation methods, a Likert scale has been used for answers in most of the questions. Two questions prepared to understand quantitative characteristics of the projects from the students as well as open-ended qualitative based questions to have a deeper understanding of the experiment.

Table 3.11: Questionnaire 7, 8 (for different representation methods)

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Which project did you look at?	Quantitative	Dropdown	Project A, Project B	Identifier
"I understood the plan organization of the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the human scale and how big the structure is."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the rooms and their relations with each other's."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the circulation between corridors, stairs, rooms, etc."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood interior and exterior space relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical elements such as walls, cladding, and façade elements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood openings and their impacts for interior."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood solid/void relation of the façade."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the interior design and the furniture organization."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical relations between	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral,	Dependent Variable,

Question	*Method*	*Type*	*Response*	*Aim*
balconies, stairs, slab overlaps, etc."			Disagree, Strongly Disagree	Spatial Perception
"I understood the volume, how it feels, how would it be like to live inside that environment."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out overall problems related with the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out problems with narrow areas and small volumes."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out wrong furniture placements in the interior areas."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest a new layout for overall room relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I can suggest a new circulation for the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest new solutions for the interior furniture placements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"Walkthrough video in the presentation was more useful in terms of understanding the project than drawings." (Questionnaire 7)	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"Walkthrough video was enough for me to understand basics of the project." (Questionnaire 7)	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"A walkable 3D model was more useful in terms of understanding the project than	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
presentation boards." (Questionnaire 8)				
"A walkable 3D model was enough for me to understand basics of the project." (Questionnaire 8)	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
To the best of our judgement, what is the square meter of total closed area of the project?	Quantitative	Multiple Choice	List of Square Meter Ranges	Dependent Variable, Spatial Perception
How many volumes are there?	Quantitative	Multiple Choice	List of Volume Amount Range	Dependent Variable, Spatial Perception
Please write a description about the project.	Qualitative	Open-ended Answer	Text	Dependent Variable, Spatial Perception
Please write a critique, request for a change about the project.	Qualitative	Open-ended Answer	Text	Dependent Variable, Feedback Process

Table 3.12: Questionnaire 9

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
Which one is more effective to understand plan organization of the project?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand human scale and how big the building is?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the rooms and their relations with each other's?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the circulation	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
between corridors, stairs, rooms, etc.				
Which one is more effective to understand interior and exterior space relations?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand vertical elements such as walls, cladding, and façade elements?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand openings and their impacts for interior?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand solid/void relation of the façade?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the interior design and the furniture organization?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand vertical relations between balconies, stairs, slab overlaps, etc.	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand the volume, how it feels, how would it be like to live inside that environment.	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand overall problems related with the project.	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand problems with narrow areas and small volumes?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is more effective to understand wrong furniture	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable,

Question	*Method*	*Type*	*Response*	*Aim*
placements in the interior areas?				Spatial Perception
Which one is more effective to evaluate the project and suggest a new layout for overall room relations?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Feedback Process
Which one is more effective to evaluate the project and suggest a new circulation for the project?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Feedback Process
Which one is more effective to evaluate the project and suggest new solutions for the interior furniture placements?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Feedback Process
Which one eases to understand the square meter of total closed area of the project?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one eases to understand how many volumes are there?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is easier to navigate for understanding the overall project?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Which one is easier to navigate for understanding the interior areas and impact of them?	Quantitative	Multiple Choice	DPB-DWV, OSVE-IVR	Dependent Variable, Spatial Perception
Please explain your opinions about differentiations related with understanding the project between perceiving it via DPB-DWV or OSVE-IVR views.	Qualitative	Open-ended Answer	Text	Dependent Variable

3.6.4. DISTANT COLLABORATION (EXPERIMENT 4)

One of the main goals of this study is to understand why architects should use virtual environments during architectural project development for communication through design itself. Last experiment designed as a process of multiple tasks in continuous weeks. Major idea was to handle this process from distant, which means students did not attend the courses physically. However, each week they assigned to different specified tasks and evaluated different types of models related with their individual or group work design studio projects. First three experiments created the base knowledge about creating a model in virtual environments for OSVE and IVR view (Experiment 1), develop an understanding related with the project and evaluate it in OSVE and IVR (Experiment 2, Experiment 3). When students were at the satisfactory level for their knowledge related with virtual reality systems, Experiment 4 presented to them. Including students' midterm and final assignment, students conducted four virtual classes. They asked specified tasks along with them and evaluation handled through questionnaires just like in the previous experiments.

Different aspects and phases of design process demonstrated for the experiment. Along with the course and students' design studios, volumetric mass models and planar model techniques presented to them first. Later, they expected to create the vertical surfaces on their planar models. Placeholders and interior organization, low-poly modelling technique presented to students. After all, a partial digital model of their projects asked from students. Virtual classes handled through these sets of tasks for four weeks.

3.6.4.1. INITIAL MASS MODELS (EXPERIMENT 4.1)

Since a virtual class does not require attendees to be together in physical terms, students asked to create their own design studio projects' mass and/or planar models in any software they use. Assignment criteria was to generate the volumetric mass and/or planar digital models of their projects with immediate surrounding, environmental objects, cars, human and tree figures. No information on building surfaces are asked. Students both uploaded their OBJ files to Lectures Page submission as well as to KeplerVR with a description about their design idea, how did they implement them on the mass, introductory information about the design studio etc. (Figure 3.47). Students uploaded their digital models to system using their personal tags as project tags.

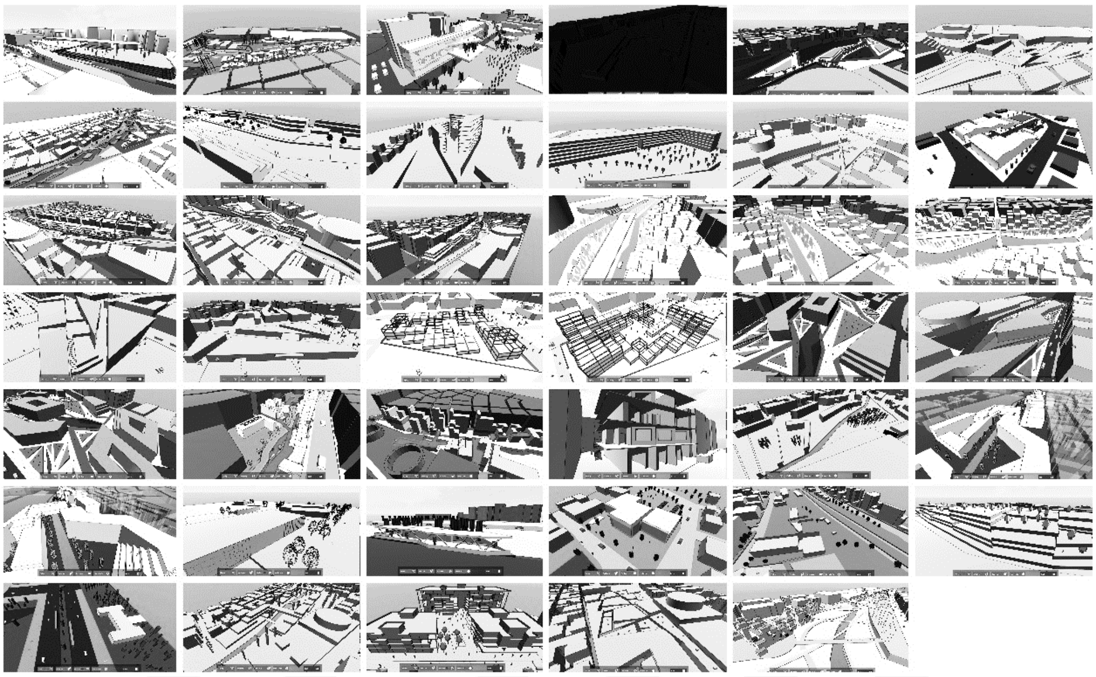


Figure 3.47: Students' Initial Models for Experiment 4.1

On 12 November 2018 until 22:00 students were expected to upload their models to KeplerVR and publish them for every student in the course to see. The day after, for all day long they were assigned to specific projects to observe, evaluate, and put reviews through KeplerVR system. The list of assigned projects announced within the Lectures Page in the morning of 13 November 2018 (Table 3.13). Every student obliged to review at least three projects. Those who assigned as reviewers, reviewed four projects. In case of a problem, extra models for students to evaluate also specified.

Table 3.13: Experiment 4.1, List of Students

Personal Tag	*Review1*	*Review2*	*Review3*	*Review4*	*Extra1*	*Extra2*
AKO	ANO	GA	FB	-	G6_2	G1_2
ANO	CO	G5_1	G4_1	-	FC	G5_3
AO	NS2	NNU	YA	-	G4_1	BO
BO	FB	G1_3	G1_2	-	YA	G8_1
CO	FC	AKO	EK	-	G4_2	G2_3
CS	ANO	DV	G5_3	-	OD	AKO
CT	G8_1	G7_1	BO	-	MS	MCK
DV	AO	G8_2	G1_1	-	CT	G3_1
EK	NS1	CT	ANO	-	G8_1	G2_1
EO	CO	NS1	FC	-	G6_1	ANO
FB	G1_1	G2_2	EO	-	CS	G2_2
FC	G3_2	G3_1	G2_2	-	G2_3	G1_3
G1_1	AO	BO	MCK	-	G3_2	MM
G1_2	CT	MCK	G6_2	-	G2_1	NS1

Personal Tag	*Review1*	*Review2*	*Review3*	*Review4*	*Extra1*	*Extra2*
G1_3	G5_3	G2_1	AKO	-	ANO	AO
G2_1	G8_2	AO	G6_1	-	NS1	CS
G2_2	EO	FC	RA	-	NS2	G8_2
G2_3	RA	G6_1	CO	-	G8_2	G4_1
G3_1	G6_2	G5_2	CS	-	G1_1	G5_1
G3_2	G4_1	CT	G2_1	-	DV	G4_2
G4_1	EK	G1_1	G3_1	-	CO	G6_1
G4_2	DV	CS	G7_1	-	GA	NNU
G5_1	G1_2	NS1	G4_2	-	NNU	OD
G5_2	G7_2	AKO	EK	-	AKO	G3_2
G5_3	AKO	G2_3	OD	-	G7_1	CO
G6_1	G5_2	ANO	G5_1	-	EO	FC
G6_2	MM	G8_1	G5_2	-	MM	NS2
G7_1	G2_3	FB	MM	-	AO	RA
G7_2	BO	MM	G8_1	-	G5_3	G6_1
G8_1	NNU	G4_2	MS	-	G1_3	G7_2
G8_2	G1_3	EO	BO	-	G5_2	G5_2
GA	G4_2	FB	AO	-	RA	G6_2
MCK	OD	EO	G3_2	-	BO	YA
MM	YA	G3_2	FC	-	FB	DV
MS	G5_1	NS2	GA	-	G1_2	CT
NNU	GA	CO	G7_2	-	G5_1	MS
NS1	MCK	G5_3	G2_3	-	MCK	G1_1
NS2	MS	G4_1	RA	-	G3_1	G8_1
OD	G3_1	G7_2	YA	-	G2_2	G2_3
RA	GA	G1_2	NS2	-	EK	EO
RV_1	G2_1	MS	MM	NNU	G7_2	G7_1
RV_2	MCK	OD	CS	MS	OD	CT
RV_3	G6_1	EK	G1_3	NS1	MS	CS
RV_4	G7_1	YA	CT	NS2	CT	GA
RV_5	G2_2	G6_2	NNU	OD	G8_1	EK
YA	CS	RA	G8_2	-	G6_1	FB

In total 41 models have been uploaded in KeplerVR HUB. Those students work in group projects were obliged to prepare different solutions to their design ideas. Therefore, they asked for different OBJ submissions. Students were asked to spend at least 30 minutes in each project for evaluation. While looking in the models, OSVE and IVR views had to be used at least for 5 minutes. After they finished looking at each project, they filled in a questionnaire (Table 3.14). Since generated digital models consists no spaces in the volumes, asked questions were only related with communication and adequateness of 3D digital modelling. Some of the questions were to check the validity of the students' uploaded projects. Also, students asked to grade their friends for the adequateness of their 3D digital models.

Table 3.14: Questionnaire 10

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
What is the name tag of the project you looked at?	Quantitative	Dropdown	Name Tag List	Identifier
"I did read the description and it was enough for me to understand the idea of the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
"I know how a mass/planar model should be like, the model I reviewed was adequate as one."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
"I understood the project's mass organization."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I was able to give reasonable reviews to help project development in the future steps."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Some of the essentials were missing in the model, those things were…"	Quantitative	Checkboxes	List of 3D Model Elements	Dependent Variable, Validity
"The reviews I gave for the project were mostly about…"	Quantitative	Checkboxes	List of Project Aspects	Dependent Variable, Feedback Process
"My grade for the project is…"	Quantitative	Dropdown	List of Grades	Independent Variable
"I gave this grade because…"	Qualitative	Open-ended Answers	Text	Independent Variable

3.6.4.2. ALL PROJECT MODELS (EXPERIMENT 4.2)

After initial mass and/or planar models of their design idea, students were asked to develop their digital models to demonstrate spatial quality. Vertical and horizontal surfaces added to their projects along with their developments in design studios. Since no spatial quality had been investigated in previous experiment (Experiment 4.1), this time quality of the spaces and their influences investigated. Procedure handled through sets of assignments in Lectures Page and KeplerVR. OBJ files of their created projects, a description of their designs and an attendance photo with VR-Boxes asked in Lectures Page. After they finished their digital creations, they were expected to upload their digital models and descriptions into KeplerVR until using their new project tags with additional revision indicator as “R1” to their personal tags. This time, due to time limitations in their design studios, those who worked on group projects uploaded one model for all group-work project. However, during the experiment they received more reviews from their friends. Since students assigned as reviewers did not have any design studio, they did not upload any project but only evaluated others’ projects. Students were expected to prepare their digital models in KeplerVR HUB with the specified tags on 4 December 2018 until 12:30. After this time, another random list of students prepared for them to evaluate each other’s’ projects (Table 3.15). Each student was obliged to review four projects.

Table 3.15: Experiment 4.2, Student List

Personal Tag	*Project Tag*	*Review1*	*Review2*	*Review3*	*Review4*
AKO	R1_AKO	R1_G5	R1_NS1	R1_NS2	R1_G8
ANO	R1_ANO	R1_YA	R1_G2	R1_FB	R1_G3
AO	R1_AO	R1_NS1	R1_G5	R1_RA	R1_FB
BO	R1_BO	R1_G5	R1_CO	R1_AO	R1_G7
CO	R1_CO	R1_FB	R1_G2	R1_MCK	R1_G3
CS	R1_CS	R1_DV	R1_CT	R1_FB	R1_RA
CT	R1_CT	R1_CS	R1_G1	R1_G6	R1_FB
DV	R1_DV	R1_MCK	R1_MS	R1_MM	R1_YA
EK	R1_EK	R1_EO	R1_MCK	R1_G8	R1_G2
EO	R1_EO	R1_G3	R1_EK	R1_G7	R1_DV
FB	R1_FB	R1_G3	R1_ANO	R1_G1	R1_NS1
FC	R1_FC	R1_AO	R1_G3	R1_G1	R1_G5
G1_1	R1_G1	R1_G2	R1_G3	R1_EK	R1_CS
G1_2	R1_G1	R1_G2	R1_G6	R1_G3	R1_OD
G1_3	R1_G1	R1_MS	R1_BO	R1_G4	R1_GA
G2_1	R1_G2	R1_G4	R1_G3	R1_CO	R1_G7
G2_2	R1_G2	R1_CT	R1_G8	R1_G7	R1_CO
G2_3	R1_G2	R1_BO	R1_FC	R1_AKO	R1_MCK
G3_1	R1_G3	R1_MM	R1_GA	R1_CT	R1_AO
G3_2	R1_G3	R1_GA	R1_FB	R1_FC	R1_CT
G4_1	R1_G4	R1_G1	R1_NNU	R1_G2	R1_G3
G4_2	R1_G4	R1_G6	R1_RA	R1_G5	R1_BO

Personal Tag	*Project Tag*	*Review1*	*Review2*	*Review3*	*Review4*
G5_1	R1_G5	R1_G8	R1_G2	R1_NS1	R1_G4
G5_2	R1_G5	R1_G3	R1_AKO	R1_G4	R1_G6
G5_3	R1_G5	R1_NS2	R1_AO	R1_AKO	R1_G8
G6_1	R1_G6	R1_RA	R1_CS	R1_ANO	R1_NS2
G6_2	R1_G6	R1_G7	R1_CT	R1_G3	R1_G1
G7_1	R1_G7	R1_OD	R1_AKO	R1_NNU	R1_ANO
G7_2	R1_G7	R1_AKO	R1_G4	R1_AO	R1_CT
G8_1	R1_G8	R1_AKO	R1_G7	R1_OD	R1_G2
G8_2	R1_G8	R1_AO	R1_G7	R1_YA	R1_AKO
GA	R1_GA	R1_CT	R1_MM	R1_DV	R1_G5
MCK	R1_MCK	R1_G4	R1_DV	R1_CT	R1_MM
MM	R1_MM	R1_EK	R1_G1	R1_EO	R1_AO
MS	R1_MS	R1_G7	R1_G4	R1_BO	R1_AKO
NNU	R1_NNU	R1_G2	R1_YA	R1_G3	R1_G4
NS1	R1_NS1	R1_G1	R1_AO	R1_G2	R1_MS
NS2	R1_NS2	R1_NNU	R1_OD	R1_RA	R1_G1
OD	R1_OD	R1_G4	R1_G5	R1_CS	R1_EO
RA	R1_RA	R1_G8	R1_EO	R1_G4	R1_G6
RV_1	-	R1_FC	R1_NS2	R1_G2	R1_RA
RV_2	-	R1_CO	R1_G4	R1_GA	R1_FC
RV_3	-	R1_RA	R1_G6	R1_MS	R1_G4
RV_4	-	R1_G6	R1_FB	R1_G8	R1_EK
RV_5	-	R1_ANO	R1_G8	R1_G6	R1_NNU
YA	R1_YA	R1_FB	R1_RA	R1_G5	R1_G2

On 4 December 2018 between 12:30 and 23:30, after every model uploaded to system and the random student list shared with the students on Lectures Page, students started evaluating the spatial qualities of the project through OSVE and IVR views. Students have informed about reading the descriptions of the projects first and spend at least 30 minutes per project and use IVR view at least 10 minutes, inside the volumes to evaluate the spatial creations. After each project evaluated, they expected to fill in a questionnaire related with mass organization, created spaces and the quality of their models (Table 3.16). Again, quantitative method used to measure the communication and spatial perception through OSVE and IVR views along with qualitative open-ended questions to have a deeper understanding of the process. Some questions related with the adequateness of the 3D digital models have been asked to validate the experiment.

Table 3.16: Questionnaire 11

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
What is the name tag of the project you looked at?	Quantitative	Dropdown	Name Tag List	Identifier
"I did read the description and it was enough for me to understand the idea of the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
"I know how a 3D digital model should be like, the model I reviewed was adequate as one."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
"I understood the project's mass organization."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I was able to give reasonable reviews to help project development in the future steps."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I understood the plan organization of the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the human scale; how big the structure is."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the rooms and their relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the circulation between corridors, stairs, rooms, etc."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood interior and exterior space relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical elements such as	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral,	Dependent Variable,

Question	*Method*	*Type*	*Response*	*Aim*
walls, cladding, and façade elements."			Disagree, Strongly Disagree	Spatial Perception
"I understood openings and their impacts for interior."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood solid/void relation of the façade."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the interior design and the furniture organization."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the volume, how it feels, how would it be like to live inside that environment."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out overall problems related with the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out problems with narrow areas and small volumes."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out wrong furniture placements in the interior areas."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest a new layout for overall room relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I can suggest a new circulation for the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest new solutions for the interior furniture placements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
"Some of the essentials were missing in the model, those things were…"	Quantitative	Checkboxes	List of 3D Model Elements	Dependent Variable, Validity
"The reviews I gave for the project were mostly about…"	Quantitative	Checkboxes	List of Project Aspects	Dependent Variable, Feedback Process
Please write a description of your own for the project.	Qualitative	Open-ended Answers	Text	Dependent Variable, Spatial Perception
Please write the critiques and revision requests for the project.	Qualitative	Open-ended Answers	Text	Dependent Variable, Feedback Process
"My grade for the project is…"	Quantitative	Dropdown	List of Grades	Independent Variable
"I gave this grade because…"	Qualitative	Open-ended Answers	Text	Independent Variable

3.6.4.3. PARTIAL SPACE MODELS (EXPERIMENT 4.3)

After the base spatial design of the students were finished for their design studio, Experiment 4.3 has been introduced to them. Due to extensive detailed works in their projects, to evaluate communication through created spaces they asked to select a specific location of their projects. For this experiment, students expected to develop detailed interior solutions of their partial digital models, they got informed to select the most significant area of their project which has a major role in their designs. They have been asked to develop the immediate surfaces of the selected volumes such as slabs, interior – exterior walls, glazing elements, doors, placeholders, and furniture. After they finished generating their 3D digital partial space models, they asked to upload them to Lectures Page and KeplerVR with a description of their projects on 11 December 2018 until 12:30. They used specified project tags along with a revision indicator as "R2" in front of their personal tags. Each student expected to upload an individual model to system and publish it in the KeplerVR HUB until the given time. Another randomly generated student list provided to students through Lectures Page to start evaluation process (Table 3.17). Each student evaluated at least two of their friends' spaces, extra two more students assigned to them in case some of them did not upload their projects to system. Since the course handled as a virtual classroom, they asked to upload a photo of them using VR-Boxes while observing the projects into the Lectures Page submission.

Table 3.17: Experiment 4.3, Student List

Personal Tag	*Project Tag*	*Review1*	*Review2*	*Extra1*	*Extra2*
AKO	R2_AKO	R2_DV	R2_NS1	R2_RA	R2_MCK
ANO	R2_ANO	R2_G2_1	R2_NS2	R2_OD	R2_G2_3
AO	R2_AO	R2_ANO	R2_G2_2	R2_G2_3	R2_G1_2
BO	R2_BO	R2_G8_2	R2_CS	R2_G5_3	R2_AKO
CO	R2_CO	R2_EO	R2_ANO	R2_G4_2	R2_G6_1
CS	R2_CS	R2_AKO	R2_EK	R2_DV	R2_G7_2
CT	R2_CT	R2_AKO	R2_GA	R2_G1_3	R2_G1_1
DV	R2_DV	R2_G5_3	R2_G1_1	R2_AKO	R2_G1_3
EK	R2_EK	R2_MCK	R2_G6_2	R2_G5_1	R2_FB
EO	R2_EO	R2_AO	R2_MM	R2_NS2	R2_CT
FB	R2_FB	R2_CO	R2_G5_3	R2_CT	R2_NS2
FC	R2_FC	R2_NS1	R2_G8_2	R2_EK	R2_G2_1
G1_1	R2_G1_1	R2_CS	R2_G4_1	R2_BO	R2_G5_1
G1_2	R2_G1_2	R2_G3_2	R2_G7_1	R2_G3_1	R2_G5_3
G1_3	R2_G1_3	R2_G2_3	R2_G3_1	R2_G5_2	R2_FB
G2_1	R2_G2_1	R2_YA	R2_G3_2	R2_G8_2	R2_FC
G2_2	R2_G2_2	R2_FC	R2_ANO	R2_MS	R2_MM
G2_3	R2_G2_3	R2_NS2	R2_AO	R2_G1_1	R2_GA
G3_1	R2_G3_1	R2_GA	R2_G8_1	R2_FC	R2_EK
G3_2	R2_G3_2	R2_G4_1	R2_BO	R2_G2_3	R2_G2_2
G4_1	R2_G4_1	R2_G3_1	R2_DV	R2_MCK	R2_RA
G4_2	R2_G4_2	R2_G1_3	R2_NNU	R2_MM	R2_MS
G5_1	R2_G5_1	R2_G8_1	R2_G6_1	R2_G6_2	R2_NNU
G5_2	R2_G5_2	R2_G7_2	R2_G4_2	R2_G8_1	R2_BO
G5_3	R2_G5_3	R2_CT	R2_G1_3	R2_MM	R2_G4_1
G6_1	R2_G6_1	R2_G5_1	R2_G1_2	R2_G3_2	R2_ANO
G6_2	R2_G6_2	R2_G8_2	R2_FB	R2_ANO	R2_EO
G7_1	R2_G7_1	R2_NNU	R2_FC	R2_CT	R2_G3_1
G7_2	R2_G7_2	R2_G6_2	R2_G2_1	R2_G1_1	R2_AO
G8_1	R2_G8_1	R2_G2_2	R2_MCK	R2_G4_1	R2_G6_2
G8_2	R2_G8_2	R2_EK	R2_G2_3	R2_YA	R2_OD
GA	R2_GA	R2_G6_1	R2_MS	R2_CO	R2_G8_2
MCK	R2_MCK	R2_OD	R2_CT	R2_G2_2	R2_NS1
MM	R2_MM	R2_MS	R2_EO	R2_AO	R2_G4_1
MS	R2_MS	R2_MM	R2_CO	R2_EO	R2_G3_2
NNU	R2_NNU	R2_RA	R2_G5_2	R2_FB	R2_G7_1
NS1	R2_NS1	R2_G5_2	R2_RA	R2_G6_2	R2_G3_2
NS2	R2_NS2	R2_BO	R2_G7_2	R2_NS1	R2_G4_2
OD	R2_OD	R2_G7_1	R2_AO	R2_G7_1	R2_CO
RA	R2_RA	R2_OD	R2_YA	R2_G7_2	R2_DV

Personal Tag	*Project Tag*	*Review1*	*Review2*	*Extra1*	*Extra2*
RV_1	-	R2_G1_1	R2_RA	R2_CS	R2_NS1
RV_2	-	R2_FB	R2_AKO	R2_G1_2	R2_G8_1
RV_3	-	R2_G4_2	R2_OD	R2_GA	R2_YA
RV_4	-	R2_G6_1	R2_G1_2	R2_NNU	R2_G7_1
RV_5	-	R2_G1_2	R2_G6_1	R2_G2_1	R2_G5_2
YA	R2_YA	R2_G7_1	R2_G5_1	R2_G6_1	R2_CS

Evaluation and reviewing session started on 11 December 2018 at 12:30 after students finished uploading their 3D digital partial space models to KeplerVR. Review process handled by students, they got informed to spend at least 30 minutes for each project including reading the description, evaluating the project with OSVE and IVR views and placing reviews on the KeplerVR system. After each evaluation cycle for a project, they asked to fill in a questionnaire (Table 3.18). Since uploaded 3D digital models include partial space models, questions related with spatial perception and how those spaces made the viewer feel have been asked. Measurement for spatial perception was the main goal of the experiment, however review session also recorded for handling the next experiment.

Table 3.18: Questionnaire 12

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
What is the name tag of the project you looked at?	Quantitative	Dropdown	Name Tag List	Identifier
"I did read the description and it was enough for me to understand the idea of the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
What was the function of the volume you looked at?	Quantitative	Checkboxes	List of Functions	Independent Variable
"I know how a 3D digital model should be like, the model I reviewed was adequate as one."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
"I understood the surface organization of the volume."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
"I was able to give reasonable reviews to help project development in the future steps."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I understood the plan organization of the selected volume."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the human scale; how big the selected volume is."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the objects, furniture and their relations."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the circulation between corridors, stairs, rooms, etc. in the volume"	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood vertical elements such as walls, glazing elements etc."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood openings and their impacts for interior."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood solid/void relation of the surfaces."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the interior design and the furniture organization."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I understood the volume, how it feels, how would it be like to live inside that environment."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out overall problems related with the selected volume."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
"I figured out problems with narrow areas and small volumes."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I figured out wrong furniture placements in the interior areas."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I can suggest a new volume to inhabit such function."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I can suggest changes on surfaces to improve the functions effect."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I can suggest new solutions for the interior furniture placements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"It was hard to navigate in the space because of the furniture."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I was not able to understand the volume because of the missing elements."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was small."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was narrow."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was depressing."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was extraordinary."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was refreshing."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception

Question	*Method*	*Type*	*Response*	*Aim*
"The volume was comfortable."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was cold."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"The volume was dark."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Spatial Perception
"I pointed out problems related with the project in my reviews."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I offered new solutions for specific needs of the volumes with my reviews."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I made reviews for the quality of 3D modeling."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Some of the essentials were missing in the model, those things were…"	Quantitative	Checkboxes	List of 3D Model Elements	Dependent Variable, Validity
"The reviews I gave for the project were mostly about…"	Quantitative	Checkboxes	List of Project Aspects	Dependent Variable, Feedback Process
Please write a description of your own for the project.	Qualitative	Open-ended Answers	Text	Dependent Variable, Spatial Perception
Please write the critiques and revision requests for the project.	Qualitative	Open-ended Answers	Text	Dependent Variable, Feedback Process
"My grade for the project is…"	Quantitative	Dropdown	List of Grades	Independent Variable
"I gave this grade because…"	Qualitative	Open-ended Answers	Text	Independent Variable

3.6.4.4. REVIEW SESSION (EXPERIMENT 4.4)

The very last experiment of the current study aimed to create a collaborative environment for students. Since students made reviews on each other's projects and spaces throughout the year using KeplerVR, they were able to see the comments, answer them and continue the process of feedback. Therefore, Experiment 4.4 focused on these reviews, their communication through them and the efficiency of giving and receiving reviews.

Starting from the Experiment 4, each project students created evaluated in KeplerVR. Review system provided them to store those reviews as well as the conversation for the given feedbacks. On 18 December 2018, a new virtual classroom assignment has been announced to the students. They were expected to go back to the reviews they got in Experiment 4.1, Experiment 4.2, and Experiment 4.3, evaluate the reviews given to them. After their evaluation was done, they were expected to answer the reviewer if necessary. Later, students were expected to go back to the projects they reviewed in the previous weeks, see if there are any answer to their reviews and answer them if necessary. This experiment went through the KeplerVR only and feedback process had been investigated. Since students were not attending the course physically, for attendance prove they were expected to upload a screenshot of their screen with the review segment in KeplerVR to Lectures Page submission until the end of the day.

After the procedure was done, on 19 December 2018 students were obliged to fill in two separate questionnaires related with the feedback process. All students filled in the first questionnaire (Table 3.19) where the reviews they made, and the effectiveness of the process was measured. However, since those students assigned as reviewers did not receive any review due to not having a design studio, they were not expected to fill in the second questionnaire (Table 3.20) where the reviews students got, and their effectiveness were measured.

Table 3.19: Questionnaire 13

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
"Descriptions were adequate to describe the projects."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity,

Question	*Method*	*Type*	*Response*	*Aim*
				Feedback Process
"Models were adequate to evaluate."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity, Feedback Process
"I understood the project and description, which created enough knowledge for me to evaluate the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity, Feedback Process
"I was able to give feedback."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Reviews I gave were helpful for developing the projects."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I gave reviews about the implementation of the idea in description to the project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"It was easy to create reviews on surfaces."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Indicating reviews with a point on the surface helped me pointing out the problems efficiently."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Continuing the conversation through 3D digital model was easy."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Communication through reviews in virtual environment was useful to give review."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I pointed out problems related with the project in my reviews."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process

Question	*Method*	*Type*	*Response*	*Aim*
"I offered new solutions for specific needs of the volumes with my reviews."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"I made reviews for the quality of 3D digital modeling."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"The reviews I gave for the projects were mostly about..."	Quantitative	Checkboxes	List of Project Aspects	Dependent Variable, Feedback Process
Please explain your experience about giving reviews, feedbacks through KeplerVR.	Qualitative	Open-ended Answers	Text	Dependent Variable, Feedback Process

Table 3.20: Questionnaire 14

Question	*Method*	*Type*	*Response*	*Aim*
What is your name tag?	Quantitative	Dropdown	Name Tag List	Identifier
"My descriptions were adequate to describe my projects."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity, Feedback Process
"My models were adequate to evaluate."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity, Feedback Process
"I believe I gave enough information in my description for others to evaluate my project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity, Feedback Process
"I got feedbacks."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Validity
"Reviews I got were helpful for developing my project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process

Question	*Method*	*Type*	*Response*	*Aim*
"I got reviews about the implementation of the idea in description to my project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"It was easy to access reviews on surfaces."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Seeing reviews with a point on the surfaces helped me finding the problems efficiently."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Continuing the conversation through 3D digital model was easy for the reviews I received."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Communication through reviews in the virtual environment was useful to receive feedbacks from others."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Reviews I got were related with the problems in my project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Reviews I got were not indicating anything useful for my project."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Reviews I got were about the quality of 3D digital modelling."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"Reviews I received were helpful for my project development."	Quantitative	Likert Scale	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree	Dependent Variable, Feedback Process
"The reviews I got for my project were mostly about…"	Quantitative	Checkboxes	List of Project Aspects	Dependent Variable, Feedback Process
Please explain your experience about receiving reviews, feedbacks through KeplerVR.	Qualitative	Open-ended Answers	Text	Dependent Variable, Feedback Process

3.7. DATA ANALYSES

Upon completion of data collection via questionnaire surveys, which was provided in detail in Section 3.5 and 3.6, the process of data analyses initiated.

The process posed significant challenges in multiple ways. The level of measurement for the collected data was mostly in nominal and ordinal scale. That is, the data at hand introduced either a group belonging (nominal, i.e. Male, Female) or a level of agreement on the argument/question that was forwarded to the sample (ordinal, i.e. Disagree, Agree).

In nominal measurement, the numbers represents group belongings or categories and therefore when the data coded into numerical values, these values does not have an order. To instance, when one numerically code “Female” as “1” and “Male” as “2”, these numbers do not imply as “2” is greater than “1” or “2” is two times greater than “1”. Such data, when accompanied with data measured in interval or ratio can be extremely useful to group observations, however posed significant limitations in data analyses – especially for inferential ones.

Likewise, in ordinal scale, which was employed in the famous Likert Scale form in the current work, level of agreement can be revealed. However, the distance between measurements are unknown. For example, one may code “partly agree” as “3”, “agree” as “4” and “strongly agree” as “5”. This time such coding would imply, and one can confidently claim, that “5” is greater than “4” and “3”. However, such measurement would not provide any information on how much greater is “5” over “3”. That is, the distance between observation points are unknown or not equal. More, in ordinal data, the data at hand only take integer values. Therefore, although the numbers represents an order, their statistics would not imply much as their probability distributions would not follow a normal distribution. Since normality cannot be maintained, any parametrical analyses and results which is derived from such analyses would be under debate. This further posed limitations on drawing inferences for the unseen data.

Based on such limitations, the current work chose to limit its analyses at the descriptive level. That is, no inferential analyses were performed. No results were drawn for the unseen data and no generalisation over results were proposed. Therefore, no formal test of hypotheses were conducted. The current work explored the data at hand in detail and attempted to describe the phenomenon under study solely for the sample. The author acknowledges such limitation on the results due to the technique of analyses that can be employed.

At the descriptive level, the current work conducted merely elementary level of analyses. According to the data at hand, aggregating the scores obtained from Likert Scale questions was particularly useful and proposed in similar exercises. Aggregated scores implied a general direction, if not a consensus, of the sample over the questioned argument. Through numerical coding of Likert Scale data, we employed a non-orthodox method. In all Likert Scale questions, measurements were taken at 5 different levels. In general, numerical coding is performed starting at 1 and finishing at 5. However, to further underline the distinction between disagreement over agreement or vice versa, the current work adopted numerical coding starting at "-2" and finishing at "+2". For an argument, all scores collected for each argument in each questionnaire was aggregated, which in turn served as so called an aggregated agreement score.

Qualitative data was also collected via open ended survey questions. The respondents were left free to make comments in an unstructured way on methods, arguments, projects, etc. Possessing qualitative data at hand was crucial and key to interpret the results which cannot be fully revealed by numerical (quantitative responses). Yet, the current work notes that no systematic qualitative analyses, such as content or word frequency, were performed due time limitations implied. Qualitative data in the current work used in a triangulated manner to support quantitative findings.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

As mentioned in the previous chapter, experiments ran through sets of different questionnaires. While first experiment used Likert scale from 1 to 5, in other experiments' questionnaires' answers indicated as strongly agree, agree, neutral, disagree and strongly disagree for the clarity of the process. Answers with Likert scale in Experiment 2, 3, and 4 mentioned within numeric values from a Likert scale of -2 to 2, -2 for strongly disagree, -1 for disagree, 0 for neutral, 1 for agree and 2 for strongly agree for the sake of simplicity. Since the questionnaires, which have been used to measure spatial perception, feedback process and out-of-scope statistics, had both qualitative and quantitative questions, only quantitative questions and their answers have been used to demonstrate the descriptive results of the experiments. Qualitative answers only have been used to have a deeper understanding related with the specified topics.

Following chapter demonstrates the statistics of the sample, descriptive statistics of each questionnaire in the experiments, and discussions. While some information gathered before the experiments to plan the future steps for the current study, along with the experiments, descriptive statistics of the sample also collected from them. Descriptive statistics of the experiments indicates the quantitative results of the questionnaires and their impacts for the current study. After demonstration of each answer sets of questionnaires, discussions handled by the help of visualizations of the data.

4.1. DESCRIPTIVE STATISTICS OF THE SAMPLE

At the beginning of the current study and investigations, a questionnaire was applied to the randomly selected sample which acquired by those selected elective course of Arch 4151 – Virtual Environments in Architecture. Since no pre-requirement asked from the students, questionnaire was used to demonstrate descriptive statistics of the sample as seen in Table 4.1. Along with students' assigned tags, specified questions were asked such as (1) What is your gender? (2) How old are you (3) Do you play recent video games? (4) Which grade are you? (5) What is the topic of the design studio you are currently taking? (6) Do you use CAD and/or BIM softwares? (7) Which software do you use mostly? (8) For how long are you using CAD and/or BIM softwares?

Table 4.1: Answers, Questionnaire 0

Tag	*Gender*	*Age*	*Videogames*	*Grade*	*Design Studio Topic*	*Use of CAD and/or BIM*	*Mostly Used Software*	*Experience (years)*
AKO	F	23	Yes	4th	Inhabiting Space	Yes	Revit	4
ANO	F	22	Yes	4th	Inhabiting Space	Yes	SketchUp	3
AO	M	22	Yes	4th	Inhabiting Space	Yes	ArchiCAD	5
BO	F	24	No	4th	Inhabiting Space	Yes	Revit	4
CO	F	22	No	4th	Inhabiting Space	Yes	ArchiCAD	4
CS	F	23	No	4th	Inhabiting Space	Yes	Revit	3
CT	M	23	Yes	4th	Inhabiting Space	Yes	ArchiCAD	5
DV	F	23	No	4th	Inhabiting Space	Yes	Revit	2
EK	M	23	No	4th	Inhabiting Space	Yes	Rhinoceros	5
EO	F	22	Yes	4th	Inhabiting Space	Yes	SketchUp	5
FB	M	22	Yes	4th	Inhabiting Space	Yes	ArchiCAD	4
FC	M	25	Yes	3rd	Cultural Centre	Yes	SketchUp	3
G1_1	F	23	No	4th	Inhabiting Space	Yes	ArchiCAD	4
G1_2	F	23	No	4th	Inhabiting Space	Yes	ArchiCAD	4
G1_3	M	23	Yes	4th	Inhabiting Space	Yes	ArchiCAD	5
G2_1	F	22	Yes	4th	Inhabiting Space	Yes	Rhinoceros	3
G2_2	F	22	No	4th	Inhabiting Space	Yes	Rhinoceros	3
G2_3	F	21	Yes	4th	Inhabiting Space	Yes	Rhinoceros	4
G3_1	F	21	No	3rd	School	Yes	Rhinoceros	3
G3_2	F	21	Yes	3rd	School	Yes	Rhinoceros	3
G4_1	M	21	No	3rd	School	Yes	SketchUp	3
G4_2	M	21	No	3rd	School	Yes	SketchUp	3
G5_1	F	22	No	4th	Inhabiting Space	Yes	ArchiCAD	4
G5_2	M	22	Yes	4th	Inhabiting Space	Yes	ArchiCAD	5
G5_3	M	22	Yes	4th	Inhabiting Space	Yes	ArchiCAD	4
G6_1	M	21	Yes	4th	Inhabiting Space	Yes	ArchiCAD	4
G6_2	M	22	No	4th	Inhabiting Space	Yes	SketchUp	4
G7_1	F	23	No	4th	Inhabiting Space	Yes	Rhinoceros	5
G7_2	F	22	No	4th	Inhabiting Space	Yes	Rhinoceros	5
G8_1	F	22	Yes	4th	Inhabiting Space	Yes	Rhinoceros	4
G8_2	F	21	Yes	4th	Inhabiting Space	Yes	Rhinoceros	6
GA	F	23	No	4th	Inhabiting Space	Yes	ArchiCAD	4
MCK	M	22	Yes	3rd	Cultural Centre	Yes	ArchiCAD	3

Tag	*Gender*	*Age*	*Videogames*	*Grade*	*Design Studio Topic*	*Use of CAD and/or BIM*	*Mostly Used Software*	*Experience (years)*
MM	M	23	Yes	3rd	Cultural Centre	Yes	ArchiCAD	3
MS	M	22	Yes	4th	Inhabiting Space	Yes	ArchiCAD	3
NNU	F	22	Yes	4th	Inhabiting Space	Yes	SketchUp	4
NS1	M	35	Yes	2nd	Immigrant Hub	Yes	ArchiCAD	3
NS2	F	23	No	4th	Inhabiting Space	Yes	SketchUp	3
OD	M	24	Yes	4th	Inhabiting Space	Yes	ArchiCAD	5
RA	F	23	No	4th	Inhabiting Space	Yes	ArchiCAD	4
RV_1	M	24	No	4th	-	Yes	AutoCAD	3
RV_2	F	23	No	4th	-	Yes	AutoCAD	3
RV_3	M	25	Yes	4th	-	Yes	ArchiCAD	4
RV_4	F	25	No	5th	-	Yes	ArchiCAD	5
RV_5	F	24	No	6th	-	Yes	Rhinoceros	4
YA	M	22	Yes	4th	Inhabiting Space	Yes	ArchiCAD	5

In total 46 attendees conducted the questionnaire. All of them were the students of the course. Answers indicated 20 males (43.5%) and 26 females (56.5%) got the course and contributed to the experiments (Figure 4.1).

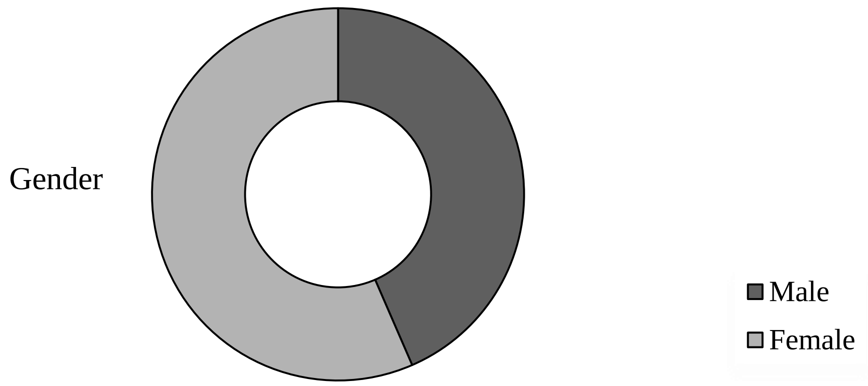


Figure 4.1: Answers, Gender

While most of the studets were undergraduate students, age range seems to differ due to course retakes and graduate students (Figure 4.2). Average age is 22.7 between 46 students. Answers indicated there are 7 students 21 years old (15.2%), 17 students 22 years old (37%), 14 students 23 years old (30.4%), 4 students 24 years old (8.7%), 3 students 25 years old (6.5%), and only a student 35 years old (2.2%).

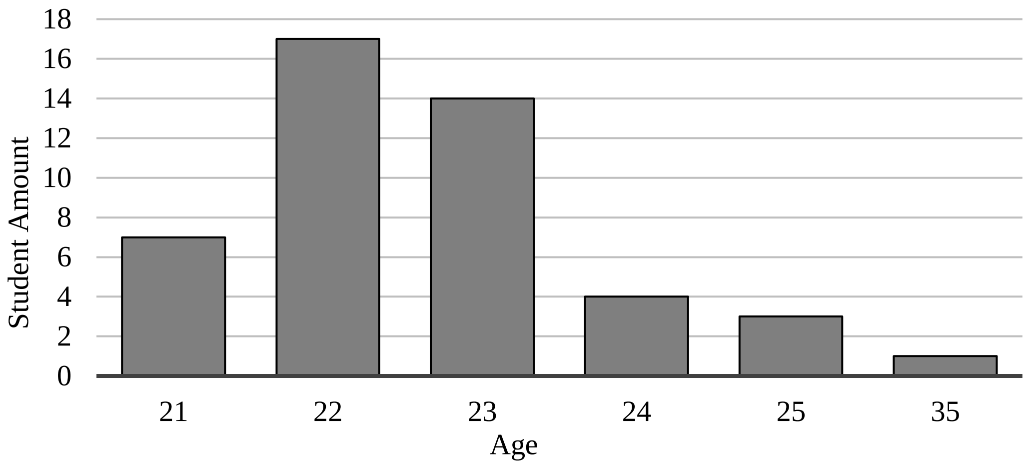


Figure 4.2: Answers, Age

Another independent value was whether student plays video games or not. For this question, 24 students (52.2%) said they are playing the recent games on the market while 22 students (47.8%) said they do not play computer games (Figure 4.3).

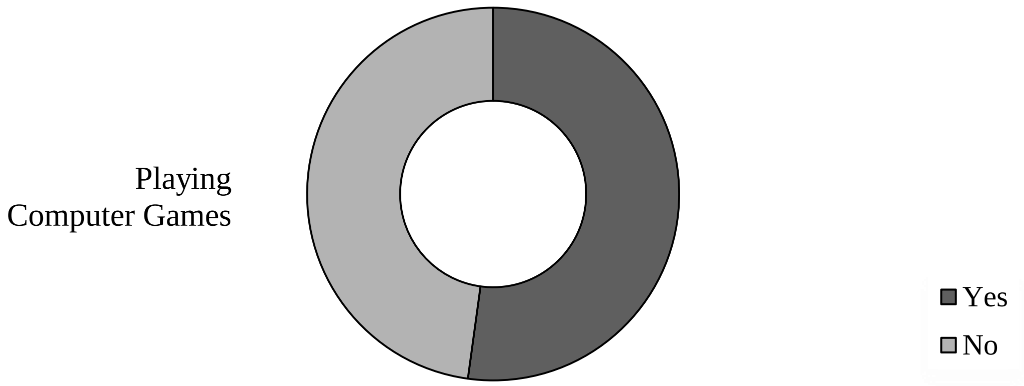


Figure 4.3: Answers, Playing Computer Games

Arch 4151 – Virtual Environments in Architecture has a course code of "Arch 4XXX" which indicates it is a elective course for 4th year students. Therefore most of the students are 4th year students, however, 2nd, 3rd, masters, and doctorate students also attended the course (Figure 4.4). Due to characteristic of architecture education, students take design studios according to their grades. Since masters and doctorate students finished their courses, they did not have any design studio. Also, some of the 4th graders finished their design studios but they only have elective courses, they also did not have any design studio. When investigated, there are 33 students who took 4th grade design studio (71.7%), 7 students took 3rd year design studio (15.2%), only a student took 2nd grade design studio (2.2%) and 5 other students had no design studio at all (10.9%). Also some of the students contribute to the design studios in group projects. Therefore, their individual work or group work data also collected. 22 students (47.8%) work individually for their projects, while 19 students (41.3%) work in groups of two or three. When investigated further, those students who work in groups distributed as 9 students (19.6%) work in three-members groups works and 10 students (21.7%) work in two-members group works (Figure 4.5).

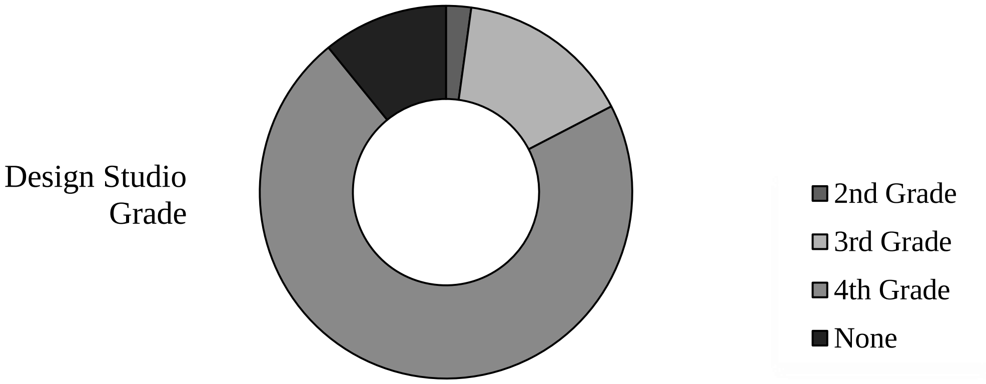


Figure 4.4: Answers, Design Studio Grade

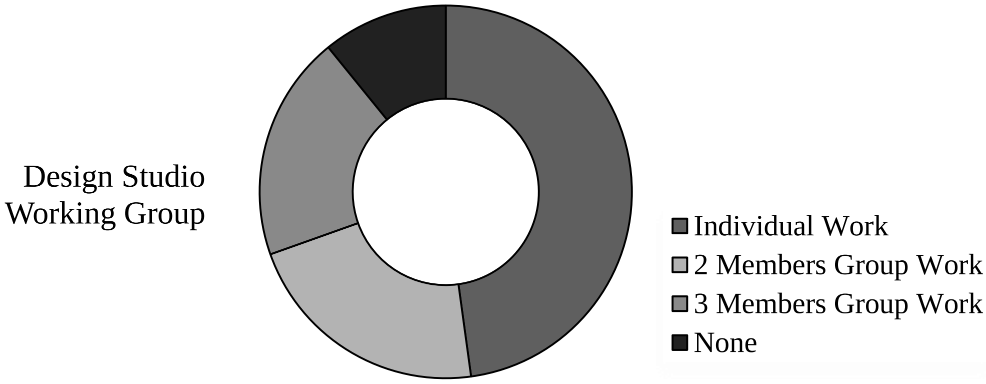


Figure 4.5: Answers, Design Studio Working Group

Since each design studio syllabus has different contents, design problems and processes, students also have been asked to indicate their design studio problems. Since 4th grade students assigned to a single topic, 3rd and 2nd grades' students had different topics (Figure 4.6). 33 students were assigned to design an inhabiting space in 4th grade design studio (71.7%). In the 3rd grade design studio, 3 students (6.5%) were handling a cultural centre while other 4 students (8.7%) were dealing with a elementary and kindergarten topic. On the other hand, 2nd grade student (2.2%) dealt with an immigrant hub for her design studio. Since 5 students (10.9%) had no design studios, they left the question empty.

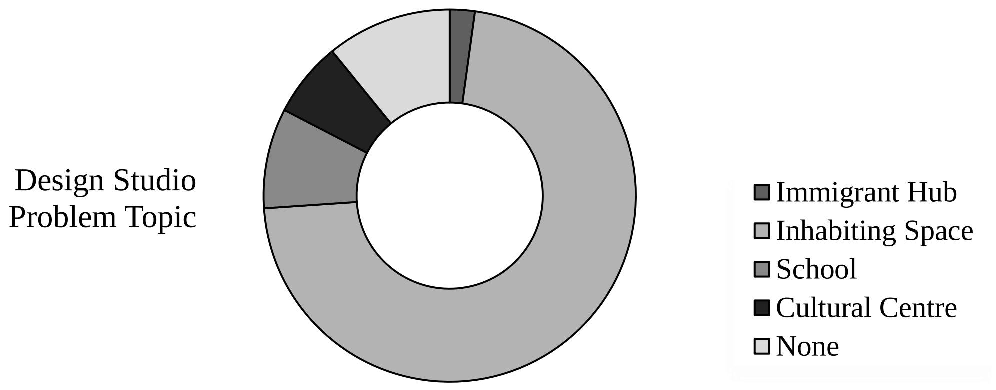


Figure 4.6: Answers, Design Studio Problem Topic

When students were asked about whether they use CAD and/or BIM softwares to develop their design studios, all of them indicated they use CAD and/or BIM softwares. However, softwares they used differed a lot due to numerous applications appearing in the market and each one of them offers unique systems to solve particular problems (Figure 4.7). 21 students (45.7%) used ArchiCAD to develop their projects. 11 students (23.9%) used Rhinoceros, 8 students (17.4%) used SketchUp, 4 students (8.7%) used Revit and only 2 students (4.3%) used AutoCAD.

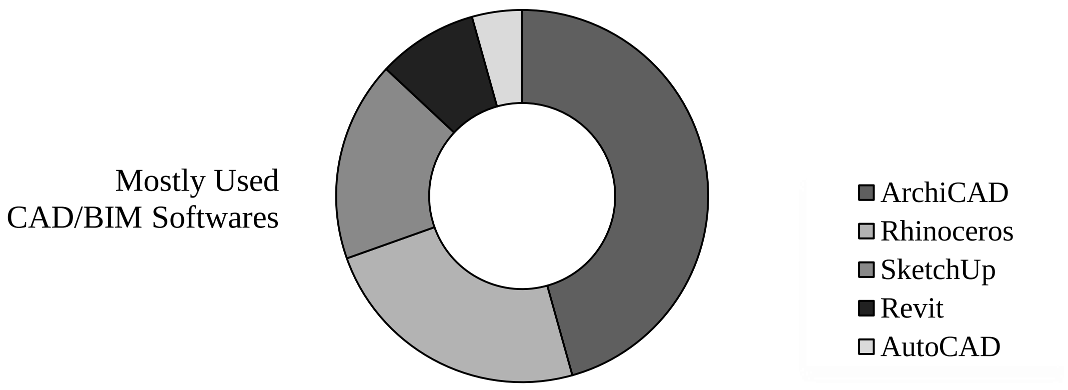


Figure 4.7: Answers, Mostly Used CAD/BIM Softwares

Each student had different level of expertise in the softwares they are using to develop their design studio projects. Since none of them are using it for more than 10 years, they asked to specify for how long they are using the significant software they selected in the previous question. 17 students (37%) said they use CAD and/or BIM softwares for 4 years. 16 students (34.8%) indicated they use them for 3 years. 11 students (23.9%) answered 5 years. 6 years (%2) and 2 years (%2) only answered by a student for each (Figure 4.8)

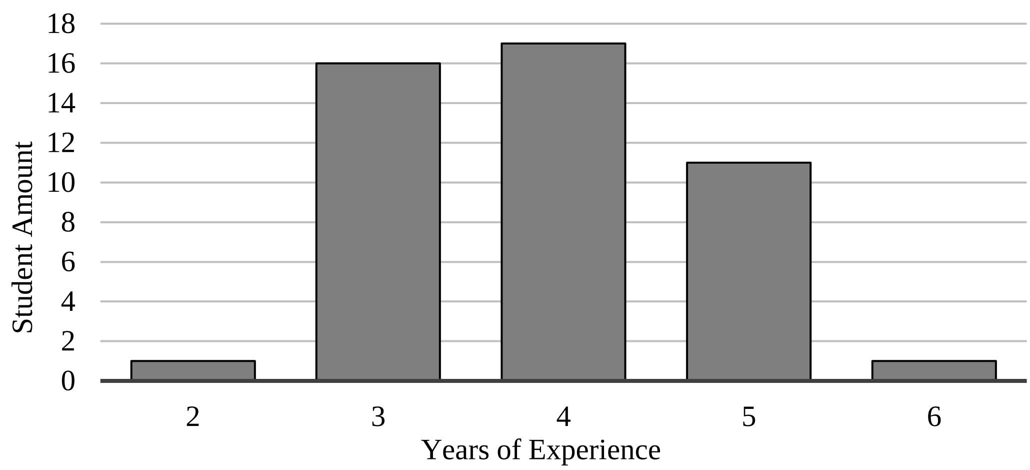


Figure 4.8: Answers, Years of Experience in CAD/BIM

4.2. RESULTS OF EXPERIMENT 1

First experiment established to generate basic descriptive statistics about the attendees' skills related with understanding basics of the projects, the difficulty to navigate in virtual environments, measure their communication ability in the 3D digital tools. For the very first time, students used digital tools to collaborate in virtual environments.

In total 41 students attended the experiment. In total 14 questions asked to students, including 7 questions to measure understanding (Figure 4.9), 2 questions to measure communication (Figure 4.11) and 5 other questions to measure difficulty of navigation and feedback process (Figure 4.10) in different representation setups such as OSVE in walking mode, OSVE in flying mode, and IVR view. Likert scale from 1 to 5 had been used in the questionnaire. In the questions related with understanding and communication, 1 to 5 matches low to high while questions related with difficulty, same scale corresponds a range from easy to high. When all answers summed up, minimum and maximum value an answer can get sets up a range between 0 and 205. While questionnaires related with understanding and communication, higher value is better, the situation with questions of difficulty is vice versa.

When answers' sum ups investigated, Questionnaire 2 indicates in OSVE view with flying mode, understanding of overall installation is 183 while understanding of the volume is 159, in OSVE view with walking mode, understanding of overall installation is 153 while understanding of the volume is 168. However, understanding of the overall installation in IVR view is 146 while the understanding of volume is 164. Level of communication via speaking with other person while in IVR view got 144, via text-based reviews on the surfaces in OSVE view is 161. Understanding of the review's students got in their installations on the surfaces answered by them as 156 (Table 4.2).

Further investigations on the Table 4.2 shows level of difficulty to navigate in OSVE view with flying mode is 106, with walking mode it is 123, and in IVR view navigation difficulty is 130. On the other hand, level of difficulty to put reviews in OSVE view is 95 and difficulty of finding the reviews made on the students' installations was 97. Therefore, difficulty of navigation in IVR view seems to be harder than navigation in OSVE view.

Table 4.2: Answers, Questionnaire 2

Question	*Q*	*1*	*2*	*3*	*4*	*5*
Level of understanding of the overall installation in OSVE view, flying mode?	Q201	0	0	6	10	25
Level of understanding of the volume in OSVE view, flying mode?	Q202	0	4	8	18	11
Level of difficulty to navigate in OSVE view, flying mode?	Q203	7	11	15	8	0
Level of understanding of the overall installation in OSVE view, walking mode?	Q204	0	5	13	11	12
Level of understanding of the volume in OSVE view, walking mode?	Q205	0	0	8	21	12
Level of difficulty to navigate in OSVE view, walking mode?	Q206	4	9	15	9	4
Level of understanding of the overall installation in IVR view?	Q207	0	6	17	7	11
Level of understanding of the volume in IVR view?	Q208	0	2	12	11	16
Level of difficulty to navigate in IVR view?	Q209	3	7	16	10	5
Level of communication via speaking with other person while in IVR view?	Q210	4	1	17	8	11
Level of communication via text-based reviews on surfaces in OSVE view?	Q211	0	2	12	14	13
Level of difficulty to put reviews in OSVE view?	Q212	12	9	15	5	0
Level of difficulty to find reviews' locations in OSVE view?	Q213	12	10	13	4	2
Level of understanding of reviews you got to your installations?	Q214	2	2	13	9	15

Further investigations on the results of Questionnaire 2 indicates students preferred OSVE view with flying mode to understand the overall installation. While 25 students answered level of understanding of the overall installation as 5, and 10 students answered as 4. The amount for the same question is 12 students answered as 5, 11 students answered as 4 for OSVE view with walking mode, and 11 students answered as 5, 7 students answered as 4 for IVR view. More than 15 students indicated level of understanding of the overall project as 3 in IVR view. On the other hand, to understand the volume, students' answers were close to each other's. However, for IVR view 16 students answered the level of understanding of the volume as 5, while 12 students for OSVE view with walking mode, and 11 students for OSVE view with flying mode. Which indicates students selected IVR view as an effective method to understand the volumes of the installations. In contrast, while more students answered the question as 5, students who answered the level of understanding the volume as 4 were more than students answered as 4 for IVR view (Figure 4.9).

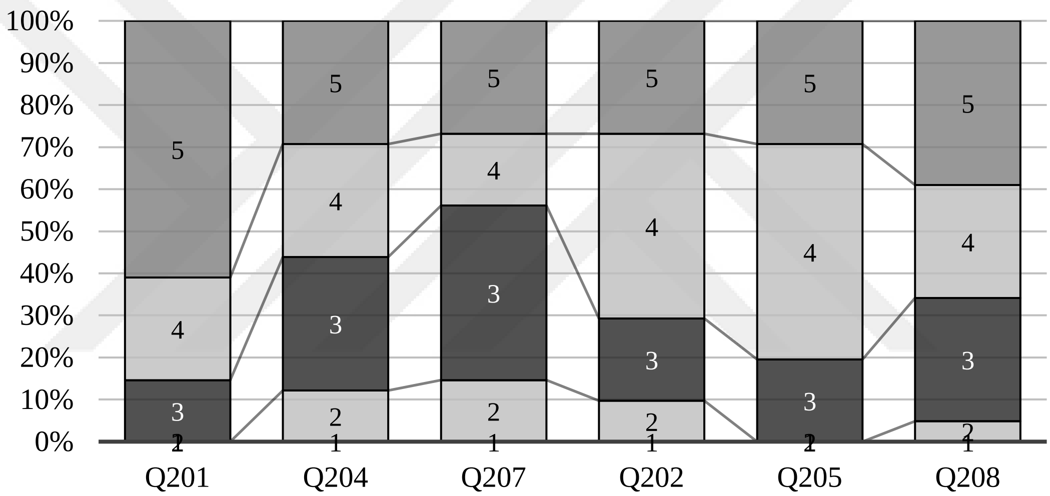


Figure 4.9: Answers, Experiment 1, Questionnaire 2, Level of Understanding

The answers' amounts for level of difficulty indicates OSVE view with flying mode is easier to navigate through the installations since none of the students indicated its difficulty as 5 in the questionnaires. Hardest method to navigate through the project seems to be IVR view due to those students answered as 5 and 4 as the level of difficulty. However, answers are significantly close to each other's for all representation methods. Generating reviews in three-dimensional virtual environment with OSVE view seems to be preferable for more than half of the students. None of the students answered as 5 to the difficulty of giving reviews. Same situation observed for finding the reviews made to the students' installations (Figure 4.10).

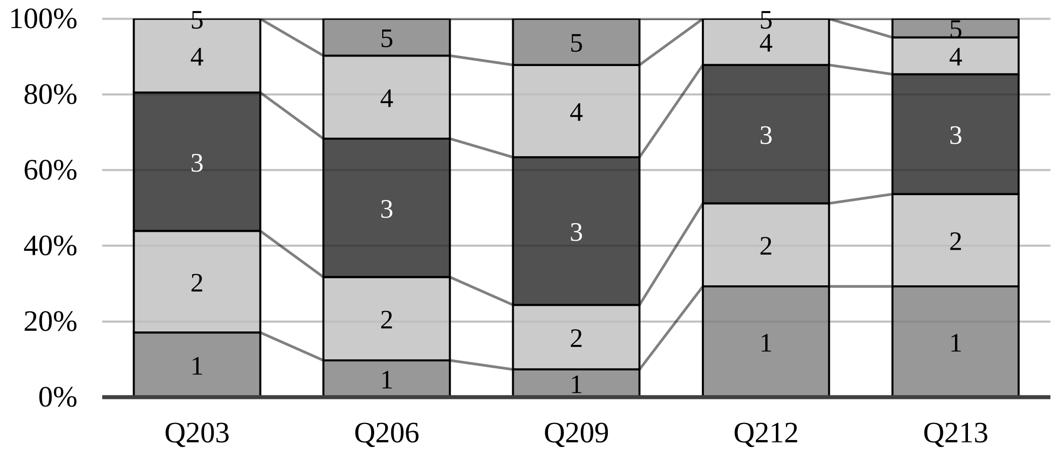


Figure 4.10: Answers, Experiment 1, Questionnaire 2, Level of Difficulty

Communication between students established both via speaking physically and reviewing in virtual environment. When the level of communication and understanding have been asked to students, students were more noncommittal for communication via speaking rather than digital reviewing system. While most of the students answered level of communication as 3 for physical conversation, few students indicated the answer as 1 and 2. However, same question answered as 4 and 5 from more students for reviewing in virtual environment. The number of noncommittal students also reduced for reviewing system. Level of understanding the reviews students got also indicated as 5 and 4 by most of the students (Figure 4.11).

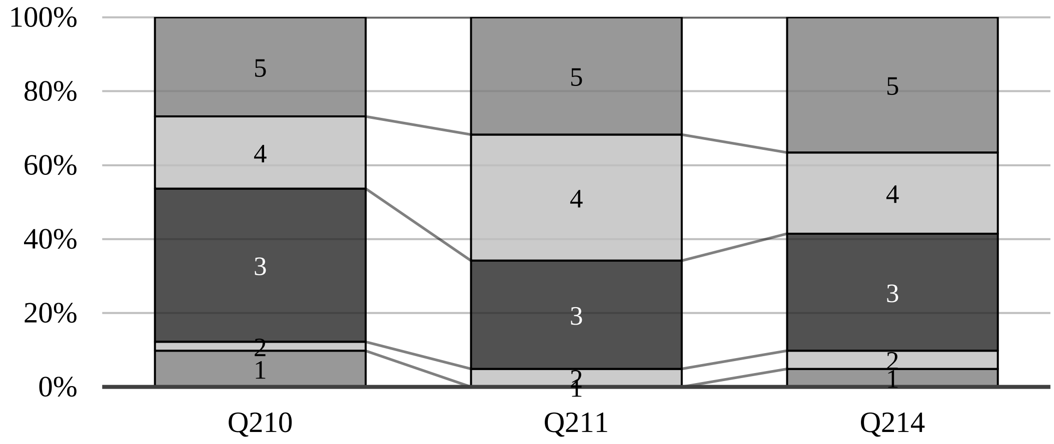


Figure 4.11: Answers, Experiment 1, Questionnaire 2, Level of Communication

4.3. RESULTS OF EXPERIMENT 2

Experiment 2 was a comparative study between DOD, OSVE and IVR views. Students observed three different housing projects in different presentation setups. Questionnaire 3, 4, and 5 have the same questions corresponding different representation methods. Questionnaire 3 (Table 4.3) is for DOD view, Questionnaire 4 (Table 4.4) is for OSVE view and Questionnaire 5 (Table 4.5) is for IVR view for the projects. On the other hand, another questionnaire has been presented for students to compare DOD, OSVE and IVR for different architectural presentation aspects, which is Questionnaire 6 (Table 4.6).

In total 43 students attended the experiment. They all filled in the questionnaires without any empty answer. When all answers summed up, minimum and maximum value an answer can get sets up a range between -86 and +86.

When answer sums of Questionnaire 3 has been observed, digital orthographic drawings (DOD) got +58 for understanding the plan organization, +47 for understanding the human scale and structure size, +50 for understanding the rooms and their relations, +45 for understanding the circulations between corridors, +26 for understanding the interior and exterior space relations, %31 for understanding the vertical elements such as walls, cladding, and façade elements, +26 for understanding the openings and their impacts for interiors, +34 for understanding the solid and void relations, +35 for understanding the interior design and furniture organization, +34 for understanding the vertical relations between balconies, stairs, slab overlaps etc., -1 for understanding the volume, how would it be like to live inside the environment, +12 for figuring out the overall problems with the project, +19 for figuring out the problems related with narrow and small areas, +2 for figuring out the wrong furniture placements, +25 for suggesting a new layout for room organization, +6 for suggesting a new circulation for the project, and +24 for suggesting new solutions for the interior furniture placements (Table 4.3).

Table 4.3: Answers, Questionnaire 3, for DOD

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood the plan organization of the project."	Q301	0	0	2	24	17
"I understood the human scale and how big the structure is."	Q302	0	1	6	24	12
"I understood the rooms and their relations with each other's."	Q303	0	1	3	27	12
"I understood the circulation between corridors, stairs, rooms, etc."	Q304	0	2	8	19	14
"I understood interior and exterior space relations."	Q305	1	5	12	17	8
"I understood vertical elements such as walls, cladding, and façade elements."	Q306	3	3	7	20	10

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood openings and their impacts for interior."	Q307	0	4	19	10	10
"I understood solid/void relation of the façade."	Q308	0	0	20	12	11
"I understood the interior design and the furniture organization."	Q309	3	0	7	25	8
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Q310	0	3	12	19	9
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q311	6	10	8	17	2
"I figured out overall problems related with the project."	Q312	0	8	17	16	2
"I figured out problems with narrow areas and small volumes."	Q313	0	6	18	13	6
"I figured out wrong furniture placements in the interior areas."	Q314	2	9	18	13	1
"I can suggest a new layout for overall room relations."	Q315	0	1	17	24	1
"I can suggest a new circulation for the project."	Q316	0	8	22	12	1
"I can suggest new solutions for the interior furniture placements."	Q317	3	3	9	23	5

When questionnaire answers' amounts investigated, students' approval to use digital orthographic drawings for understanding the plan organization of the project can be observed (Q301 in Figure 4.12). On the other hand, another major advantage of DOD view seems to be rooms' relations with each other's, the scale of the building, and understanding of the circulation between rooms by corridors, stairs, etc. (Q302, Q303, Q304 in Figure 4.12). Also, students seem to understand the interior design and furniture organization and they feel comfortable with suggesting new solutions for the interior furniture placements (Q309, Q317 in Figure 4.12). Further observations on the results also shows digital orthographic drawings are not suitable for understanding the volume, how it feels, how would it be like to live inside those environments; figuring out overall problems related with the project, narrow areas, small volumes, wrong furniture placements in the interior areas, and suggesting new circulations for the project (Q311, Q312, Q313, Q314, Q316 in Figure 4.12). Last, students seem to be more noncommittal with DOD for understanding the openings of the projects, their impacts for interior life, and solid/void relations of the façade (Q307, Q308 in Figure 4.12) since a significant amount of students answered neutral.

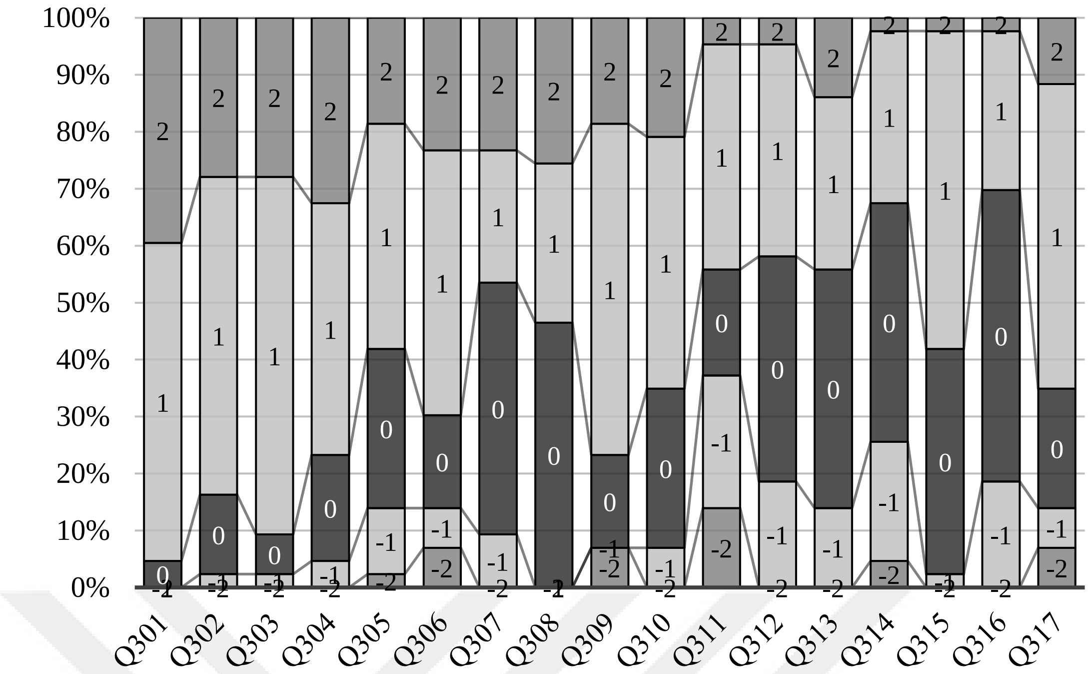


Figure 4.12: Answers, Questionnaire 3, for DOD

When answer sums of Questionnaire 4 has been observed, on-screen virtual environment view (OSVE) got +54 for understanding the plan organization, +56 for understanding the human scale and structure size, +56 for understanding the rooms and their relations, +54 for understanding the circulations between corridors, +53 for understanding the interior and exterior space relations, %34 for understanding the vertical elements such as walls, cladding, and façade elements, +39 for understanding the openings and their impacts for interiors, +49 for understanding the solid and void relations, +47 for understanding the interior design and furniture organization, +57 for understanding the vertical relations between balconies, stairs, slab overlaps etc., +45 for understanding the volume, how would it be like to live inside the environment, +39 for figuring out the overall problems with the project, +39 for figuring out the problems related with narrow and small areas, +33 for figuring out the wrong furniture placements, +37 for suggesting a new layout for room organization, +32 for suggesting a new circulation for the project, and +44 for suggesting new solutions for the interior furniture placements (Table 4.4).

Table 4.4: Answers, Questionnaire 4, for OSVE View

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood the plan organization of the project."	Q401	0	1	8	13	21

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood the human scale and how big the structure is."	Q402	0	3	3	15	22
"I understood the rooms and their relations with each other's."	Q403	0	1	7	13	22
"I understood the circulation between corridors, stairs, rooms, etc."	Q404	0	2	5	16	20
"I understood interior and exterior space relations."	Q405	1	1	2	22	17
"I understood vertical elements such as walls, cladding, and façade elements."	Q406	3	1	9	19	11
"I understood openings and their impacts for interior."	Q407	0	5	6	20	12
"I understood solid/void relation of the façade."	Q408	0	2	5	21	15
"I understood the interior design and the furniture organization."	Q409	0	1	6	24	12
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Q410	0	0	3	23	17
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q411	0	1	7	24	11
"I figured out overall problems related with the project."	Q412	0	1	11	22	9
"I figured out problems with narrow areas and small volumes."	Q413	0	2	9	23	9
"I figured out wrong furniture placements in the interior areas."	Q414	2	2	9	21	9
"I can suggest a new layout for overall room relations."	Q415	0	3	7	26	7
"I can suggest a new circulation for the project."	Q416	1	4	7	24	7
"I can suggest new solutions for the interior furniture placements."	Q417	0	0	7	28	8

When questionnaire answers' amounts investigated in Questionnaire 4, since all questions got more than 70% agree and strongly agree answers, it can be concluded as students felt comfortable with OSVE view for understanding the projects, figuring out problems, and suggesting new ideas (Figure 4.13). However, further investigations show understanding the interior - exterior relations, and understanding vertical relations between balconies, stairs, slab overlaps etc. are easier with OSVE view for the students since 90% of them answered positively (Q405, Q410 in Figure 4.13).

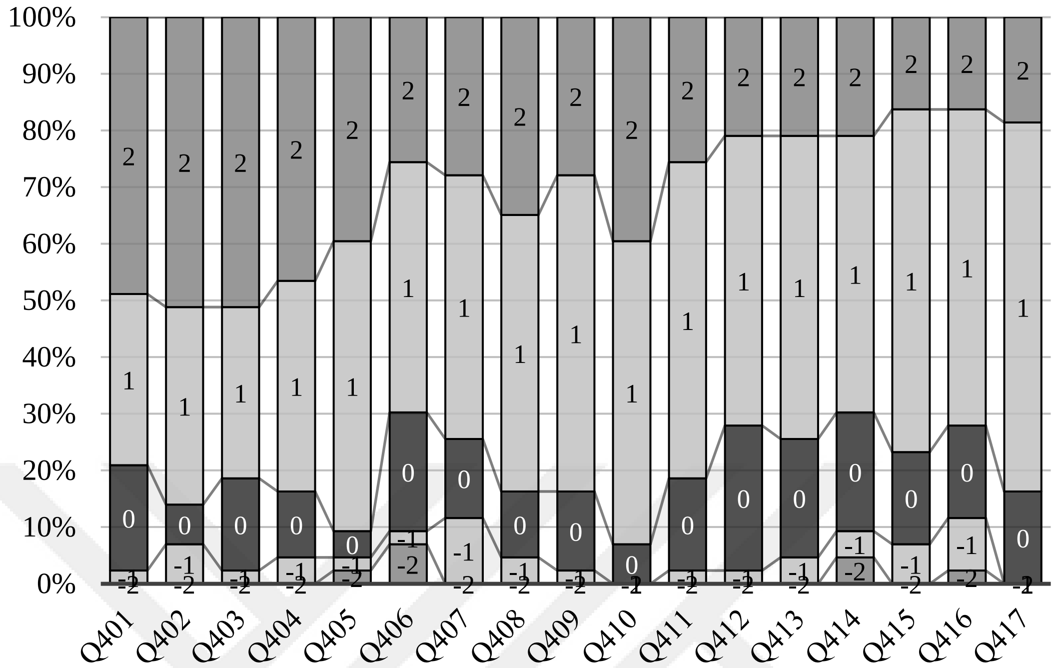


Figure 4.13: Answers, Questionnaire 4, for OSVE View

When answer sums of Questionnaire 5 has been observed, immersive virtual reality view (IVR) got +28 for understanding the plan organization, +56 for understanding the human scale and structure size, +32 for understanding the rooms and their relations, +39 for understanding the circulations between corridors, +35 for understanding the interior and exterior space relations, %35 for understanding the vertical elements such as walls, cladding, and façade elements, +45 for understanding the openings and their impacts for interiors, +28 for understanding the solid and void relations, +44 for understanding the interior design and furniture organization, +35 for understanding the vertical relations between balconies, stairs, slab overlaps etc., +43 for understanding the volume, how would it be like to live inside the environment, +22 for figuring out the overall problems with the project, +51 for figuring out the problems related with narrow and small areas, +26 for figuring out the wrong furniture placements, +18 for suggesting a new layout for room organization, +19 for suggesting a new circulation for the project, and +33 for suggesting new solutions for the interior furniture placements (Table 4.5).

Table 4.5: Answers, Questionnaire 5, for IVR View

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood the plan organization of the project."	Q501	1	5	9	21	7
"I understood the human scale and how big the structure is."	Q502	1	1	4	15	22
"I understood the rooms and their relations with each other's."	Q503	1	3	11	19	9
"I understood the circulation between corridors, stairs, rooms, etc."	Q504	0	2	10	21	10
"I understood interior and exterior space relations."	Q505	1	5	5	22	10
"I understood vertical elements such as walls, cladding, and façade elements."	Q506	1	4	8	19	11
"I understood openings and their impacts for interior."	Q507	1	4	3	19	16
"I understood solid/void relation of the façade."	Q508	2	6	6	20	9
"I understood the interior design and the furniture organization."	Q509	1	2	5	22	13
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Q510	2	4	6	19	12
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q511	0	2	7	17	17
"I figured out overall problems related with the project."	Q512	1	6	11	20	5
"I figured out problems with narrow areas and small volumes."	Q513	1	1	2	24	15
"I figured out wrong furniture placements in the interior areas."	Q514	4	3	6	23	7
"I can suggest a new layout for overall room relations."	Q515	1	3	18	19	2
"I can suggest a new circulation for the project."	Q516	3	3	16	14	7
"I can suggest new solutions for the interior furniture placements."	Q517	0	4	7	27	1

Answers' amounts of Questionnaire 5 indicate IVR view was significantly useful to figure out problems related with narrow areas and small volumes (Q513 in Figure 4.14). Also, to understand the human scale, size of the structure, openings, their impacts for interior areas, interior design, and the furniture organizations IVR is a viable tool for students (Q502, Q507, Q509 in Figure 4.14). On the other hand, IVR seems not suitable for suggesting a new layout for overall room relations and suggesting a new circulation for the project (Q515, Q516 in Figure 4.14). Yet, positivity amount of answers indicates students feel comfortable with IVR tools except for understanding overall project related issues (Figure 4.14).

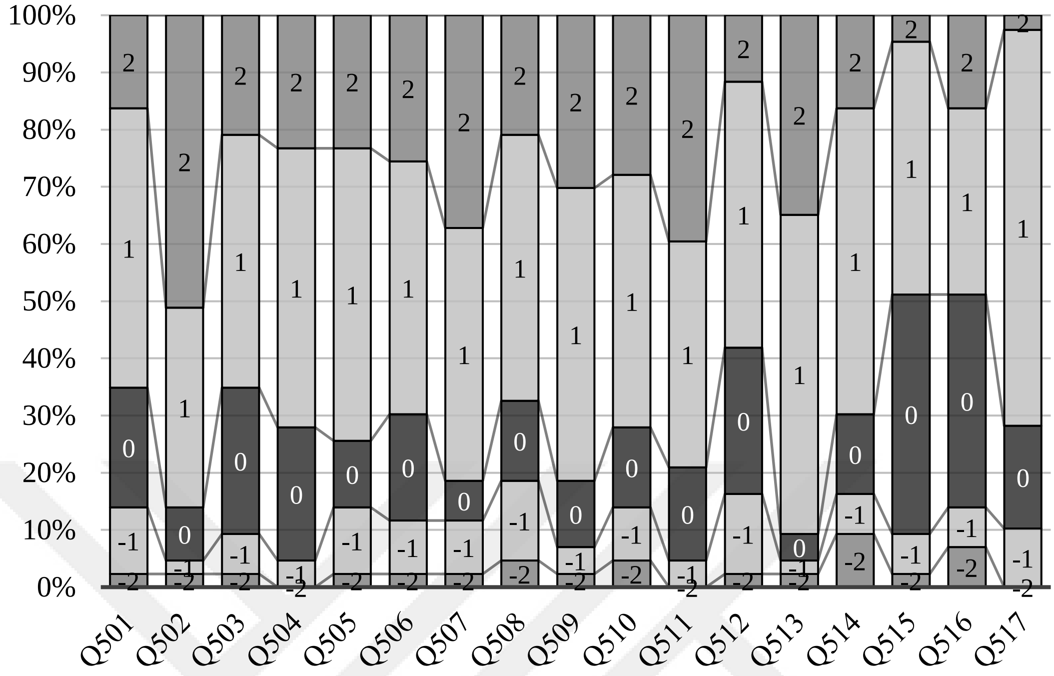


Figure 4.14: Answers, Questionnaire 5, for IVR View

Last questionnaire of the Experiment 2 has been prepared for students to compare the representation methods for specified features. Since all of them already used all the systems and answered questionnaires related with their previous experiences, this questionnaire has been used for both comparing the different methods as well as cross-check the previous questionnaires' answers. Students' answers for Questionnaire 6 indicates both DOD and OSVE for understanding the plan organization, IVR for understanding the human scale and structure size, both DOD and OSVE for understanding the rooms and their relations, DOD for understanding the circulations between corridors, OSVE for understanding the interior and exterior space relations, understanding the vertical elements such as walls, cladding, and façade elements, IVR for understanding the openings and their impacts for interiors, OSVE for understanding the solid and void relations, IVR for understanding the interior design and furniture organization, OSVE for understanding the vertical relations between balconies, stairs, slab overlaps etc., IVR for understanding the volume, how would it be like to live inside the environment, OSVE for figuring out the overall problems with the project, IVR for figuring out the problems related with narrow and small areas, both OSVE and IVR for figuring out the wrong furniture placements, both DOD and

OSVE for suggesting a new layout for room organization, DOD for suggesting a new circulation for the project, both IVR and OSVE for suggesting new solutions for the interior furniture placements, DOD for understanding the closed square meter of the all project, and how many volumes there are, OSVE for easier navigation through the projects, and IVR for understanding the interior volumes and their impacts on users are the most preferable ones compare to each other's. (Table 4.6).

Table 4.6: Answers, Questionnaire 6, Comparative

Question	*Q*	*DOD*	*OSVE*	*IVR*
Which one is more effective to understand plan organization of the project?	Q601	21	21	4
Which one is more effective to understand human scale and how big the building is?	Q602	2	16	28
Which one is more effective to understand the rooms and their relations with each other's?	Q603	19	19	8
Which one is more effective to understand the circulation between corridors, stairs, rooms, etc.	Q604	19	14	13
Which one is more effective to understand interior and exterior space relations?	Q605	7	30	9
Which one is more effective to understand vertical elements such as walls, cladding, and façade elements?	Q606	8	29	9
Which one is more effective to understand openings and their impacts for interior?	Q607	3	16	27
Which one is more effective to understand solid/void relation of the façade?	Q608	4	32	10
Which one is more effective to understand the interior design and the furniture organization?	Q609	5	17	24
Which one is more effective to understand vertical relations between balconies, stairs, slab overlaps, etc.	Q610	10	26	10
Which one is more effective to understand the volume, how it feels, how would it be like to live inside that environment.	Q611	1	14	31
Which one is more effective to understand overall problems related with the project.	Q612	11	28	7
Which one is more effective to understand problems with narrow areas and small volumes?	Q613	4	6	36
Which one is more effective to understand wrong furniture placements in the interior areas?	Q614	4	21	21
Which one is more effective to evaluate the project and suggest a new layout for overall room relations?	Q615	20	20	6
Which one is more effective to evaluate the project and suggest a new circulation for the project?	Q616	18	15	13

Question	*Q*	*DOD*	*OSVE*	*IVR*
Which one is more effective to evaluate the project and suggest new solutions for the interior furniture placements?	Q617	11	17	18
Which one eases to understand the square meter of total closed area of the project?	Q618	33	6	7
Which one eases to understand how many volumes are there?	Q619	22	12	12
Which one is easier to navigate for understanding the overall project?	Q620	16	25	5
Which one is easier to navigate for understanding the interior areas and impact of them?	Q621	1	12	33

When answers' amounts of Questionnaire 6 are investigated further, it can be concluded that from all three representation methods, OSVE seems to be useful for almost all cases except figuring out the problems with the small volumes and understanding the square meter of the project (Q613, Q618 in Figure 4.15). More than 70% of the students choose digital orthographic drawings to understand the square meter of the projects (Q618 in Figure 4.15), while almost 80% of the students selected immersive virtual reality as a useful method to figure out the problems related with the small areas and narrow volumes (Q613 in Figure 4.15). On the other hand, OSVE selected by more than half of the students for understanding interior – exterior relations, vertical elements like walls and façade, solid – void relations of the façade, and to navigate in the project for understanding the overall organization (Q605, Q606, Q608, Q620 in Figure 4.15). Almost 40% of the students selected digital orthographic drawings for understanding plan organization, rooms relations with each other's, circulation, suggesting new layouts for both rooms and circulation, and figuring out how many volumes are there (Q601, Q603, Q604, Q615, Q616, Q619 in Figure 4.15). While the situation with immersive virtual reality is not steady, majority of students selected IVR for understanding the building size, human scale, openings, their impacts for the interior, furniture organization, interior design, how the volume make the inhabitant feel like, figuring out problems related with narrow areas and small volumes, and navigating the project to understand interior creations impacts on the person (Q602, Q607, Q609, Q611, Q613, Q621 in Figure 4.15).

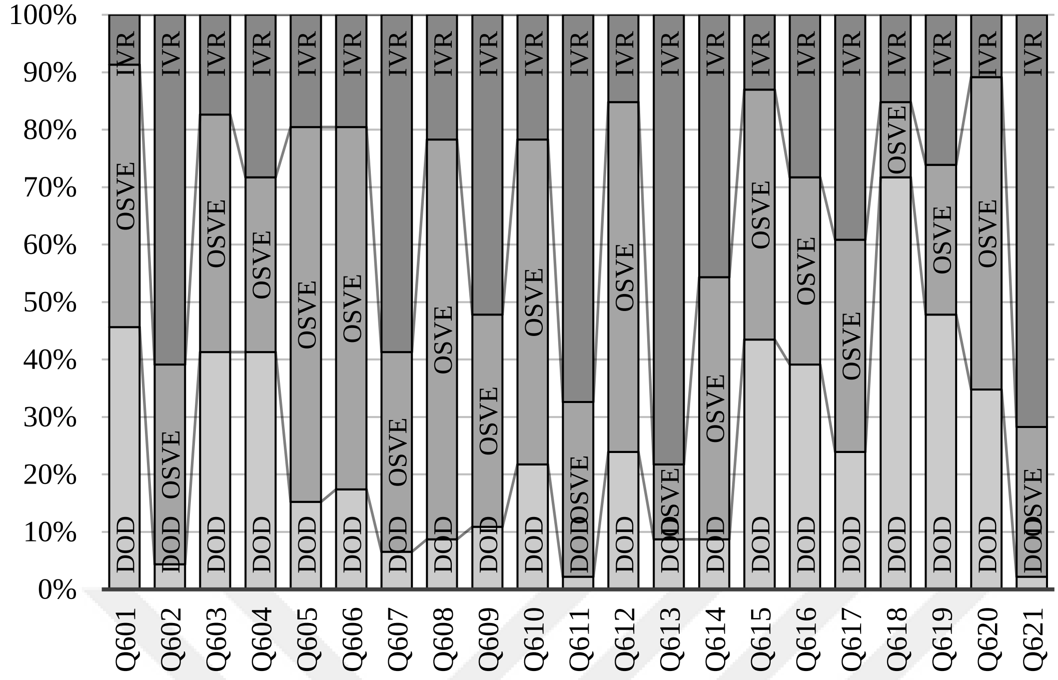


Figure 4.15: Answers, Questionnaire 6, Comparative

4.4. RESULTS OF EXPERIMENT 3

Experiment 3 was a comparative study between digital presentation boards (DPB), walkthrough videos (DWV) and on-screen virtual environment (OSVE), immersive virtual reality (IVR) views. Students observed two different design studio projects in different presentation setups. Questionnaire 7, and 8 have the same questions corresponding different representation methods. Questionnaire 7 (Table 4.7) was used measuring the influences of DPB and DWV presentation methods, while Questionnaire 8 (Table 4.8) was for OSVE and IVR views. On the other hand, another questionnaire has been presented for students to compare DPB-DWV and OSVE-IVR for different architectural presentation aspects, which is Questionnaire 9 (Table 4.9). Experiment done right after the mid-term exams of the students. Since students usually skip the classes after their mid-terms, 34 students attended the experiment. They all filled in the questionnaires without any empty answer. When all answers summed up, minimum and maximum value an answer can get sets up a range between -68 and +68.

When answers' sums of Questionnaire 7 has been observed, digital presentation boards and digital walkthrough videos (DPB-DWV) got +45 for understanding the plan organization of the project, +42 for understanding the human scale and how bit the structures are, +24 for the relations between the rooms, +30 for understanding the circulation, +31 for understanding the interior – exterior relations, +43 for vertical elements such as walls, cladding, and façade, +35 for understanding the openings and their impacts for interiors, +36 for solid – void relation of the façade, +27 for understanding the interior design and furniture organization, +23 for understanding the vertical relations between balconies, slabs overlaps and stairs, +26 for understanding the feeling of the volume, and how would it be like to live inside that environment, +17 for figuring out the overall problems with the project, +6 for figuring out the problems related with the narrow areas and small volumes, +5 for figuring out the wrong furniture placements in interior areas, +15 for suggesting new layouts for overall room relations, +16 for suggesting a new circulation to the project, +12 for suggesting new interior solutions to the project. Additionally, students answered as +53 for the use of walkthrough video to understand the project rather than the drawings, and +32 for understanding the basics of the project just by seeing DWV (Table 4.7).

Table 4.7: Answers, Questionnaire 7, for DPB-DWV

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood the plan organization of the project."	Q701	0	0	1	21	12
"I understood the human scale and how big the structure is."	Q702	0	2	2	16	14
"I understood the rooms and their relations with each other's."	Q703	0	0	15	14	5
"I understood the circulation between corridors, stairs, rooms, etc."	Q704	0	2	8	16	8
"I understood interior and exterior space relations."	Q705	0	3	5	18	8
"I understood vertical elements such as walls, cladding, and façade elements."	Q706	0	1	2	18	13
"I understood openings and their impacts for interior."	Q707	0	1	6	18	9
"I understood solid/void relation of the façade."	Q708	0	1	6	17	10
"I understood the interior design and the furniture organization."	Q709	0	2	10	15	7
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Q710	0	3	11	14	6
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q711	1	3	7	15	8
"I figured out overall problems related with the project."	Q712	0	1	16	16	1
"I figured out problems with narrow areas and small volumes."	Q713	0	8	13	12	1

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I figured out wrong furniture placements in the interior areas."	Q714	2	7	11	12	2
"I can suggest a new layout for overall room relations."	Q715	0	4	15	11	4
"I can suggest a new circulation for the project."	Q716	1	4	9	18	2
"I can suggest new solutions for the interior furniture placements."	Q717	2	3	11	17	1
"Walkthrough video in the presentation was more useful in terms of understanding the project than drawings."	Q718	0	0	1	13	20
"Walkthrough video was enough for me to understand basics of the project."	Q719	0	2	7	16	9

When answers' amount investigated further, significant number of students found DPB-DWV systems useful to understand plan organization of the project, human scale, size of the structures, and vertical elements such as walls, cladding etc. (Q701, Q702, Q706 in Figure 4.16). However, almost half of the students were noncommittal about understanding the rooms, their relations with each other's, and figuring out the overall problems related with the project (Q703, Q712 in Figure 4.16). Another aspect proves this situation was, almost 60% of the students found this representation method not useful to understand the problems related with narrow areas, small volumes and to suggest a new layout for overall room relations (Q713, Q715 in Figure 4.16). Nearly 70% of the students answered the questions positive to understand the openings, their impacts for the interior, solid – void relation of the façade, interior design of the furniture, and how would it be like to live inside that environment (Q707, Q708, Q709, Q711 in Figure 4.16). 90% of the students indicated the walkthrough videos were more useful to understand the project rather than the drawings (Q718 in Figure 4.16), while 70% of all students indicated only the walkthrough videos were enough for them to understand the basics of the projects (Q719 in Figure 4.16).

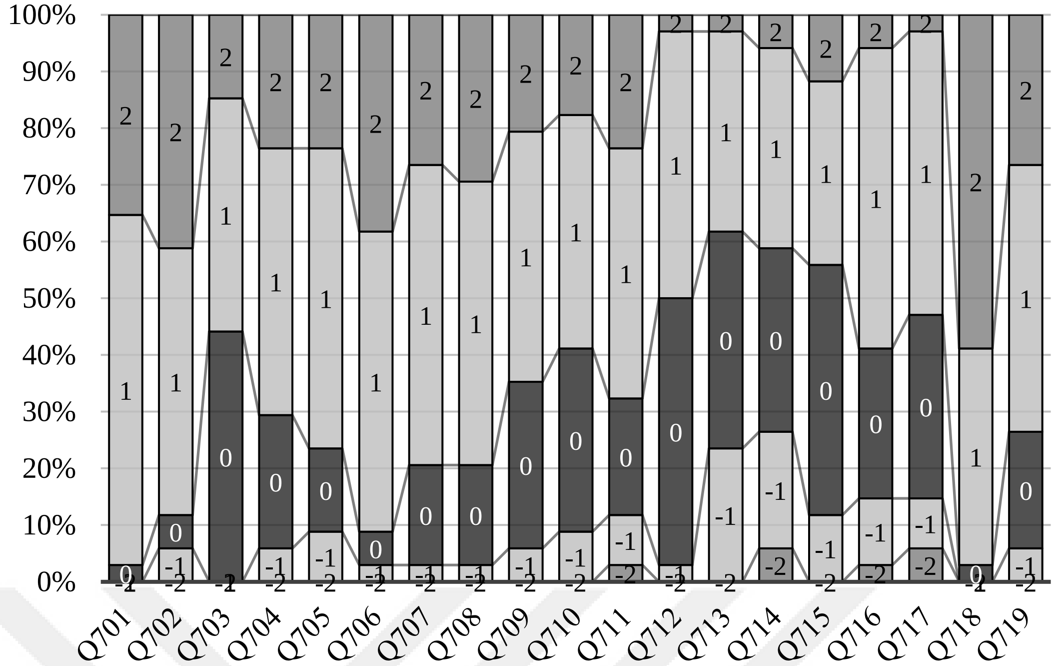


Figure 4.16: Answers, Questionnaire 7, for DPB-DWV

On a scale between -68 to +68, when answers' sums of Questionnaire 8 has been investigated, on-screen virtual environment view and immersive virtual reality view (OSVE-IVR) got +46 for understanding the plan organization of the project, +60 for understanding the human scale and how bit the structures are, +55 for the relations between the rooms, +52 for understanding the circulation, +59 for understanding the interior – exterior relations, +45 for vertical elements such as walls, cladding, and façade, +54 for understanding the openings and their impacts for interiors, +57 for solid – void relation of the façade, +57 for understanding the interior design and furniture organization, +46 for understanding the vertical relations between balconies, slabs overlaps and stairs, +54 for understanding the feeling of the volume, and how would it be like to live inside that environment, +42 for figuring out the overall problems with the project, +45 for figuring out the problems related with the narrow areas and small volumes, +29 for figuring out the problems related with the furniture placements, +30 for suggesting new layouts for overall room relations, +32 for suggesting a new circulation to the project, +37 for suggesting new interior solutions to the project. Additionally, +52 when they asked whether a walkable 3D model was more useful rather than presentation boards or not in terms of understanding the project, +49 for preferring only 3D walkable models to understand the basics of the projects (Table 4.8).

Table 4.8: Answers, Questionnaire 8, for OSVE-IVR

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I understood the plan organization of the project."	Q801	0	1	3	13	17
"I understood the human scale and how big the structure is."	Q802	0	0	1	6	27
"I understood the rooms and their relations with each other's."	Q803	0	0	1	11	22
"I understood the circulation between corridors, stairs, rooms, etc."	Q804	0	2	0	10	22
"I understood interior and exterior space relations."	Q805	0	0	0	9	25
"I understood vertical elements such as walls, cladding, and façade elements."	Q806	0	1	1	18	14
"I understood openings and their impacts for interior."	Q807	0	0	0	14	20
"I understood solid/void relation of the façade."	Q808	0	0	0	11	23
"I understood the interior design and the furniture organization."	Q809	0	1	1	6	26
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Q810	0	0	5	12	17
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q811	0	0	0	14	20
"I figured out overall problems related with the project."	Q812	0	0	3	20	11
"I figured out problems with narrow areas and small volumes."	Q813	0	0	2	19	13
"I figured out wrong furniture placements in the interior areas."	Q814	0	4	8	11	11
"I can suggest a new layout for overall room relations."	Q815	0	2	10	12	10
"I can suggest a new circulation for the project."	Q816	0	1	8	17	8
"I can suggest new solutions for the interior furniture placements."	Q817	0	1	7	14	12
"A walkable 3D model was more useful in terms of understanding the project than presentation boards."	Q818	0	1	3	7	23
"A walkable 3D model was enough for me to understand basics of the project."	Q819	0	0	4	11	19

Answers' amounts of the Questionnaire 8 show when on-screen virtual environment view and immersive virtual reality view used together, almost all students indicates OSVE and IVR as a useful tool to understand every aspect of the project. More than 80% of the students preferred the bundle of OSVE-IVR for understanding of the organization of the project, human scale, structure size, rooms' relations, circulation, interior – exterior relations, vertical surfaces, openings, their impacts for interiors, solid – void of the façade, interior design, furniture organizations, vertical relations of horizontal surfaces, and figuring out the problems related with the overall project, narrow areas, and small volumes (Q801, Q802, Q803, Q804, Q805, Q806, Q809, Q810, Q811, Q812, Q814 in Figure 4.17). On the other hand, more than 60% of the students indicated OSVE-IVR views are useful to figure out the wrong furniture placements, suggest new layouts for overall room relations, new circulations, and new solutions for interior furniture placements (Q814, Q815, Q816, and Q817 in Figure 4.17). Last, almost 80% of the students said a walkable 3D model was more useful than the presentation boards and they only a virtual model is enough for them to understand the basics of the projects (Q818, Q819 in Figure 4.17).

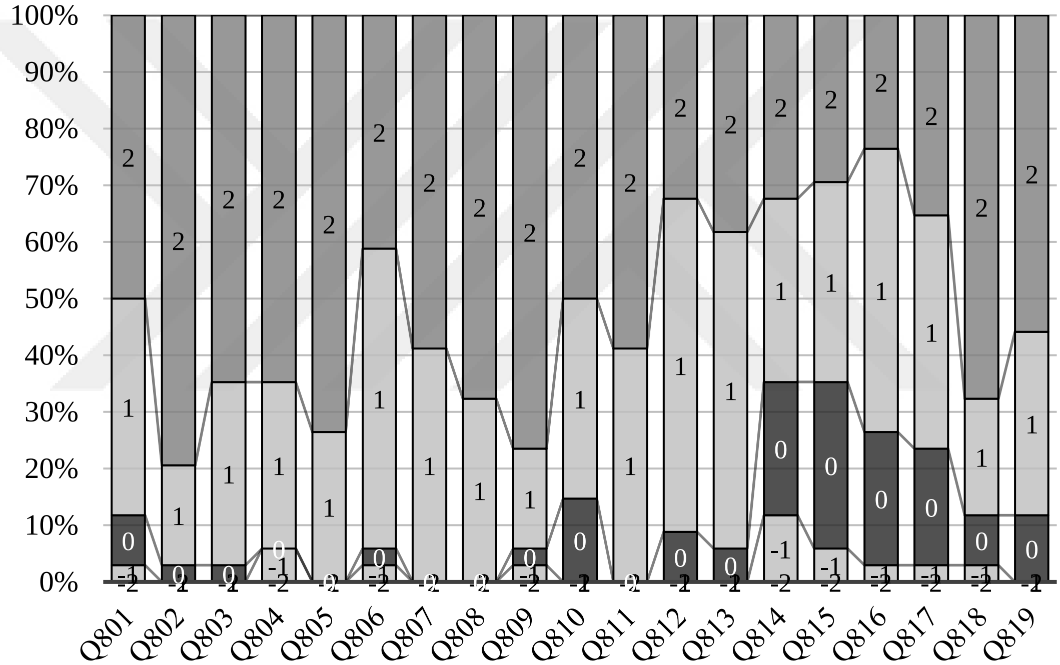


Figure 4.17: Answers, Questionnaire 8, for OSVE-IVR

When majority of the answers of Questionnaire 9 has been observed, on a comparison between DPB-DWV and OSVE-IVR, students indicated both DPB-DWV and OSVE-IVR for understanding the plan organization of the project, OSVE-IVR for understanding the human scale and how bit the structures are, the relations between the rooms, understanding the circulation, understanding the interior – exterior relations, vertical elements such as walls, cladding, and façade, understanding the openings and their impacts for interiors, solid – void relation of the façade, understanding the interior design and furniture organization, understanding the vertical relations between balconies, slabs overlaps and stairs, understanding the feeling of the volume, and how would it be like to live inside that environment, figuring out the overall problems with the project, the problems related with the narrow areas and small volumes, the wrong furniture placements in interior areas, for suggesting new layouts for overall room relations, a new circulation to the project, new interior solutions to the project is preferable than the other. Additionally, DPB-DWV is considered as more useful to understand the total closed area of the project, OSVE-IVR is preferred to understand the amount of the volumes in the project, and navigating in the project for both understanding the overall project, interior spaces and their impacts on the person using it (Table 4.9).

Table 4.9: Answers, Questionnaire 9, Comparative

Question	*Q*	*DPB DWV*	*OSVE IVR*
Which one is more effective to understand plan organization of the project?	Q901	15	15
Which one is more effective to understand human scale and how big the building is?	Q902	4	26
Which one is more effective to understand the rooms and their relations with each other's?	Q903	9	21
Which one is more effective to understand the circulation between corridors, stairs, rooms, etc.	Q904	7	23
Which one is more effective to understand interior and exterior space relations?	Q905	5	25
Which one is more effective to understand vertical elements such as walls, cladding, and façade elements?	Q906	7	23
Which one is more effective to understand openings and their impacts for interior?	Q907	6	24
Which one is more effective to understand solid/void relation of the façade?	Q908	5	25
Which one is more effective to understand the interior design and the furniture organization?	Q909	6	24
Which one is more effective to understand vertical relations between balconies, stairs, slab overlaps, etc.	Q910	8	22
Which one is more effective to understand the volume, how it feels, how would it be like to live inside that environment.	Q911	0	30
Which one is more effective to understand overall problems related with the project.	Q912	11	19
Which one is more effective to understand problems with narrow areas and small volumes?	Q913	4	26
Which one is more effective to understand wrong furniture placements in the interior areas?	Q914	9	21

Question	*Q*	*DPB DWV*	*OSVE IVR*
Which one is more effective to evaluate the project and suggest a new layout for overall room relations?	Q915	12	18
Which one is more effective to evaluate the project and suggest a new circulation for the project?	Q916	12	18
Which one is more effective to evaluate the project and suggest new solutions for the interior furniture placements?	Q917	9	21
Which one eases to understand the square meter of total closed area of the project?	Q918	16	14
Which one eases to understand how many volumes are there?	Q919	9	21
Which one is easier to navigate for understanding the overall project?	Q920	10	20
Which one is easier to navigate for understanding the interior areas and impact of them?	Q921	3	27

When answers' amounts compared between DPB-DWV and OSVE-IVR views, virtual walkable models and their perceivability by students is higher in all cases. More than 50% of the students selected OSVE-IVR in each question. Especially the question related with the understanding of the impact of the space on the person, and how would it be like to live inside that environment answered 100% as OSVE-IVR (Q911 in Figure 4.18). However, understanding the plan organization of the project and the total square meter of the project seemed to be equal in both DPB-DWV and OSVE-IVR views (Q901, Q918 in Figure 4.18) On the other hand, walkable virtual 3D models preferred more than 80% for understanding the human scale, size of the structure, interior – exterior space relations, the openings, their impacts for the interior, solid – void relation of the façade, interior design, furniture organization, problems with narrow areas, small volumes, and navigate to understand the interior areas and their impacts (Q902, Q905, Q907, Q908, Q909, Q913, Q921 in Figure 4.18). In contrast, even if the preference of OSVE-IVR is more than DPB-DWV, it seems less effective than others for questions related with suggesting new layouts, organizations, solutions for different aspects of the projects (Q914, Q915, Q916, and Q917 in Figure 4.18).

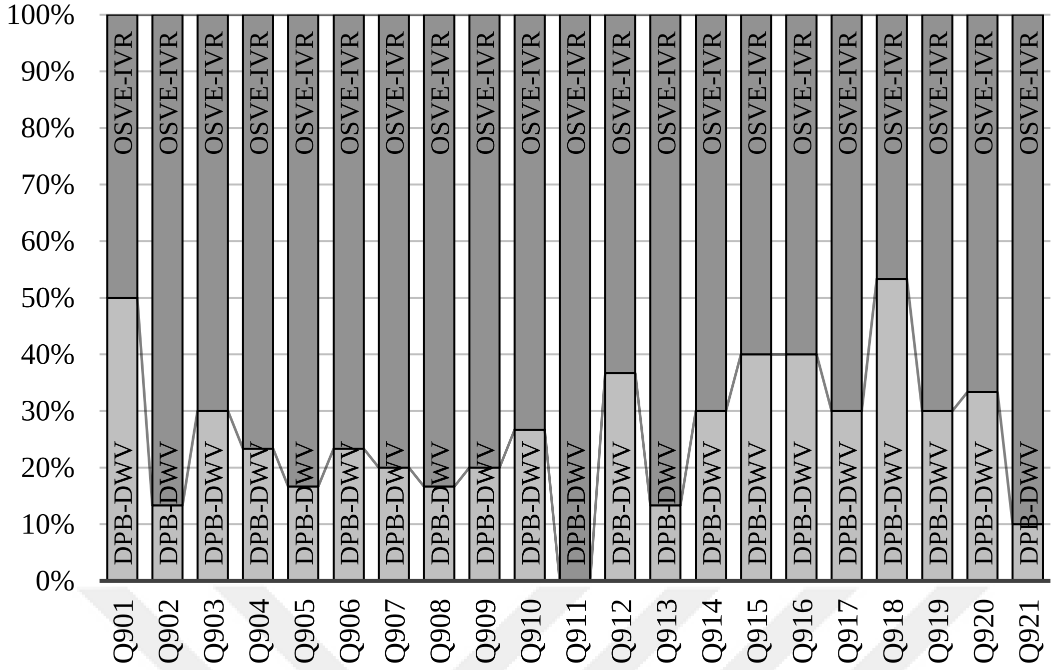


Figure 4.18: Answers, Questionnaire 9, Comparative

4.5. RESULTS OF EXPERIMENT 4

After initial experiment of installation (Experiment 1) where students met with virtual environments for the first time, and two major experiments related with the advantages and disadvantages of different virtual architectural representation methods (Experiment 2 and Experiment 3), last experiment designed as a series of experiments. The current study focused on the investigation of the use of virtual tools on architectural feedback process among distant members. Students were asked to develop their projects throughout 4 virtual classes, share within a randomly generated list, give feedback to each other's and revise their projects accordingly. For the process and its measurements related with the feedback process and understanding of the projects, students have been asked Questionnaire 10, 11, 12, 13, and 14. Each week, students were expected to develop a different aspect of their design studio projects, which created the 4 different phases of the experiment. At first, along with the schedule of students' design studios, they have been asked to develop their initial mass models. After the virtual feedback process, Questionnaire 10 applied to the attendees. Second phase of the experiment was to generate the volumes inside the masses with horizontal and vertical surfaces. Later, students shared the models between themselves and answered Questionnaire 11. As the third phase of the Experiment 4, due to large sizes of the projects, students were asked to choose a part of their design, develop the interior organization and everything related with the space itself. Later, they shared their partial space models with each other's virtually and handled a feedback process again. At the end of this phase, students took Questionnaire 12. All three phases were to understand if students were able to give reasonable feedbacks. Last phase of the Experiment 4 was a communication exercise, where students went back to their old feedbacks, answer the reviews, write down new reviews and continue the virtual critique sessions. After this process, two different questionnaires were applied to students, Questionnaire 13 to measure the effectiveness of giving virtual reviews, and Questionnaire 14 to measure the influences of virtual reviews to students' projects. Questionnaire 10, 11, and 12 answered multiple times by students for different projects, due to this reason, answer scales change between questionnaires. However, each student filled in Questionnaire 13, and 14 once. Since students created the virtual models and they observed them from distant, technical errors might cause distortion in the results.

4.5.1. EXPERIMENT 4.1

After the process of reviewing initial mass models, 146 answers collected by the students. Since it was the mid-term exam of the course, all students attended the experiment. They all filled the questionnaire multiple times and left no answer empty. When all answers summed up, minimum and maximum value an answer can get sets up a range between -292 and +292. On this scale, the satisfactoriness for descriptions to be enough to understand the idea of the project got +140, adequateness of mass models students created and looked at got +161, understanding of the projects' mass organizations got +148, and being able to give reasonable reviews for the projects' developments in future steps got +127 (Table 4.10).

Table 4.10: Answers, Questionnaire 10

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I did read the description and it was enough for me to understand the idea of the project."	Q1001	1	9	27	67	42
"I know how a mass/planar model should be like, the model I reviewed was adequate as one."	Q1002	1	3	24	70	48
"I understood the project's mass organization."	Q1003	0	10	25	64	47
"I was able to give reasonable reviews to help project development in the future steps."	Q1004	1	10	30	71	34

When students' answer amounts investigated further, almost more than 70% of the answers were positive for all questions. However, being able to give reasonable feedback for the projects got the most negative and noncommittal answers from the students (Q1004 in Figure 4.19). Adequateness of the mass models and understanding of the projects' mass organizations got the most positive answers from the students (Q1002, Q1003 in Figure 4.19). On the other hand, none of the questions answered negative more than 10% (Figure 4.19).

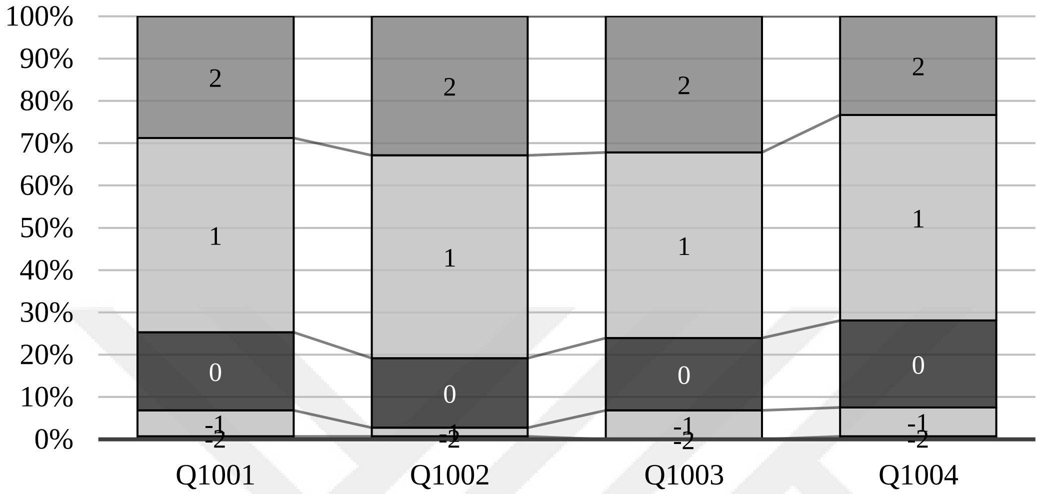


Figure 4.19: Answers, Questionnaire 10

Out of 146 answers, when the missing things in the mass models have been asked the students, they answered as sidewalks, parks, and cars as the missing elements in the models most of the time. Also, necessary surfaces of the masses and vehicle roads are also considered as major incomplete essentials of the virtual models. Other primary missing elements were trees, human figures, and necessary idea elements (Figure 4.20).

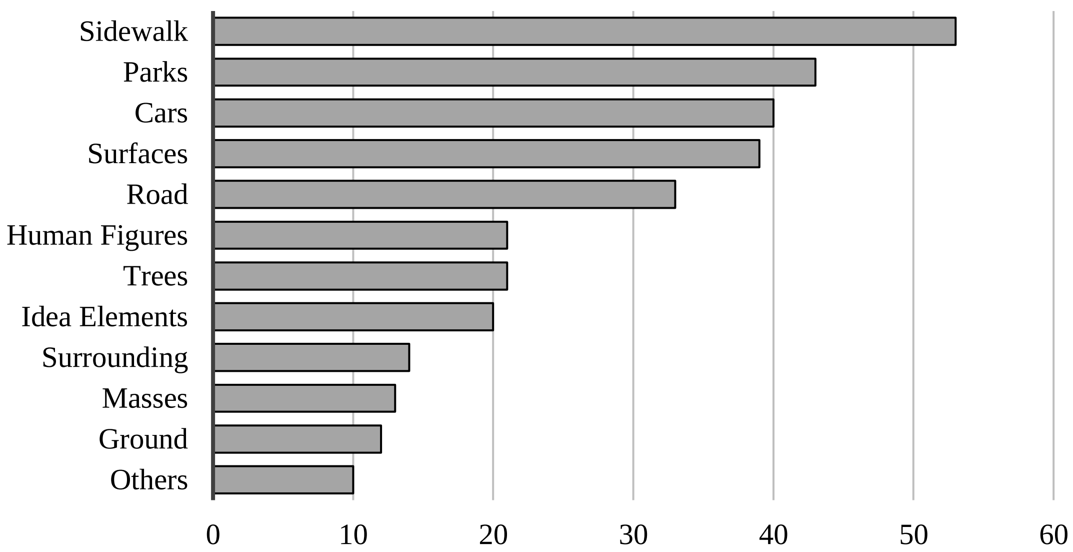


Figure 4.20: Answers, Questionnaire 10, Missing Elements in the Models

Another focus of the questionnaire was to collect data about the subjects of the reviews students made for their friends' projects' mass models. Out of 146 answers, when asked in Questionnaire 10, students indicated they asked questions related with the quality of 3D modelling, masses relation with the idea, organization of the mass primarily. Second most popular review subjects were the masses relation with the surrounding, sizes of the masses and defined circulations. Some students also answered the question as they gave feedback related with the human scale (Figure 4.21).

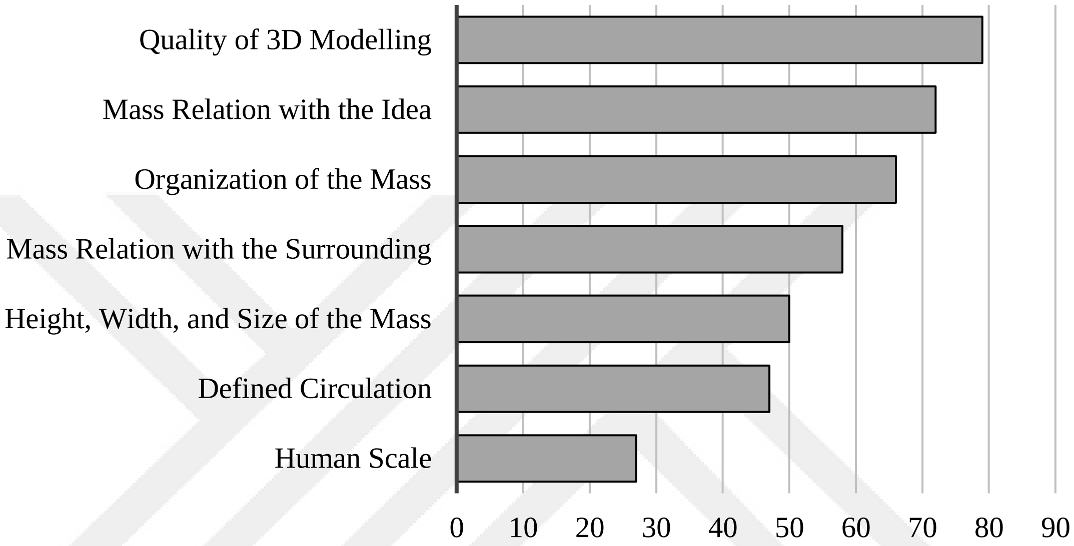


Figure 4.21: Answers, Questionnaire 10, Subjects of the Reviews

As mentioned before, since the course happen to be in an experimental approach, students were asked to grade their friends' 3D modelling for virtual collaboration related with their projects. The average of the grades' students gave to each other's was 77. Only few of the answers indicated students to have less than 60 as a grade. No project had a grade lower than 40. Therefore, students' 3D digital mass models can be accepted as adequate ones (Figure 4.22).

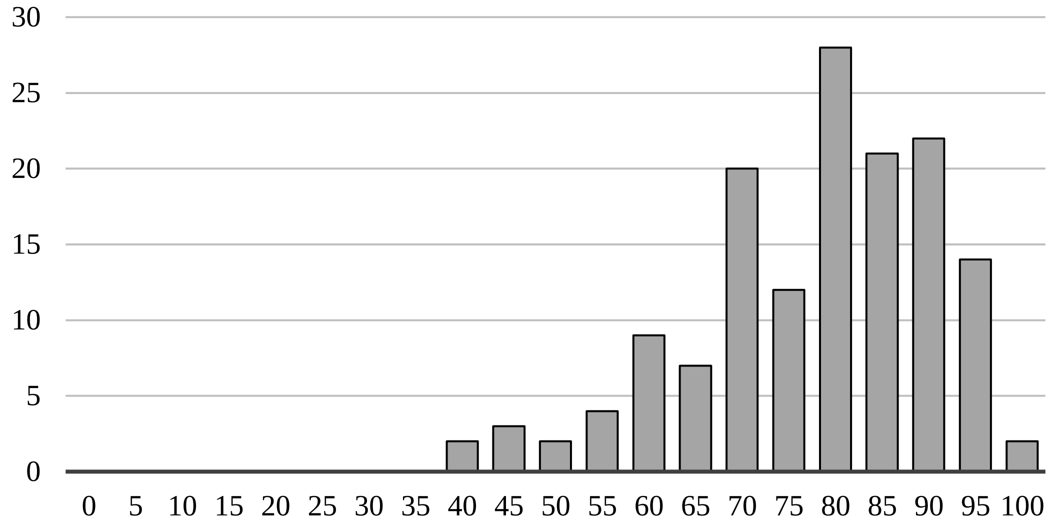


Figure 4.22: Answers, Questionnaire 10, Grade

4.5.2. EXPERIMENT 4.2

42 virtual attendees executed the experiment from distant. After their evaluation and feedback process ended in KeplerVR, students gave 126 answers in total for Questionnaire 11 (Figure 4.23).

Figure 4.23: Students Executing Experiment 4.2

When all answers summed up, minimum and maximum value an answer can get sets up a range between -252 and +252. Within this scale, students evaluated the process with +90 for satisfactoriness of the description to understand the idea of the project, +92 for assessing the models they looked at as adequate 3D digital models, +110 for understanding the mass organization of the project, +102 for being able to give reasonable reviews to help projects' further development, +72 for understanding the plan organization of the project, +115 for understanding the size of the structure and human scale, +63 for understanding the rooms and their relations, +75 for understanding the circulation, +66 for understanding the interior – exterior relations, +88 for understanding the vertical surfaces such as walls, cladding and façade elements, %57 for understanding the openings and their impacts for the interior, %85 for understanding the solid – void relations of the façade, -1 for understanding the interior design and furniture organization, +72 for understanding the vertical relations of slabs overlaps, balconies, stairs etc., +66 for understanding the volume and how would it be like to live inside that environment, +105 for figuring out the overall problems related with the project, +95 for figuring out the problems with narrow areas and small volumes, +33 for figuring out the wrong furniture placements, +50 for suggesting new layouts for the rooms, +60 for suggesting a new circulation for the project, and +56 for suggesting new solutions for interior furniture organization (Table 4.11).

Table 4.11: Answers, Questionnaire 11

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I did read the description and it was enough for me to understand the idea of the project."	Q1101	13	9	18	47	39
"I know how a 3D digital model should be like, the model I reviewed was adequate as one."	Q1102	7	14	24	42	39
"I understood the project's mass organization."	Q1103	6	14	9	58	39
"I was able to give reasonable reviews to help project development in the future steps."	Q1104	7	8	22	54	35
"I understood the plan organization of the project."	Q1105	9	13	33	39	32
"I understood the human scale; how big the structure is."	Q1106	10	7	14	48	47
"I understood the rooms and their relations."	Q1107	16	11	25	42	32
"I understood the circulation between corridors, stairs, rooms, etc."	Q1108	12	18	16	43	37
"I understood interior and exterior space relations."	Q1109	16	17	16	39	38
"I understood vertical elements such as walls, cladding, and façade elements."	Q1110	13	14	14	42	43
"I understood openings and their impacts for interior."	Q1111	16	15	21	44	30
"I understood solid/void relation of the façade."	Q1112	12	14	18	41	41

Question	Q	-2	-1	0	1	2
"I understood the interior design and the furniture organization."	Q1113	24	28	24	25	25
"I understood vertical relations between balconies, stairs, slab overlaps, etc."	Q1114	11	16	24	40	35
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q1115	14	10	22	56	24
"I figured out overall problems related with the project."	Q1116	7	6	24	53	36
"I figured out problems with narrow areas and small volumes."	Q1117	9	6	30	43	38
"I figured out wrong furniture placements in the interior areas."	Q1118	18	15	38	26	29
"I can suggest a new layout for overall room relations."	Q1119	13	13	38	35	27
"I can suggest a new circulation for the project."	Q1120	10	14	37	36	29
"I can suggest new solutions for the interior furniture placements."	Q1121	14	13	31	39	29

When answers' amounts investigated further, Experiment 2 and full sized project models with created volumes shows OSVE and IVR views seemed to be useful to create the connection between the description of the project and the created masses, volumes, understanding the overall 3D digital creation, understanding the mass organization of the project, to give reasonable reviews for helping further developments in the project, understanding the human scale and the size of the structure, vertical elements such as walls, cladding, façade elements etc., and figuring out the overall problems related with narrow areas and small volumes since around 70% of the answers were positive (Q1101, Q1102, Q1103, Q1104, Q1106, Q1110, Q1116 in Figure 4.24). Also, understanding the plan organization, rooms and their relations, the circulation, interior – exterior space relations, openings and their impacts for interiors, solid – void relations of the façade, vertical relations of horizontal surfaces, the feeling of living inside that environment, and figuring out the problems related with narrow areas and small volumes also possible with OSVE and IVR views since the answers were positive in the range of 50% and 65% (Q1105, Q1107, Q1108, Q1109, Q1111, Q1112, Q1114, Q1115 in Figure 4.24). Since the primary focus of this experiment was to evaluate the volumes in overall masses for all the project, interior spaces left blank from most of the students (Figure 4.25). Due to this extend, understanding the interior design, furniture and placeholder placement, figuring out problems related with the furniture organization and suggesting new interior solutions were not sufficient within the scope of this experiment, as results also indicated (Q1113, Q1118, Q1121 in Figure 4.24). On the other hand, even if majority of students concluded positively, when compared with other questions' answers, suggesting new layouts and circulations for the project seemed to be less feasible since 30% of the students were noncommittal, and another 20% answered negatively (Q1119, Q1120 in Figure 4.24).

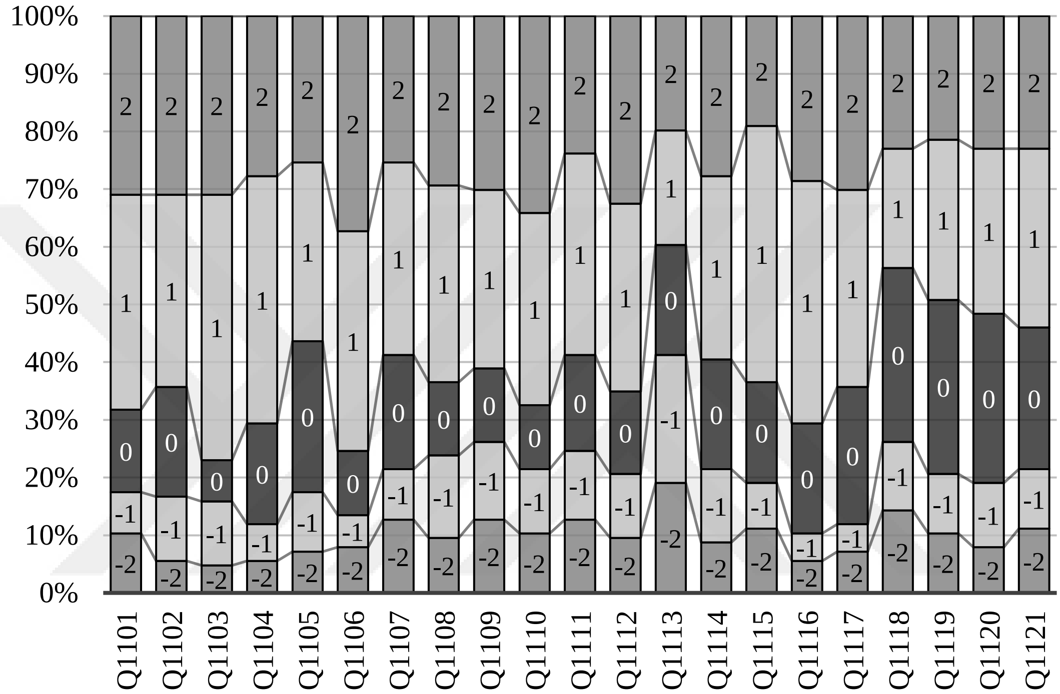


Figure 4.24: Answers, Questionnaire 11

When students were asked to designate the missing essentials of the 3D digital models they observed, out of 126 answers, most commonly made mistake was the lack of putting human figures, cars, trees, sidewalks indicated more than 70 times and furnishing, parks and roads which all got indicated more than 50 times. Secondary mistakes observed as placeholders, glazing, necessary modelling for idea related elements, surroundings, surfaces, ground, and masses (Figure 4.25).

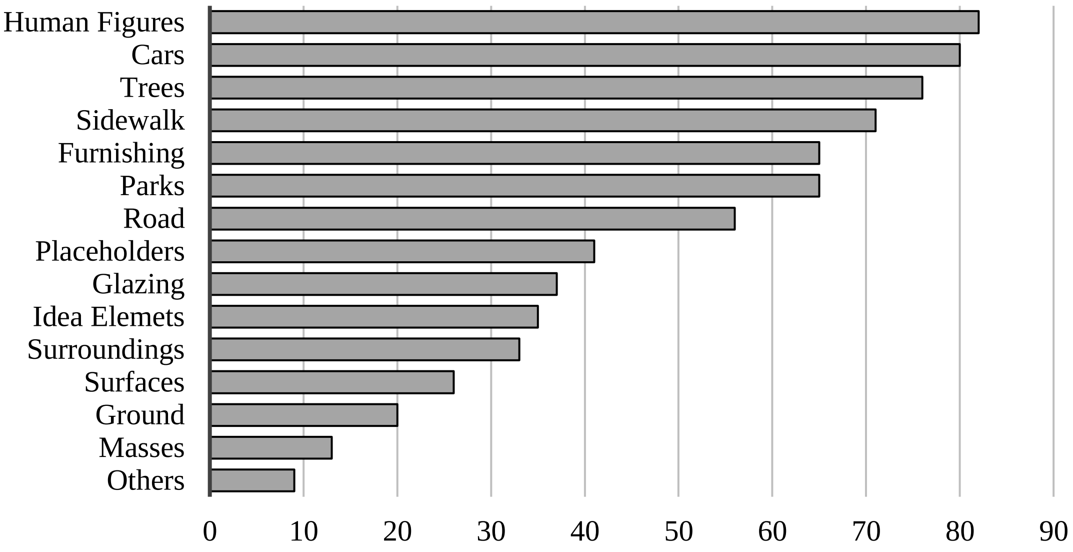


Figure 4.25: Answers, Questionnaire 11, Missing Elements in the Models

For evaluating the projects, students also indicated the subjects of their reviews. Out of 126 answers, most significant subject of the reviews was quality of 3D modelling. However, students also pointed out problems related with the organization of the project, interior organization, projects relation with the idea and surrounding, defined circulation and façade design more than 40 times. Other major topics for the reviews were created volumes, height, width, and size of the proposal, human scale and the scale of the project (Figure 4.26).

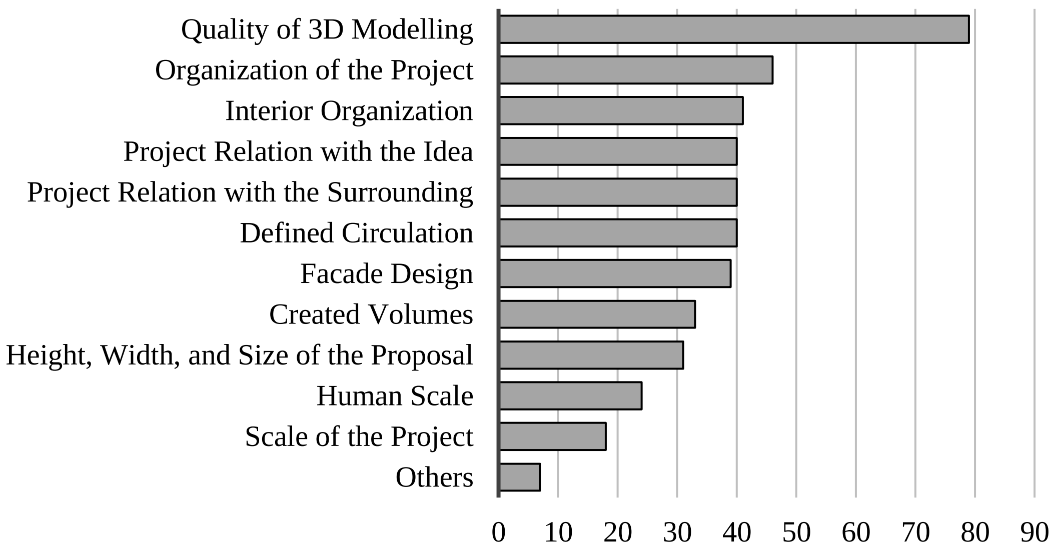


Figure 4.26: Answers, Questionnaire 11, Subjects of the Reviews

Compare the previous phase of the experiment, students' grades for each other's was lower this time. Average grade of all class was 68. However, since there were 4 answers indicating 0, 3 answers indicating 20, and 2 answers indicating 30 and review subjects were about the quality and validity of the 3D digital models, this may occurred due to technical problems and data exchange process (Figure 4.27). Also, upon the verbal investigation among students, instead of grading the virtual creations and their influences for the development process, students got involved with the design ideas and architectural solutions for this experiment.

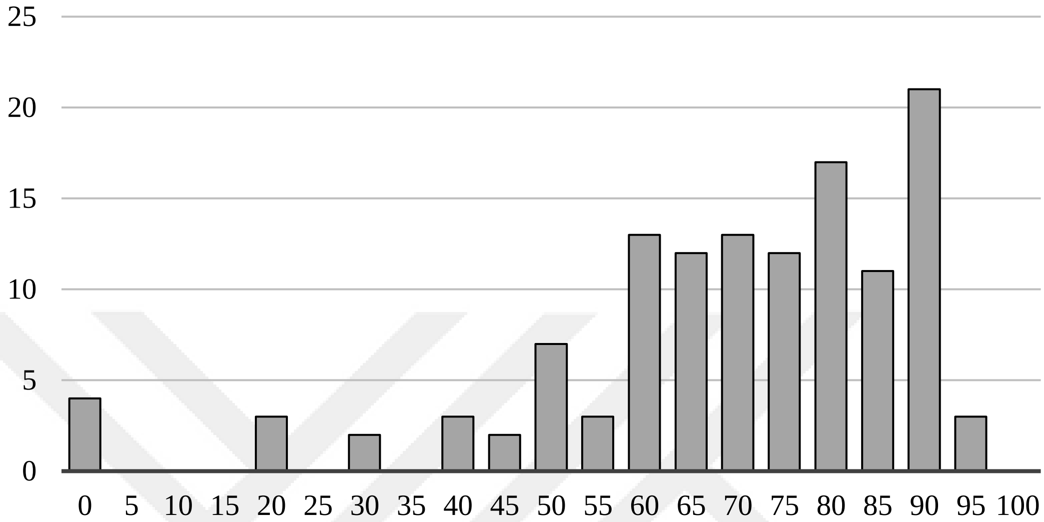


Figure 4.27: Answers, Questionnaire 11, Grades

4.5.3. EXPERIMENT 4.3

Third phase of Experiment 4 based on a partial space of students' choices in their projects. They developed a 3D digital model for selected volume. After evaluation and feedback process, Questionnaire 12 has been applied.

Figure 4.28: Students Executing Experiment 4.3

Students filled the form multiple times for different projects. 87 answers have been collected from the students with no empty answer. When all answers summed up, minimum and maximum value an answer can get sets up a range between -174 and +174. Within this scale, students evaluated the process with +101 for satisfactory level of the description for understanding the idea of the volume, +78 for adequateness of 3D digital modelling, +88 for understanding the volume, +104 for being able to give reasonable reviews for further developments of the volume, +88 for understanding the plan organization of the volume, +97 for understanding the human scale and building size, +75 for understanding the furniture, objects, and their relations, +80 for understanding the circulation in the volume, +92 for understanding the vertical elements, +85 for understanding openings and their impacts for interior, +101 for understanding the solid – void relations of the surfaces, +69 for understanding the interior design and furniture organization, +85 for understanding how would it be like to be inside that volume, +82 for figuring out the overall problems related with the volume, +65 for figuring out the problems with narrow areas and small volumes, +54 for figuring out the wrong furniture placements, +73 for suggesting new volume to inhabit such function, +85 for suggesting changes on the surfaces to improve the efficiency of the function, +82 for suggesting new solutions for interior furniture placements, -7 for the difficulty of navigation due to organization of the furniture, +20 for not being able to understand the volume due to missing necessary elements, +88 for pointing out the problems related with the volume in the reviews, +71 for offering new solutions for the specific needs of the volume with the reviews, and +87 for placing reviews related with the 3D modelling quality. Additionally, the questionnaire had a different section than others where students were asked to describe the feeling spaces created on them such as small, narrow, depressing, extraordinary, refreshing, comfortable, cold, and dark. Since negative answers of these questions also defines a feeling, disagreement and strongly disagreement of students accepted as positive as an outcome. When all answers' absolutes summed up, minimum and maximum value an answer can get sets up a range between 0 and +174. On this scale, students' feelings for the spaces were +154 for whether small or large, +94 for whether narrow or wide, +94 for being depressing or not, +73 for being extraordinary or dull, +64 for being refreshing or not, +58 for being comfortable or not, +65 for being cold or warm, +93 for being dark or bright (Table 4.12).

Table 4.12: Answers, Questionnaire 12

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"I did read the description and it was enough for me to understand the idea of the project."	Q1201	2	3	12	32	38
"I know how a 3D digital model should be like, the model I reviewed was adequate as one."	Q1202	3	9	10	37	28
"I understood the surface organization of the volume."	Q1203	2	6	12	36	31
"I was able to give reasonable reviews to help project development in the future steps."	Q1204	1	1	11	41	33
"I understood the plan organization of the selected volume."	Q1205	2	6	13	37	29
"I understood the human scale; how big the selected volume is."	Q1206	1	5	12	34	35
"I understood the objects, furniture and their relations."	Q1207	3	8	11	41	24
"I understood the circulation between corridors, stairs, rooms, etc. in the volume"	Q1208	2	6	13	42	24
"I understood vertical elements such as walls, glazing elements etc."	Q1209	1	4	13	40	29
"I understood openings and their impacts for interior."	Q1210	2	5	13	40	27
"I understood solid/void relation of the surfaces."	Q1211	0	3	12	40	32
"I understood the interior design and the furniture organization."	Q1212	3	9	17	32	26
"I understood the volume, how it feels, how would it be like to live inside that environment."	Q1213	0	3	18	44	22
"I figured out overall problems related with the selected volume."	Q1214	0	2	22	42	21
"I figured out problems with narrow areas and small volumes."	Q1215	3	9	20	30	25
"I figured out wrong furniture placements in the interior areas."	Q1216	5	9	21	31	21
"I can suggest a new volume to inhabit such function."	Q1217	0	8	18	41	20
"I can suggest changes on surfaces to improve the functions effect."	Q1218	0	3	22	36	26
"I can suggest new solutions for the interior furniture placements."	Q1219	0	3	23	37	24
"It was hard to navigate in the space because of the furniture."	Q1220	13	21	24	18	11
"I was not able to understand the volume because of the missing elements."	Q1221	7	22	19	22	17

Question	Q	-2	-1	0	1	2
"The volume was small."	Q1222	17	34	13	14	9
"The volume was narrow."	Q1223	13	33	14	19	8
"The volume was depressing."	Q1224	11	39	13	15	9
"The volume was extraordinary."	Q1225	10	19	30	22	6
"The volume was refreshing."	Q1226	2	13	31	35	6
"The volume was comfortable."	Q1227	1	9	35	37	5
"The volume was cold."	Q1228	2	26	34	15	10
"The volume was dark."	Q1229	19	32	18	13	5
"I pointed out problems related with the project in my reviews."	Q1230	0	2	20	40	25
"I offered new solutions for specific needs of the volumes with my reviews."	Q1231	0	3	27	40	17
"I made reviews for the quality of 3D modelling."	Q1232	1	4	19	33	30

Answers of the first segment of Questionnaire 13 indicates students felt comfortable with the partial 3D digital models to understand the specified volumes in their friends' projects. More than 80% of the answers were positive for satisfactory level of descriptions to understand the idea of the volumes, being able to give reasonable reviews, understanding the human scale, volume size, vertical surfaces, and solid – void relations of the surfaces (Q1201, Q1204, Q1206, Q1209, and Q1211 in Figure 4.29). When difficulty of navigation in the volumes with furniture and placeholders have been asked to students, answers indicated 30% of the students struggled with navigation (Q1220 in Figure 4.29). 45% of the students also indicated missing elements such as furniture, placeholders, surfaces etc. affected their understanding of the volume negatively (Q1221 in Figure 4.29). Other aspects of volumetric feedback process answered between the 70% and 80% by the students, such as adequateness of 3D digital models, understanding of the surface organization, plan organization of the volume, object – furniture relations, circulation, openings, their impacts for the interior, how would it be like to live inside that environment, figuring out the problems related with the volume, and making reviews related with the quality of 3D digital modelling (Q1202, Q1203, Q1205, Q1207, Q1208, Q1210, Q1213, Q1214, and Q1232 in Figure 4.29). Additionally, positive outcomes of the answers continue as understanding the interior design and furniture organization, figuring out the problems with narrow areas and small volumes, wrong furniture placements, suggesting new volumes for such functions, changes on the surfaces, and new solutions for interior furniture organizations within 60% and 70% range (Q1212, Q1215, Q1216, Q1217, Q1218, and Q1219 in Figure 4.29). Reviews made by students specified problems related with the projects by 75% and offered new suggestions for project owners to evaluate by 65% (Q1230, and Q1231 in Figure 4.29)

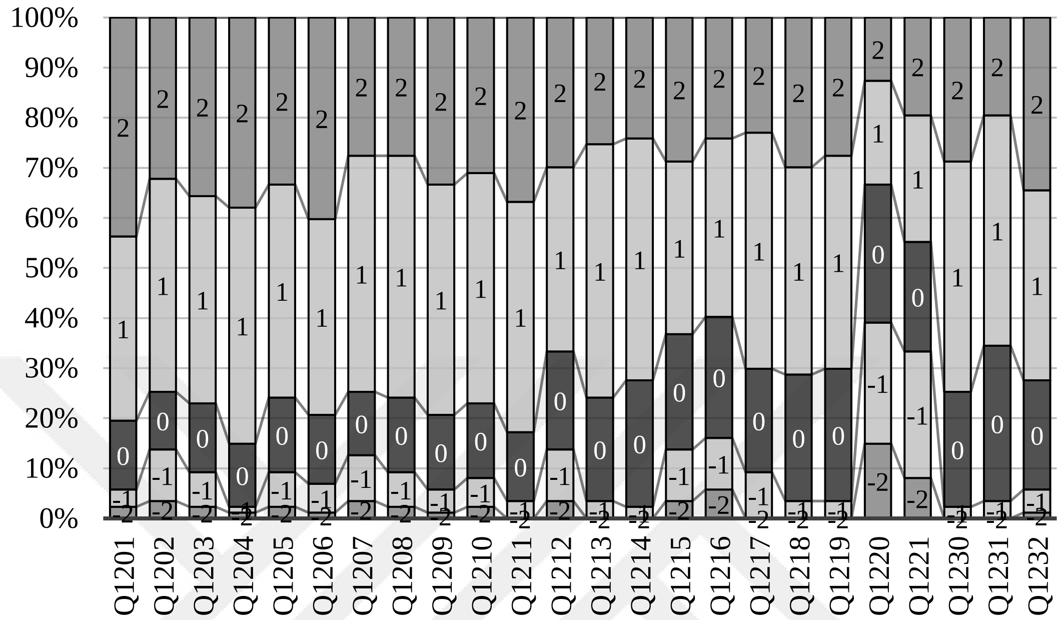


Figure 4.29: Answers, Questionnaire 12

Another aspect of the experiment and Questionnaire 12 was to measure whether students perceived any attribute related with the volume just by spending time with IVR view in their friends' projects. Due to this search, eight questions have been asked to students. Since those questions were about the specified feelings students had or their opposites, both positive and negative answers counted as an outcome that shows they had a feeling about the volumes. Therefore, only neutral answers match with not feeling anything in the 3D digital models. When answers of the questionnaire have investigated further, features such as being small, narrow, depressing, dark or their opposites were the most certain feelings students had in the immersive virtual reality since the noncommittal answers were below 20% for these questions (Q1222, Q1223, Q1224, and Q1229 in Figure 4.30). However, even if feelings such as observing an extraordinary, refreshing, comfortable, cold and opposites got responsive feedback, noncommittal answers were around 40% for those questions (Q1225, Q1226, Q1227, and Q1228 in Figure 4.30).

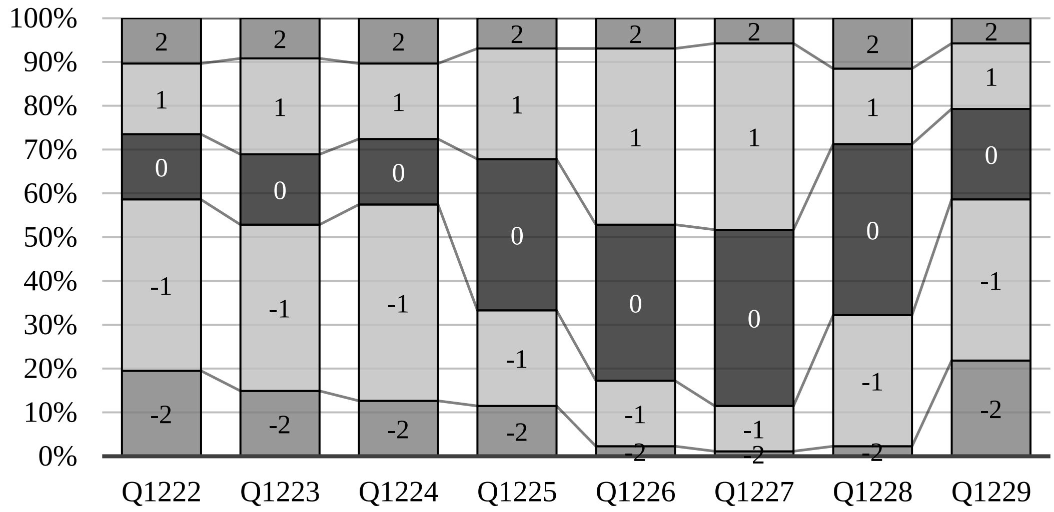


Figure 4.30: Answers, Questionnaire 12, Spatial Feeling

Students were free to choose whatever volume they want in their own design studio projects. Therefore, their selections and volume types asked. They could select more than one answer since their volumes may contain multiple functions. Students choose public spaces most of the time including café, restaurant, exhibition hall, open areas, and non-defined public spaces. Houses as private spaces and circulation areas were also one of the primary volumes that the students evaluated. Secondary choice of students to generate partial space models were foyer, library, waiting halls as public spaces, workshops, other non-defined commercial spaces, and classrooms as private spaces. Also, students choose non-defined private spaces, accommodation areas, hall, meeting rooms, offices, markets, stand, and a museum to show to their friends (Figure 4.31).

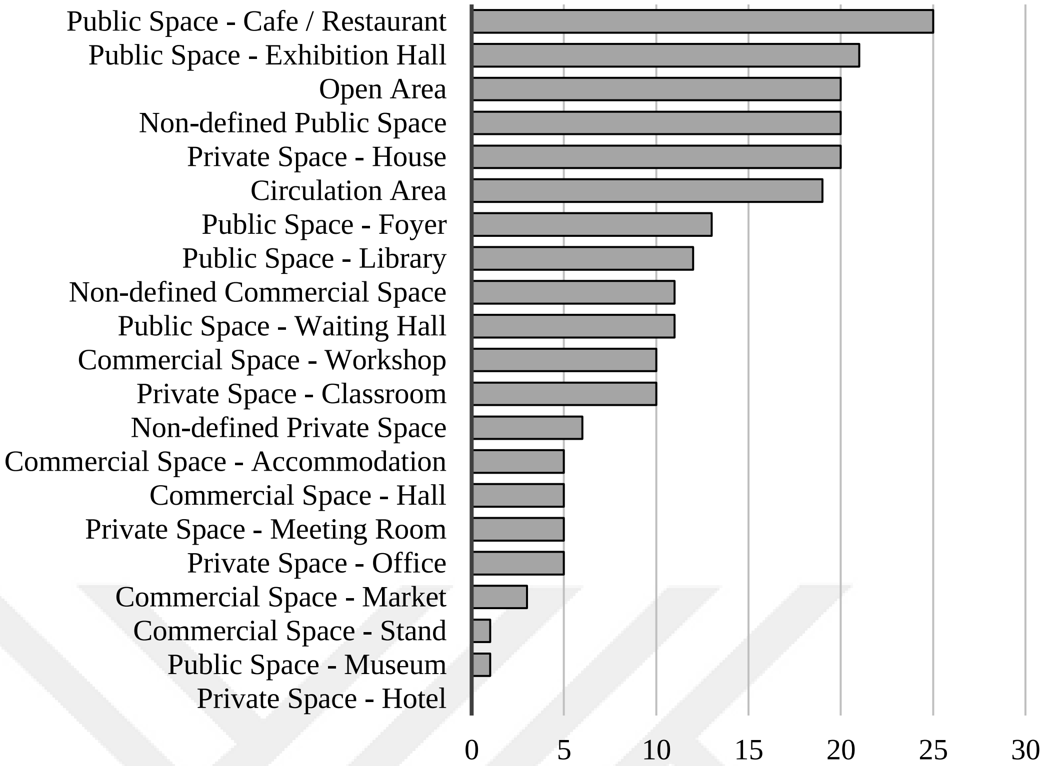


Figure 4.31: Answers, Questionnaire 12, Functions of the Selected Volumes

When students were asked to specify what was missing in the 3D digital models, out of 87 answers students answered human figures for 35 times, glazing elements as 28 times, and furnishing as 26 times. They also indicated placeholders, necessary elements for executing the design ideas, and surfaces were missing in the models (Figure 4.32).

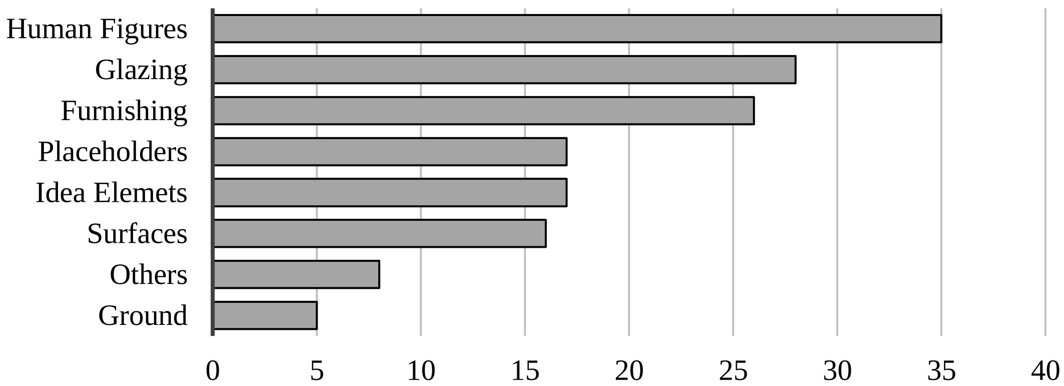


Figure 4.32: Answers, Questionnaire 12, Missing Elements in the Models

Another question was presented to students to measure what types of reviews they gave to each other's. Out of 87 answers, students indicated they choose quality of 3D modelling for 50 times, volumes' relations with the idea for 41 times, and interior furniture organization for 32 times as subjects of reviews they made. Other most popular review topics were defined circulation, façade design, created volumes, and scale of the volume (Figure 4.33).

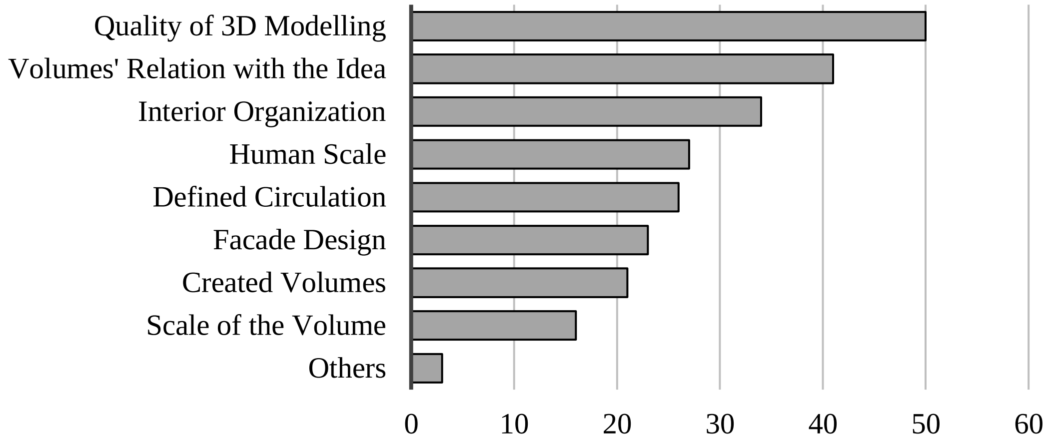


Figure 4.33: Answers, Questionnaire 12, Subjects of the Reviews

Since students were grading each other's throughout Experiment 4, as the last grading for the semester, the grades they gave are demonstrated in Figure 4.34. Average of the class was 77 for this experiment which is suitable for an assignment. While most of the grades stayed in between 75 and 85, minimum and maximum grades defined as 45 and 95 (Figure 4.34).

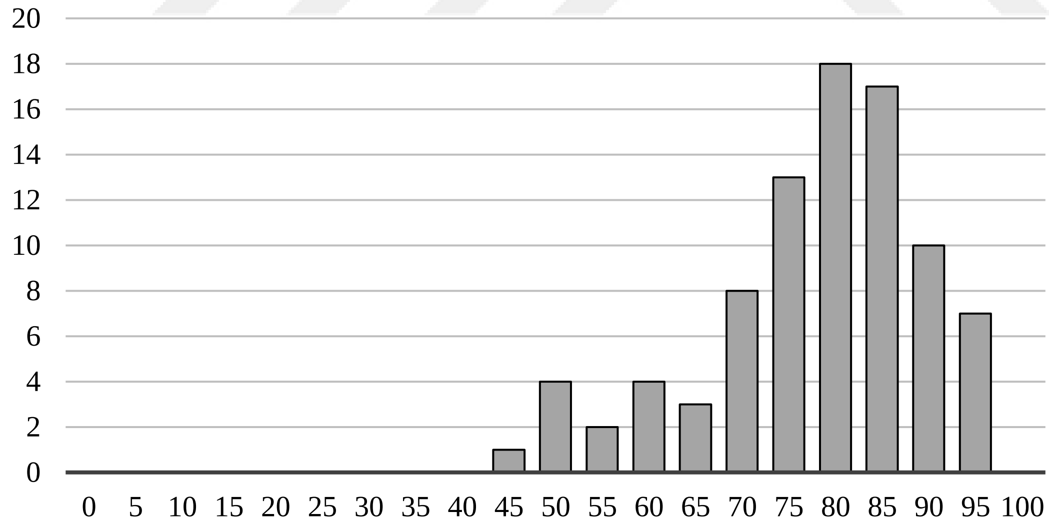


Figure 4.34: Answers, Questionnaire 12, Grades

4.5.4. EXPERIMENT 4.4

Last phase of Experiment 4 has been designed to measure the collaboration in virtual environments using OSVE and IVR views among distant students related with different aspects of their feedback process. Therefore, two separate questionnaires presented to students, Questionnaire 13 (Table 4.13) to measure the process of giving feedback and Questionnaire 14 (Table 4.14) for measuring the effectiveness of received feedbacks and reviews from students, as well as their influences on their design studio projects. All students could fill in the first questionnaire, but second questionnaire was only available for those who have design studios. Therefore, students assigned as reviewers since the beginning of the semester did not fill in second questionnaire.

Figure 4.35: Students Executing Experiment 4.4, Distant Feedback Process

In total 44 students took the first questionnaire. When all answers summed up, minimum and maximum value an answer can get sets up a range between -88 and +88. Within this range, process of giving reviews in OSVE and IVR to other students' 3D digital models got +38 for adequateness of the descriptions to explain the models, +41 for adequateness of 3D digital models to evaluate, +42 for the understanding the connection between the descriptions and the models. +62 for being able to give feedback, +46 for helpfulness of the reviews students made, +45 for giving reviews related with the implementation of the idea to the models, +54 for the difficulty to creating reviews on the surfaces, +53 for efficiency of specifying the problems with a point on surfaces, +43 for the continuity of the conversations through 3D digital model, +56 for usefulness of the virtual environments for communicating distantly, +63 for pointing out the problems related with the projects in the reviews, +50 for offering new solutions to the specific needs with the reviews, +57 for making reviews about the quality of 3D digital modelling (Table 4.13).

Table 4.13: Answers, Questionnaire 13

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"Descriptions were adequate to describe the projects."	Q1301	0	4	6	4	8
"Models were adequate to evaluate."	Q1302	0	2	6	2	7
"I understood the project and description, which created enough knowledge for me to evaluate the project."	Q1303	0	1	9	1	9
"I was able to give feedback."	Q1304	0	1	1	1	21
"Reviews I gave were helpful for developing the projects."	Q1305	0	1	10	1	14
"I gave reviews about the implementation of the idea in description to the project."	Q1306	0	1	11	1	14
"It was easy to create reviews on surfaces."	Q1307	0	5	3	5	23
"Indicating reviews with a point on the surface helped me pointing out the problems efficiently."	Q1308	2	2	2	2	21
"Continuing the conversation through 3D digital model was easy."	Q1309	0	5	5	5	14
"Communication through reviews in virtual environment was useful to give review."	Q1310	1	2	3	2	22
"I pointed out problems related with the project in my reviews."	Q1311	0	1	3	1	24
"I offered new solutions for specific needs of the volumes with my reviews."	Q1312	0	3	7	3	19
"I made reviews for the quality of 3D digital modelling."	Q1313	1	1	6	1	24

Further investigations on the answer groups of Questionnaire 13 show at least 50% of the answers for all questions are positive. When observed in detail, especially students' ability to give feedback and point out problems related with the project and models with them answered positively by 80% of the students (Q1304 and Q1311 in Figure 4.36). Attendees also found communication through reviews in virtual environments useful to give feedback for the project by 80% (Q1310 in Figure 4.36). The difficulty of creating reviews on the surfaces, efficiency of pointing out the problems with a point on the surface, continuity of the conversation about the feedback within the 3D digital model, offering new solutions, and making reviews related with the quality of 3D modelling got positive answers in the range of 60% and %75 (Q1307, Q1308, Q1309, Q1312, and Q1313 in Figure 4.36). One of the major outcomes of the results was around 40% of the students were noncommittal for adequateness of 3D digital models, understanding of the models and descriptions, its satisfaction level to evaluate the project, helpfulness of the reviews they made, and creating reviews about implementation of the idea to the models (Q1302,Q1303, Q1305, and Q1306 in Figure 4.36). Also, half of the students were noncommittal and disagreeing about the sufficiency of the descriptions to make reviews (Q1301 in Figure 4.36).

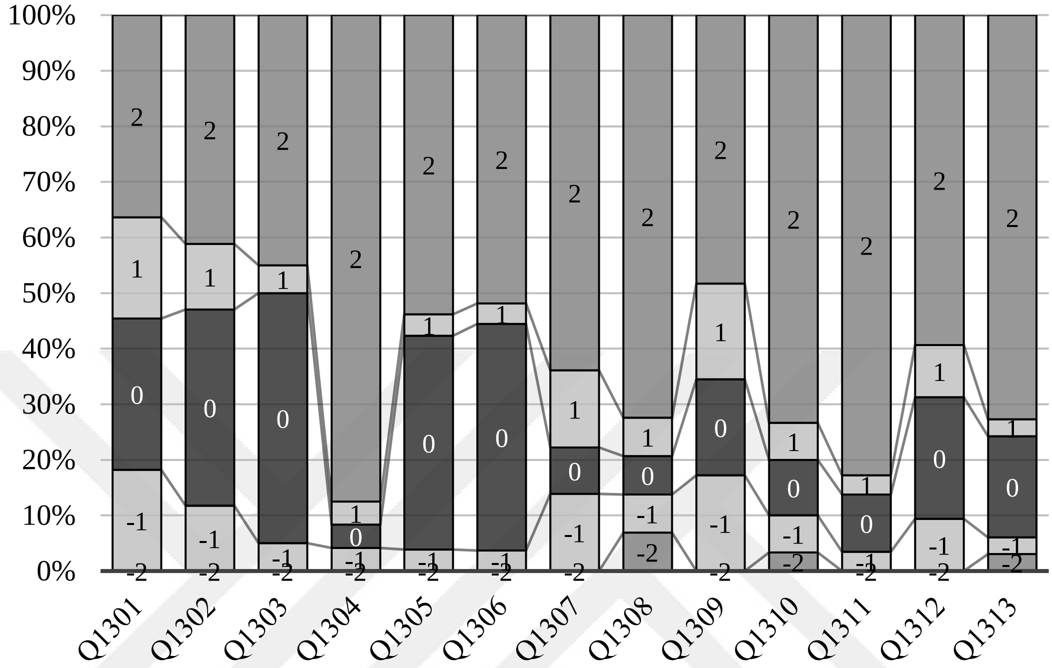


Figure 4.36: Answers, Questionnaire 13

Since those who assigned as reviewers did not answer Questionnaire 14, in total 39 students answered the questionnaire. When all answers summed up, minimum and maximum value an answer can get sets up a range between -78 and +78. Within this range, different aspects of receiving reviews from other students in virtual environments answered by model owners as +37 for adequateness of descriptions in relation with the models, +52 for the suitability of 3D digital models for evaluation, +49 for being able to give enough information in description about the model to allow evaluation process, +52 for getting feedback, +37 for helpfulness of the reviews to projects, +27 for getting reviews related with the implementation of the ideas to the projects, +48 for difficulty to access reviews on the surfaces, +45 for efficiency of pointing out problems with an indicator on the surfaces, +42 for continuity of the communication in virtual environments to receive reviews, +55 for communication usefulness through reviews in virtual environments, +40 for reviews' relations with the problems in the projects, -5 for reviews not having any use about the projects, +42 for receiving reviews related with 3D digital modelling (Table 4.14).

Table 4.14: Answers, Questionnaire 14

Question	*Q*	*-2*	*-1*	*0*	*1*	*2*
"My descriptions were adequate to describe my projects."	Q1401	2	2	8	11	16
"My models were adequate to evaluate."	Q1402	0	0	1	24	14
"I believe I gave enough information in my description for others to evaluate my project."	Q1403	0	1	4	18	16
"I got feedbacks."	Q1404	0	1	3	17	18
"Reviews I got were helpful for developing my project."	Q1405	2	1	8	14	14
"I got reviews about the implementation of the idea in description to my project."	Q1406	0	8	6	15	10
"It was easy to access reviews on surfaces."	Q1407	1	1	4	15	18
"Seeing reviews with a point on the surfaces helped me finding the problems efficiently."	Q1408	1	1	5	16	16
"Continuing the conversation through 3D digital model was easy for the reviews I received."	Q1409	0	0	7	22	10
"Communication through reviews in the virtual environment was useful to receive feedbacks from others."	Q1410	1	0	3	13	22
"Reviews I got were related with the problems in my project."	Q1411	0	0	7	24	8
"Reviews I got were not indicating anything useful for my project."	Q1412	3	14	10	9	3
"Reviews I got were about the quality of 3D digital modelling."	Q1413	0	0	6	24	9
"Reviews I received were helpful for my project development."	Q1414	1	0	7	14	17

Questionnaire 14 was prepared to measure the influence of receiving feedbacks throughout 4 weeks of virtual classes. Since 39 design studio project owners answered the questionnaire, answer amounts indicated students significantly agree with the idea of models to be adequate evaluate their own designs since more than 95% gave positive answers (Q1402 in Figure 4.37). In general, all questions got positive reactions from students above 60% limit. Other two major positive outcome was students indicated they received reviews without any trouble and usefulness of receiving reviews through virtual environments about their projects got positive answers more than 90% (Q1404 and Q1410 in Figure 4.37). When a negative question has been asked to students as whether reviews, they received were useful for their projects or not, 30% of the students indicated as the reviews were not useful while 25% were noncommittal. However, 45% of the students found the reviews they got in virtual environments from their friends useful for further developments in their projects (Q1412 in Figure 4.37). Which is also indicated within same ranges in other question in reverse (Q1405 in Figure 4.37). Apart from noncommittal answers, no students answered negatively about receiving feedback about the quality of 3D digital modelling, continuing the conversation about the problems related with the projects, and reviews relation about the projects (Q1409, Q1411, and Q1413 in Figure 4.37).

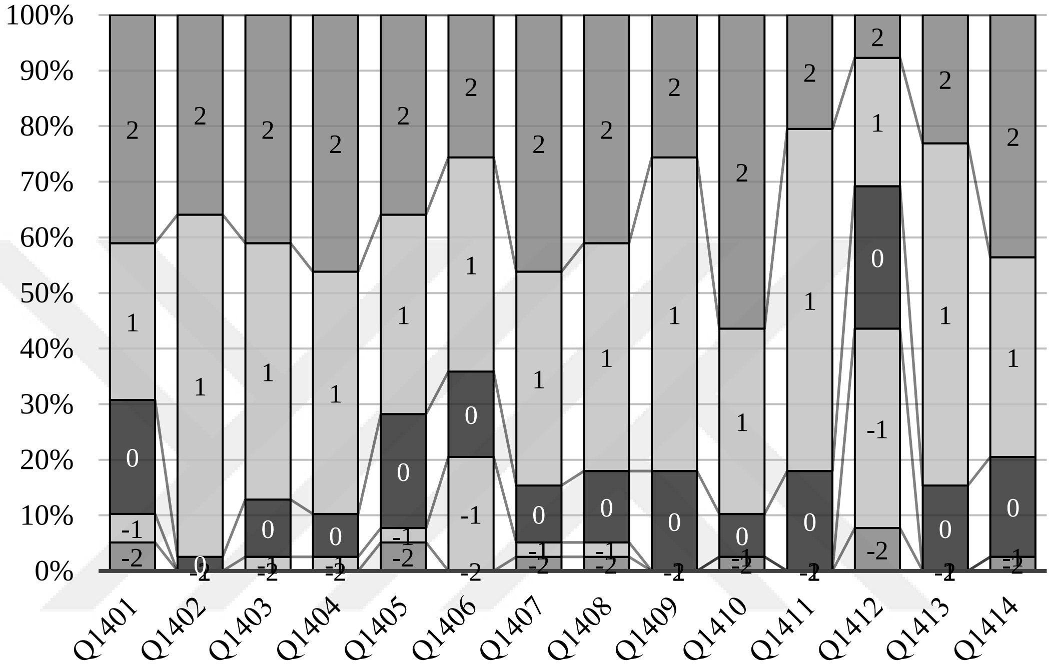


Figure 4.37: Answers, Questionnaire 14

4.6. DISCUSSIONS

All experiments were done by the students in different settings at the end of the semester. Individual results of each experiment have been given previously in this chapter. In the current section, discussions about interrelations between experiments and commentary qualitative outcomes of questionnaires have been demonstrated. Also, similarities and diversities with the previous studies have been investigated.

4.6.1. EXPERIMENT 2 AND 3 INTERRELATIONS

Both Experiment 2 and Experiment 3 were focused on comparisons between different architectural representation methods and spatial perception differentiations in between. Experiment 2 focused on digital orthographic drawings (DOD), on-screen virtual environment (OSVE) view, and immersive virtual reality (IVR) view. However, for

Experiment 3, OSVE and IVR views combined and compared with digital presentation boards (DPB) and digital walkthrough videos (DWV). Since DOD, DPB, and DWV systems are currently in use by most of the students, they labelled these representation techniques as the traditional method. However, OSVE and IVR views were tagged as the innovative approaches in the architectural design presentation. Discussions between different presentation setups will be demonstrated by using different types of questions in the surveys which have been asked to students in the experiments. While the questions related with “understanding” correspond to spatial perception and project presentation, the questions related with “figuring out” and “suggesting” corresponding to architectural collaboration and the feedback process.

The understanding of the plan organization of the project seems to be clearer in DOD and DPB-DWV systems since they also include explanations and diagrams about the project and main ideas related with its design choices (Figure 4.38). Additionally, immersive virtual reality system appears to be the most insufficient way of understanding the scheme of the project.

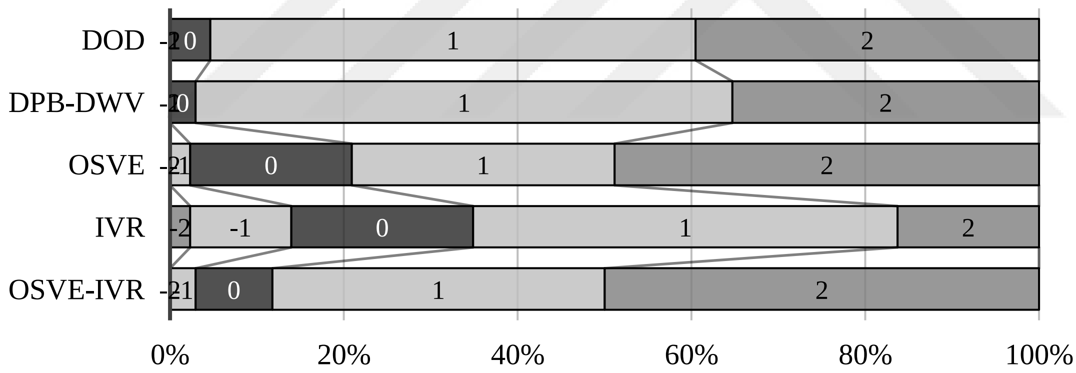


Figure 4.38: Understanding of the Plan Organization of the Project

Even if all architectural presentation methods demonstrate a clear understanding about the understanding of the human scale and the building size individually, the use of OSVE and IVR views together creates significantly affective perception related with the size. When compared to other presentation methods, DOD materials seems to be the less effective one to understand the human scale (Figure 4.39).

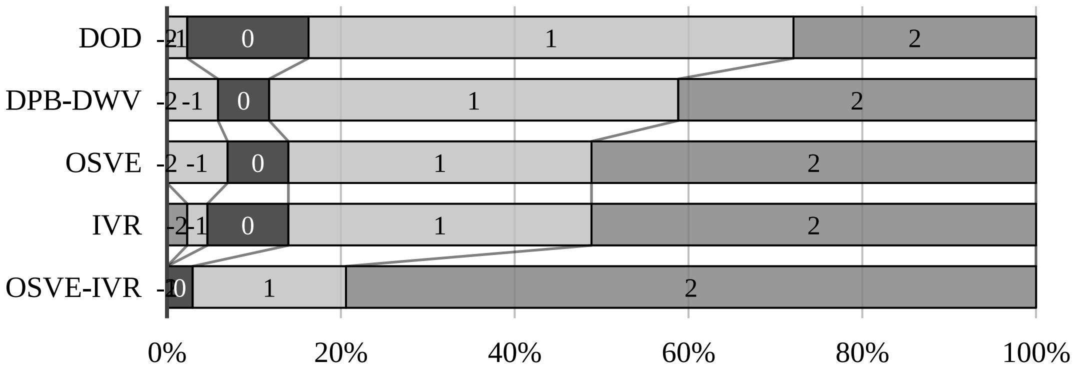


Figure 4.39: Understanding of the Human Scale and Building Size

The understanding of the rooms and their relations has one of the primary needs of an architect to overcome. The study demonstrated that the most non-affective method to explain the relations of the rooms is digital presentation board and digital walkthrough videos. Students preferred digital orthographic drawings and especially the use of OSVE and IVR to understand the relations between the rooms (Figure 4.40). The significant differentiation about understanding the rooms and their relations in DPB and DWV may have been caused due to presentation technique and the quality of the drawings on the presentation boards.

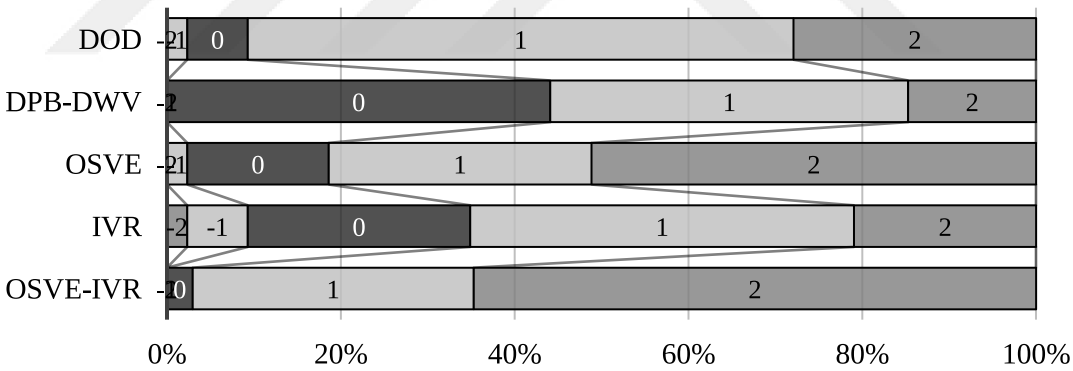


Figure 4.40: Understanding of the Rooms and Their Relations

The circulations among the floors and the functions appears to be a main element of the architectural pieces. To this extend, attendees of the experiments preferred OSVE-IVR views to understand the circulations (Figure 4.41). In all the answers, there are significant number of students which were noncommittal, except the cooperation between OSVE and IVR views to observe the projects to understand the circulation.

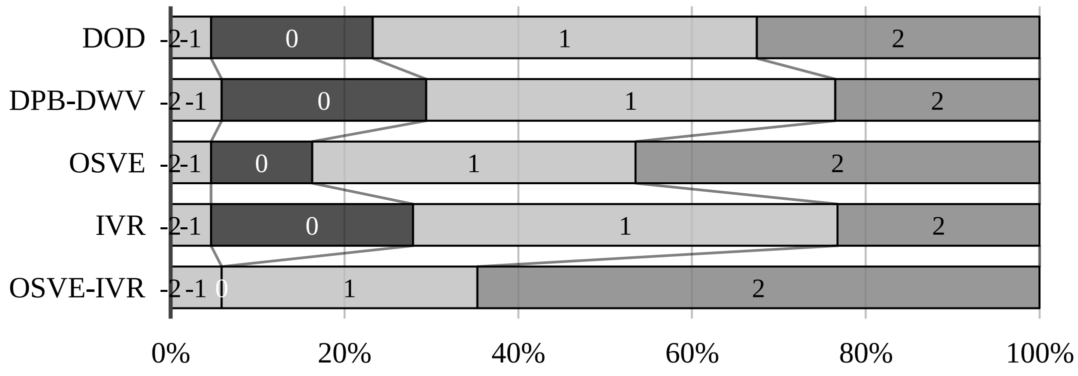


Figure 4.41: Understanding of the Circulations

All the projects which were shared with the students had different levels of interior and exterior space relations from private to public. Our findings suggest students preferred the use of both OSVE and IVR systems together to understand such relations. However, when OSVE and IVR views have been used to understand it, they both appear to be nonsufficient compared to cooperation between them. Less effective method has been demonstrated as digital orthographic drawings including whole set of construction documentations (Figure 4.42).

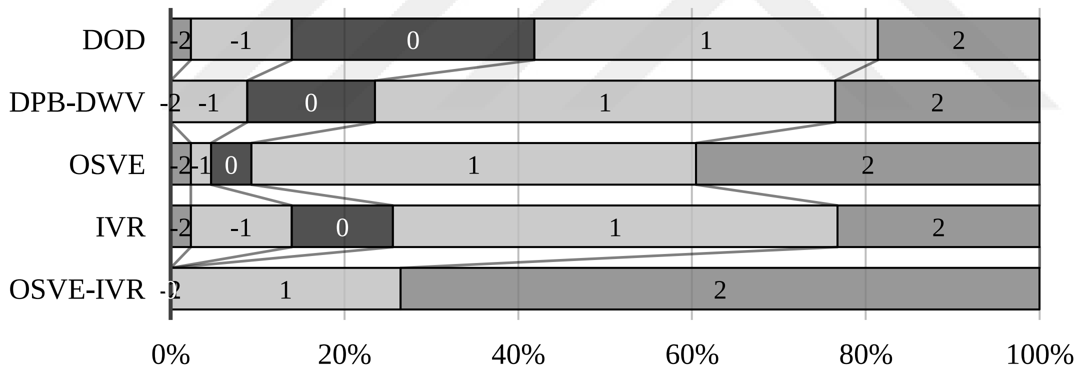


Figure 4.42: Understanding of the Interior - Exterior Relations

The vertical elements such as walls, columns, façade elements, glazing, cladding, etc. appear to be understood most efficiently by using OSVE-IVR views and DPB-DWV materials. Additionally, use of DOD and individual OSVE and IVR views were found equally efficient by the students. Seeing an element in many perspectives may have been helpful for students to understand the things they missed in one of them (Figure 4.43).

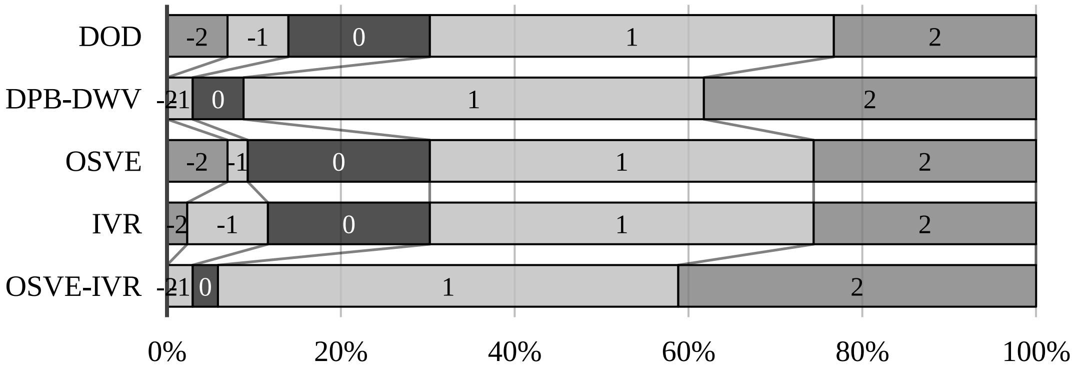


Figure 4.43: Understanding of the Vertical Elements

As one of the major outcomes of the study, the understanding of the openings and their impacts for the interior living areas appeared to be completely feasible by using OSVE and IVR views together within a consensus of the students. None of them answered neither noncommittal nor negative. However, digital orthographic drawings were nonefficient to understand the openings and their impacts since a significant number of students were noncommittal about it (Figure 4.44). The use of DPB-DWV materials together was more affective then seeing the projects only by OSVE or IVR.

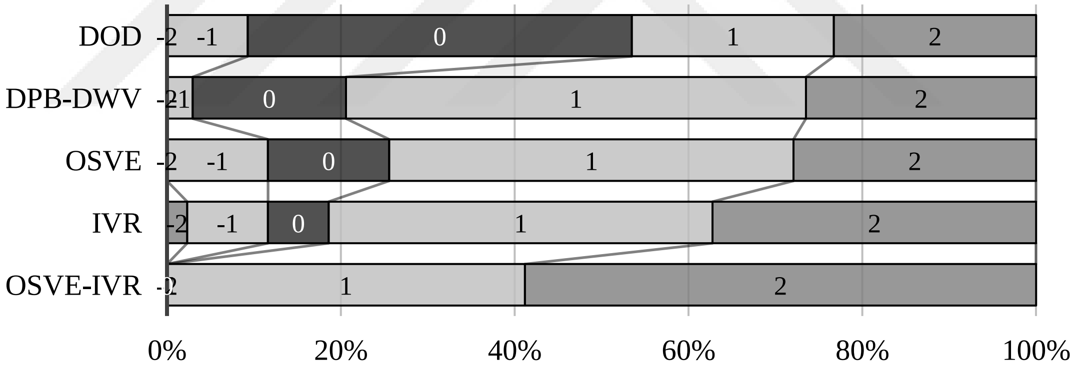


Figure 4.44: Understanding of the Openings and Their Impacts for the Interior

Another main outcome of the study was the understanding of the solid – void relations of the façade. Just like with the openings and their impacts, students preferred the use of OSVE and IVR views together to understand the patterns on the façade. Since understanding the whole façade is important, seeing all architectural piece at once in DPB-DWV and OSVE views also have been preferred by the students. However, DOD materials have been assigned as the less effective method to understand the façade decisions and elements on the elevations (Figure 4.45).

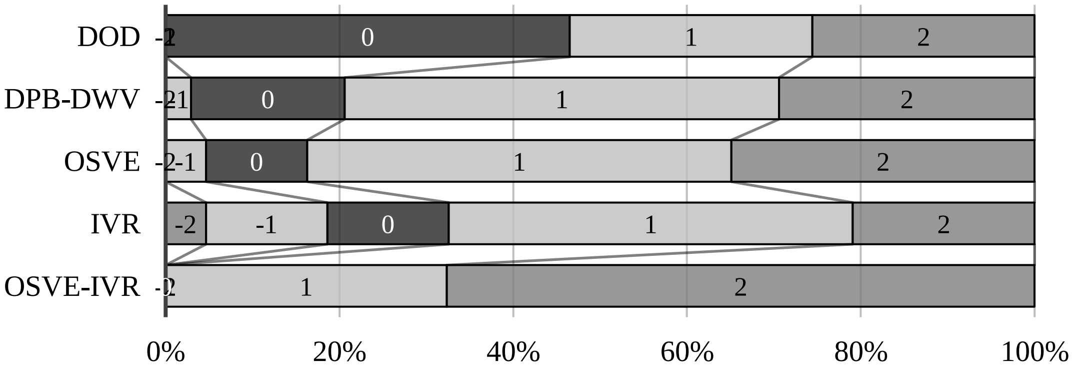


Figure 4.45: Understanding of the Solid - Void Relations of the Façade

The understanding of the interior design and the furniture organization, the digital presentation boards and the walkthrough videos appear to be the most nonpreferred methods. However, the use of OSVE and IVR views together, again demonstrates its usefulness for this architectural understanding (Figure 4.46).

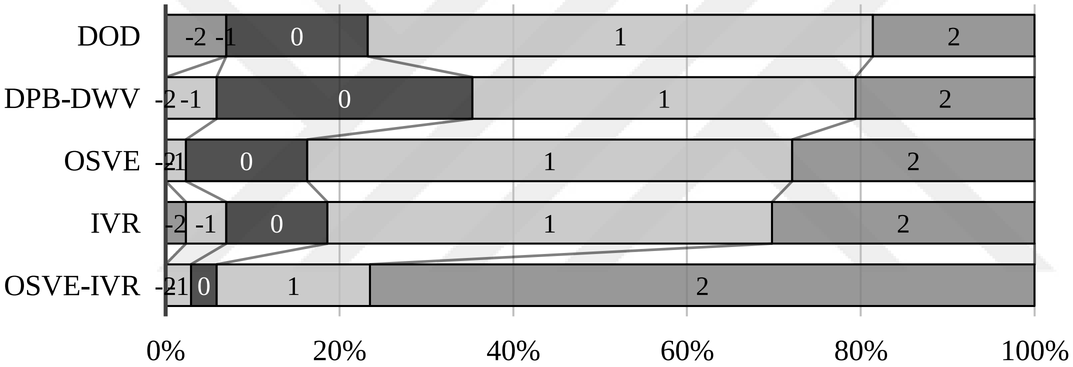


Figure 4.46: Understanding of the Interior and the Furniture Organization

One of the most unexpected outcomes of the study was the understanding of the vertical relations between horizontal surfaces. Even if these relations such as slab overlaps, balconies, galleries, double height spaces etc. thought as easily understandable with horizontal drawings and sections, the students preferred digital 3D models with on-screen virtual environments to observe them. Even if seeing projects only by IVR view is not significantly preferred by the students, evaluating projects with DOD and DPB-DWV materials appeared to be the less effective methods than the innovative approaches to the architectural representations. The use of OSVE and IVR views together again have been preferred by the students to understand the vertical relations in the projects (Figure 4.47).

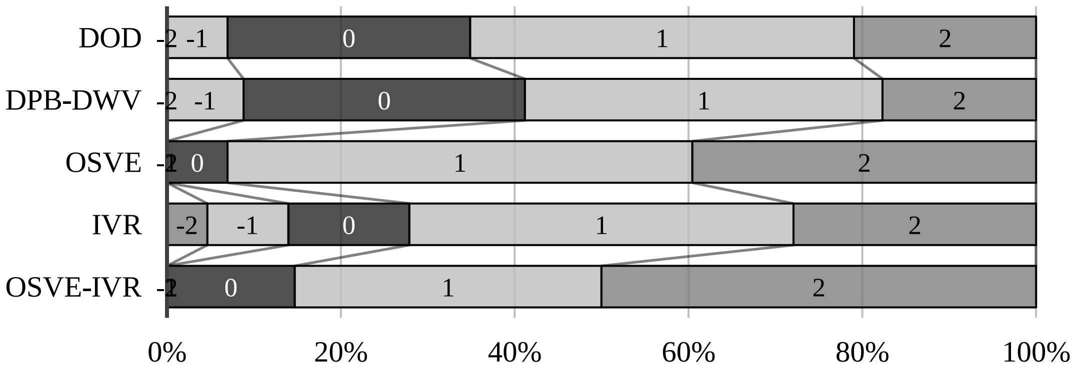


Figure 4.47: Understanding of the Vertical Relations of the Horizontal Surfaces

Another main outcome of the study was to see how OSVE-IVR views together improved the spatial perception to understand the volume itself and how it feels like to be in that environment. All attendees stated that they agree or strongly agree for this specific understanding. While OSVE and IVR views individually have been preferred by the students, DOD and DPB-DWV materials appeared to be the less effective methods to virtualize the feeling of the space for the person (Figure 4.48).

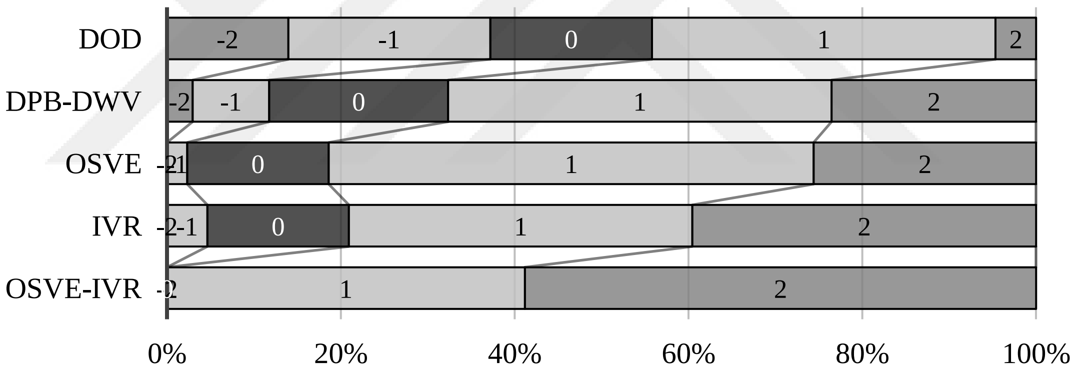


Figure 4.48: Understanding of the Volume and How It Feels Like to Be There

For the project evaluation process in architecture, figuring out the problems are playing a crucial role to state and solve it. Architectural feedback process and collaboration get feed from this input if it is fulfilled. For all the projects and architectural presentation methods, when the efficiency of figuring out the overall problems related with the project have been asked to students, they strongly preferred the use of OSVE and IVR views together over other presentation methods. The most traditional method of the digital orthographic drawings, and others as the presentation boards, and the walkthrough videos appeared to be the less efficient ones. One of the reasons of this situation might be caused by seeing an end-product in traditional methods instead of observing a changeable virtual 3D data in the innovative approaches (Figure 4.49).

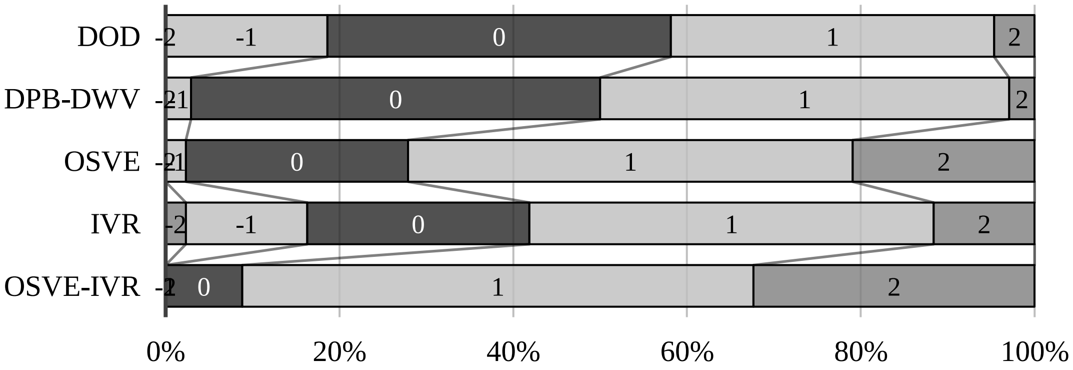


Figure 4.49: Figuring Out the Overall Problems with the Project

Figuring out the problems with the narrow areas and the small volumes appeared to be most effectively feasible by using the immersive virtual reality view and the use of OSVE-IVR views together. The less effective method is concluded as the DBP and DWV materials since they usually get prepared to show the appealing parts of the projects instead of an evaluation material. The digital orthographic drawings also have been stated as noneffective since most of the small and narrow areas appears feasible in the drawings, however when it is built or perceived in 3D virtual environments, their sizes can be understandable (Figure 4.50).

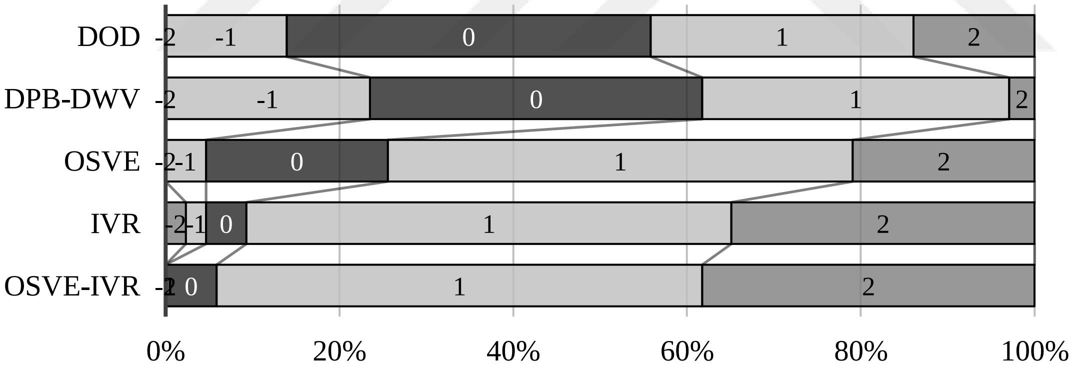


Figure 4.50: Figuring Out the Problems with Narrow Areas and Small Volumes

In the interior spaces of the projects, the understanding of the furniture and their organizations have been stated as preferable with OSVE and IVR views in previous questions. As a parallel outcome, figuring out the problems related with the furniture placement also significantly feasible with OSVE-IVR, OSVE and IVR views. DOD and DPB-DWV systems got noncommittal answers the most from the students (Figure 4.51).

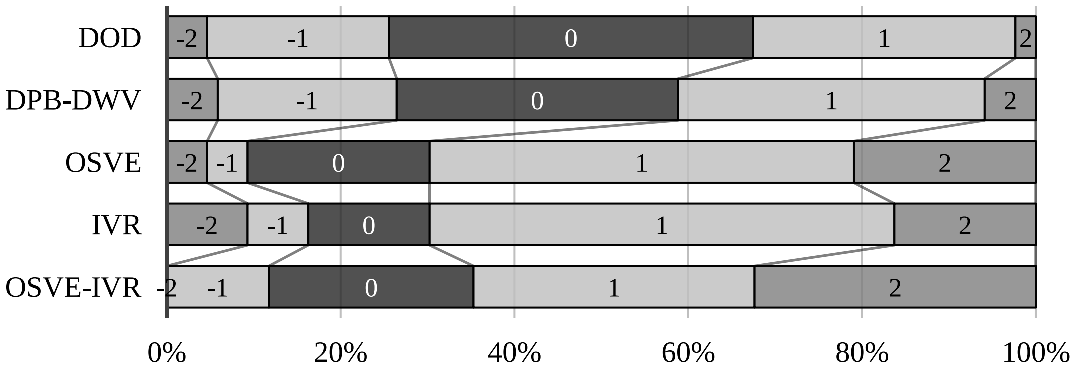


Figure 4.51: Figuring Out the Problems with the Furniture Placement

After evaluating the projects and figuring out the problems, making new suggestions is mostly preferred by the architects to conduct an architectural collaboration. To this extend, when suggesting a new layout for the overall room organizations have been asked to the students, they preferred OSVE view the most. However, apart from other questions, the ones related with suggesting new solutions appeared to have more noncommittal answers from the students. The most non-satisfactory methods to make new suggestions have appeared to be DPB-DWV materials and individual IVR views (Figure 4.52). Almost half of the students were noncommittal about suggesting new layouts for the room organization in DOD, DPB-DWV and IVR views.

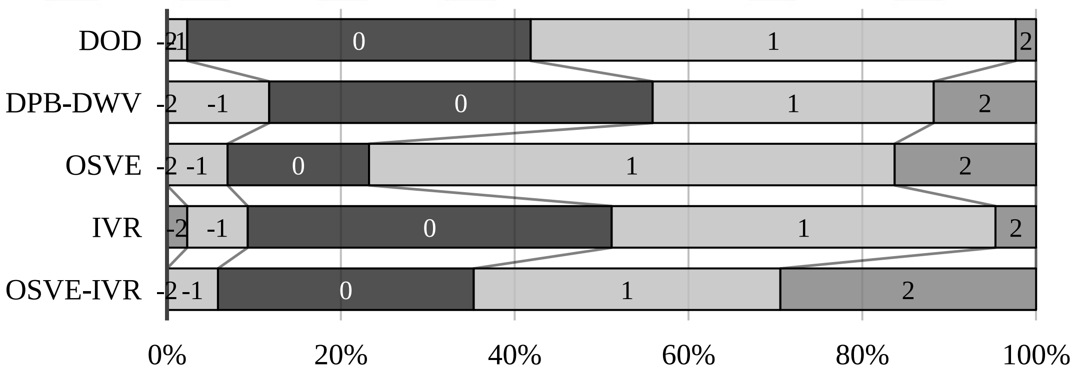


Figure 4.52: Suggesting a New Layout for the Overall Room Organization

One of the most unexpected outcomes of the study was to see the use of DOD as noneffective to suggest new circulations for the project. Since the very beginning of architectural practice, the digital orthographic drawings have been used to discuss and present architectural pieces. However, the students stated that they preferred the most traditional method was the most insufficient one. The students also stated that OSVE-IVR views and OSVE view individually are significantly effective to suggest new circulations for the project (Figure 4.53).

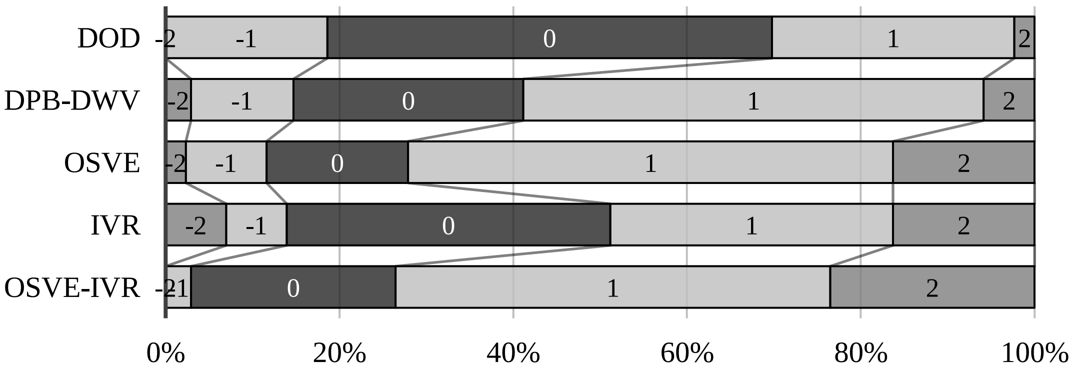


Figure 4.53: Suggesting a New Circulation for the Project

As expected, suggesting new solutions for the interior furniture placement, since students can get in direct contact with the volume and the interior themselves, have found most feasible with the help of OSVE, IVR and the use of OSVE-IVR views together. However, DPB-DWV materials appeared to have the most noncommittal answers among all architectural presentation techniques (Figure 4.54).

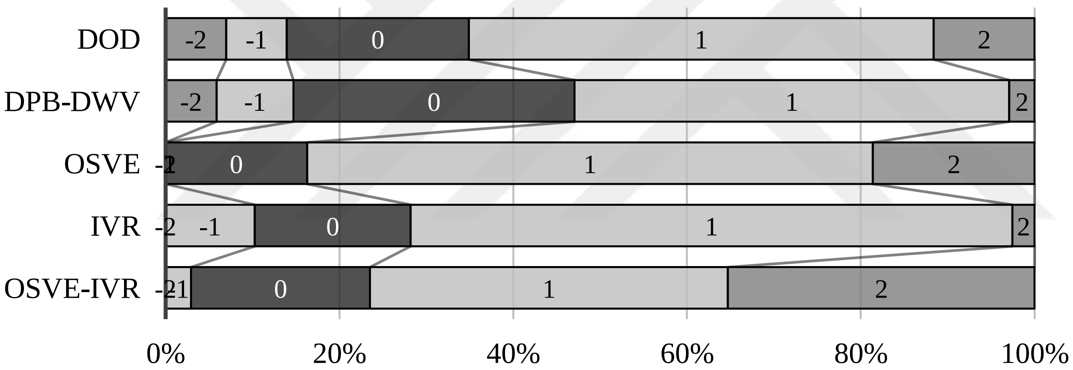


Figure 4.54: Suggesting a New Solution for the Interior Furniture Placement

Additionally, digital orthographic drawings appeared to be the most effective method to understand the total square meter of the projects from all the representation methods.

As an outcome of a comparison of Experiment 2 and Experiment 3 about the differentiations between architectural presentation methods and spatial perception in them, each presentation technique has its own advantage and disadvantage. However, using both on-screen virtual environment view and immersive virtual reality view together is significantly preferred by the students. Since they are 3rd and 4th year students mostly, their ability to understand the projects, to evaluate them, to figure out general problems, and to suggest new solutions were adequate to demonstrate a comparison between different digital presentation setups. Results indicates the use of innovative technologies with interactive applications, immersive and non-immersive virtual 3D digital models are preferable for spatial perception rather than traditional items such as orthographic drawings, presentation boards, and walkthrough videos in digital environments.

4.6.2. EXPERIMENT 1 AND 4 PROCESS EVALUATION

As mentioned before, the current study has been conducted through an elective course of a semester. Since architectural education has a design studio-oriented teaching model; students' projects, development processes, and their architectural collaboration were crucial for the study. However, in the literature no consensus was previously reached on measuring effectiveness of collaboration or feedback process. Therefore, students have been asked open ended questions along with the questionnaires they took for all the process. That is, qualitative data was collected. Experiment 1 and Experiment 4 were aimed to demonstrate the efficiency of the course and the improvements of students' ability to collaborate through virtual environments with the content of the course.

When students first engaged with the virtual environments in Experiment 1, half of the students struggled with the navigation in OSVE view with walking mode and IVR views (Figure 4.10). However, along with the process, students have been observed as they prefer using OSVE walking mode to evaluate the projects to give reviews in the virtual environments rather than IVR or OSVE flying mode. Even if 40% of the students answered the communication through virtual environment with the reviews on the surfaces of 3D digital data was preferable at the beginning of the semester with Experiment 1 (Figure 4.11). At the end, after a semester of practice in the virtual environments, with Experiment 4 and the questions related with the virtual reviewing session, 75% of the students seemed to be comfortable with creating reviews on the surfaces and indicating problems related with the projects (Figure 4.36). Therefore, it can be concluded to that, when students get the opportunity to work with virtual environments, their ability to collaborate and give feedback to their friends can be improved. Not only this, but when usefulness of the reviews they got have been asked to students, they answered 50% of them indicated that the reviews they received were helpful to their project development (Figure 4.37).

At the end of the Experiment 4, the students have been asked to explain their experience about reviewing their friends' projects in the virtual environments (VE) throughout the semester, out of 28 answers, 26 students indicated the positive effects of distant collaboration in VE. Only 2 students mentioned about a technical problem related with the software that caused trouble for their reviewing sessions. Some of the comments from the students were; "It was easy and fun to review and comment on the models in a virtual environment…", "It was quite easy to use…", "This was a very new experience for us…I gave reviews to my friends as I can think about the 3D modelling quality and some design aspects.", "In my opinion, reviewing the surface is very useful. When you comment, the model owner can see where I left it. In this way, he/she understands the problem quickly and efficiently.", "…it was easy and useful to give reviews and having conversations within them…", "…when we look at to the physical models, it is more difficult to understand narrow areas and interior space than looking at them in digital models.", "…reading the description was enough to create a knowledge for me to evaluate the projects…", "Feedback on the system is actually fun. Different ideas may emerge by different people…", "Process for the development of the projects was very useful…", "Using a third party application to give feedbacks on others' projects is easy and descriptive. Communicating with other people through project was also useful.", "…due to some system errors, the application crashed or could not open the reviews…", "It was a good experience for me to give reviews to somebody without seeing them. Because getting to know somebody or interact with them personally are killing the objectivity in terms of pointing out the negative issues about the projects…reviews I gave were short, direct and obvious…", "Doing reviews for my friends' projects made me more careful for my own modelling…", "…it was a good experience to help a distant friend with a single click in seconds without any errors in the system…even in the narrowest part of the building.", "my critiques were mainly related to modelling, façade and general organization. I believe that reviewing and contributing to my friends in VE in terms of design, makes me develop myself…these assessments allowed us to improve our shortcomings about communication…we can also learn more about spatial relations and scale by examining the projects in VE…", "It is nice to evaluate the projects through a virtual system. Because we can only evaluate the errors we see, not only this, but we provide ideas for the development of the projects…", "…the reviews were straightforward to solve the problems and give the opportunity to improve the projects…", "Reviews through the system were easy to use, especially with the added feature of clicking on the surfaces. So that it can point out where exactly or about what exactly the reviews for. I think as an overall it was a great experience and as we are living in the era of technology, I hope that maybe one day, a similar system will be used by the professors to be able to see inside the projects and experience the spaces first hand for a better understanding. This is achievable from both the students and the professors."

After an investigation on qualitative data collected from the students, most of them found the idea of giving digital reviews in virtual environments with 3D digital models for distant collaboration is useful for project development. While for partial distant collaboration such as reviewing others' projects in VE has been preferred as easy, fast, direct, and useful for all the students, students also indicated not conducting the project owners in person but communication through a platform, being able to see spaces themselves in an immersive setup, the process of teaching virtual environments, fulfilling the needs of the new generation of students about technology, including the design studio professors and the students would be beneficial for distant collaboration in virtual environments.

The students also commented about their experiences with the reviews they received within the 3D digital data in virtual environment from their distant friends. Out of 25 comments, 20 students found the reviews they received useful concerning their projects. However, 5 students indicated the reviews they received were about the quality of 3D digital modelling, therefore those students said the reviews had not much use for their projects. In addition to the previous answers, students' comments were; "It is good to see what my friends put as a comment on my project…because sometimes you can miss a point and others can catch them…so it is very useful…", "I learned the idea of my friends and what to explain for others to understand my project in all the aspects.", "…it was very helpful for me because they gave feedbacks about my design idea and some technical solutions…", "It was easy to find the reviews inside my project…", "…it was easy to understand the problematic spaces and the communication was really simple. I got reviews about implementation of the idea to the project and some human scale problems and at the end, I fixed them…it was helpful for my project process.", "…feedbacks were useful for my project…", "…if reviews topics remain only about the quality of 3D digital modelling, I do not believe it can contribute to the project…", "…if the reviews' descriptions were good enough, they would lighten me more…reviews about 3D modelling did not help much…but still it was a good experience for me since I took critics from so many people about so many issues…", "Thanks to one of the feedbacks, I changed my design in a whole new positive way…", "It is good to learn what people think about your project. How they feel inside it because we are going to design for different kind of users who has different perceptions. All people who gave comments on my project mostly wrote about furniture, openings and placements. A few people talked about volumes in the building, design idea and the relationships of the shapes. I would be glad if I could get more comments about overall design, idea and volumes, then I could develop my project concerning them.", "I believe distant review system is successful…two of my friends criticized the same point…I realized that space was not very certain…I changed that immediately and waiting for new comments for my solutions.", "Some of the comments were about design and helped me to find out what was missing…in other comments I received constructive feedbacks…review sessions with my friends resulted with nice dialogs.", "I got reviews about placements of furniture, openings, and missing objects…few people wrote about design idea, overall shape and volumes…if I knew what they thought about volumes, I could revise my volumes to put furniture properly…", "…I believe the comments were very logical and accurate concerning the development of my project…I was able to understand how to revise my projects easier…they were important critics for the final phase of my project.", "I think review system is beneficial since everyone has different point of views…for my project…", "It was nice to get comments about the project. These comments contributed to the development of the project. They made it easier to see the errors in the project and were effective in the development…the comments showed me the good and the bad sides of my project…", "My friends got good point of view to explain both good things and the problems. I understood where I made mistakes and wrongs, now I am able get better decisions…"

Further observations on students' comments about the reviews they received pointed out most of them found the idea of getting critiques from many people, useful for the development of their projects. Also, quality of the reviews and the topics within them is a concerning issue for the students. However, constructive reviews generated a good impact on the design studio process.

4.6.3. COMPARISON WITH THE PREVIOUS STUDIES

The current study focused on the spatial perception of Yaşar University architecture students in different digital representation methods and effectiveness of distant collaboration along with the virtual environment training. To these extends, the conclusions of the previous studies focused on the spatial perception by using various methods and distant collaboration have been investigated further.

Paes et al. (2017, p. 11) indicated their outcomes of a comparison of spatial perception between immersive and non-immersive virtual reality systems as; (1) IVR systems provided a superior spatial perception of the 3D digital model rather than non-immersive views and other traditional methods, (2) subjects over 26 years old had improved spatial perception in IVR than the others, (3) architects and engineers had better spatial perception than students and non-designers, (4) subjects with higher education had better spatial perception. All these findings are in accordance by the studies done by Witmer (1998), Gifford (2007), Okamoto (2002). However, the immersive virtual reality technology has been used as a panoramic screen provided by three projectors and coloured filtered glasses in these studies (Figure 4.55). Same method for adopting immersive virtual reality also occurs in different studies (Figure 4.56). Our findings also suggest the improvement of spatial perception in both IVR and OSVE views rather than conventional methods. Since all the subjects were architecture undergraduate students at the age range of 25 to 30, other outcomes of the previous study could not be compared with the results of the current study. However, satisfaction level of students and their feedbacks about the distant collaboration and understanding their creations in virtual environments can be concluded as a success.

Figure 4.55: Participants Exploring the Non-immersive (left) and Immersive Environments (right) (Adopted from Paes et al., 2017, p. 297)

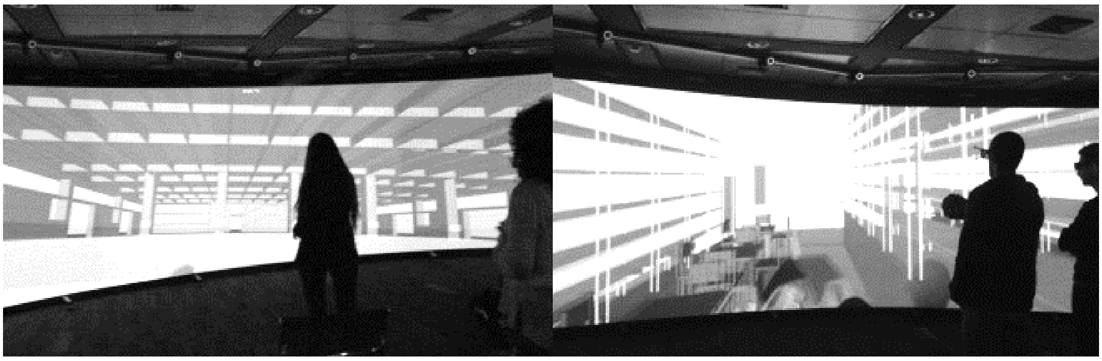


Figure 4.56: Attendees Observing in Immersive Virtual Reality (Adopted from Portman et al., 2015, p. 379)

Henry and Furness (2002) in their study about evaluating an architectural virtual reality application concluded their research with a major outcome of perceiving the spaces to be smaller in simulated virtual environments. Researchers used 4 different observation methods including real, monitor (OSVE), fixed and tracked (IVR) (Figure 4.57). They also pointed out, a different setting of field of view (rather than 90 degrees as they used) might have cause errors from the subjects. However, by using a wider field of view, our findings related with figuring out the problems related with small areas and narrow volumes are in accordance with the results of the previous study (Figure 4.50). Their results also indicates the use of head mounted displays improved people's spatial perception and the ability to feel as if they were in that environment. Findings of the current study also measured this aspect and attendees' reaction with IVR and OSVE views overlaps with the previous study (Figure 4.48).

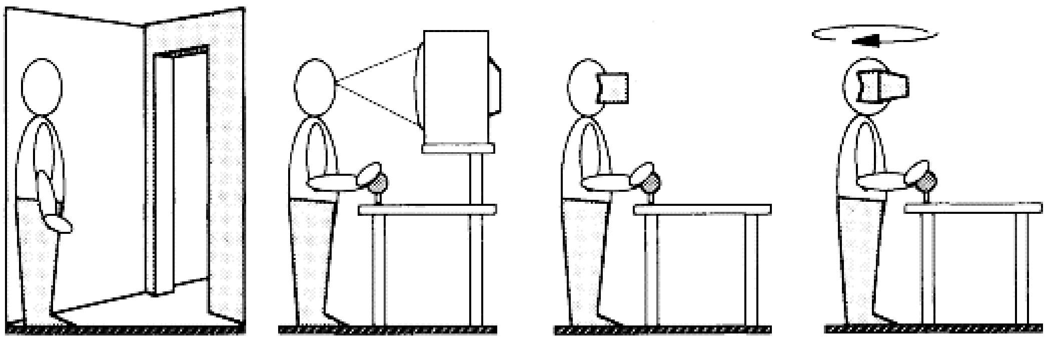


Figure 4.57: Real Condition, Monitor Condition, Fixed Condition, Tracked Condition (Adopted from D. Henry & Furness, 2002)

Okechukwu and Udoka (2011a, pp. 67, 68) indicated the disadvantages of VR systems in their studies as high level of skill requirement, steep learning curve, programming requirement, expensive hardware and software. The current study demonstrated a method which aimed to teach the introductory level of skills to explore and evaluate

3D digital data in virtual environments. Since outcomes of the study indicated an improvement of navigation, communication and evaluation from the beginning of the course till the end, a semester of training seems to be beneficial for gaining the specific skillset to use virtual environments both for spatial perception and distant collaboration. Programming requirement also has been eliminated by using a software which automates the data conversation from architectural softwares which students are used to, to 3D digital environments where students can explore, evaluate and review the projects. The expensive hardware setup with high-end computers was also not necessary for developing a virtual environment for students, since current smartphone technologies provide enough CPU and GPU powers to overcome the visualization of 3D digital architectural models in virtual environments for observing.

Schnabel et al. (2001, pp. 398, 399) developed a virtual collaborative studio between distant members in different universities around the world using immersive virtual environments with high-end computer systems. They established a collaborative workflow of 8 hours between parties (Figure 4.58). Their findings indicated a virtual studio is possible and teams did engage in collaborative work. They implemented a chat-based communication by using another party of software which was also used by other studies too (Kan et al., 2001; Kvan et al., 2000).

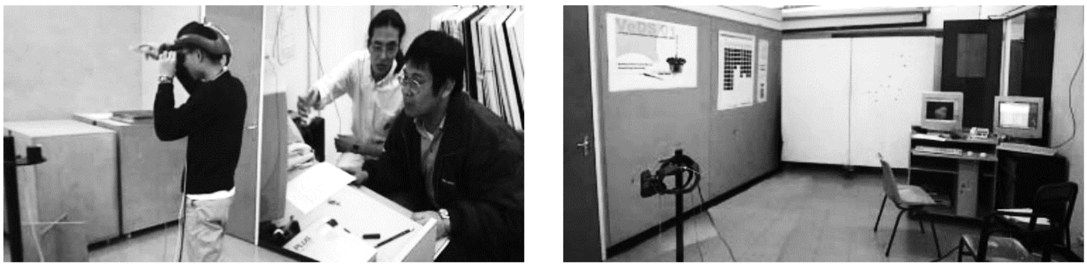


Figure 4.58: Virtual Design Studio Setup for Distant Collaboration (Adopted from Schnabel, Marc et al., 2001)

Another study that aimed to create a collaborative virtual environment have been conducted by Frost and Warren (2000, pp. 571, 572). Attendees' interactions directly affected the designs since they were creating the projects within the virtual environment. Students had troubles with generating their design ideas and using the virtual system to design their material creations. The outcomes of the current study also suggest a collaborative virtual environment is possible. However, the creation method was different than the previous study. Since students are used to the current CAD and/or BIM environments to use in their design studio process, those 3D digital models have been imported to the system to generate virtual environment setup. Therefore, struggling to create shapes and geometries in 3D digital world have been eliminated. Both studies indicated a collaborative environment is possible by using chat-based communication even if the method to implement such feature differs from one to another. While the previous study used an external method to send and receive feedbacks, the current study implemented a virtual review system where users can indicate the problems within the 3D digital data. The outcomes showed such feedback process is useful for both project development and distant reviewing by multiple participants.

CHAPTER FIVE
CONCLUSION

Over the years, architecture had different working domains as well as different definitions for each one of them. There are four different practices in architecture, academic architect, the craftsman (builder), the civil engineer and social scientist (Salama, 1995). However, in today's situation, architecture as a profession requires different interdisciplinary actions to be undertaken. The most common description for architect is "a person whose job is to design new buildings and make certain that they are built correctly" (Cambridge Advanced Learner's Dictionary & Thesaurus, 2018). Due to these various extends of architecture education, curricula has become the compositions of sets of different courses including architectural design, building construction, history of architecture, structures, materials, equipment, professional code, professional practice, art and even more (Muschenheim, 1964). Despite this situation, architecture education just like any other design discipline education has mainly a studio-based learning model (Büyükkeçeci, 2017). In a regular design studio structure, students have been assigned to specific design problems and expected to solve them with architectural pieces.

Since outcomes of any design process is highly imaginary, different representation methods have been proposed by and/or for architects, such as conceptual sketches, analytical sketches, observational sketches, orthographic projections such as plans, sections, elevations, details; three-dimensional perspective, axonometric, isometric drawings, photomontage, collage, physical modelling, CAD models, fly-through videos, layout presentations, oral presentations, story boards, portfolios, etc. (Farrelly, 2008). Using these methods, architects not only understand the architectural works with volumes among them but also are able to communicate through the design process (N. Cross, 1990; Nelson & Stolterman, 2012). Yet, technological advancements enabled designers to realize their creations digitally using new methods. To this end, the current work aimed to investigate the effects of virtual environments and data within them, on spatial perception and architectural collaboration. Two main research questions were postulated: (1) How digital architectural representation methods influence architects' perception of space? (2) How can distant collaboration between architects in virtual environments effect the project development process?

The current study has been conducted through an elective course through a semester. That is, the study benefitted from using longitudinal data rather than cross sectional one. As relevant literature has reached no consensus on methods to measure neither spatial perception nor effectiveness of collaboration, the current work adopted, so called, a mixed research design. In this research design, both quantitative and qualitative data was collected through a set of experiments conducted within the content of an elective course prolonged 14 weeks. These experiments categorized in two. First set of experiments aimed at measuring influence of different architectural representation method on understanding different aspects of architectural projects. Within the first set of experiments, Experiment 2 was designed to the compare digital orthographic drawings (DOD), the on-screen virtual environment (OSVE) with the immersive virtual reality (IVR) views, whereas Experiment 3 was to compare the digital presentation boards and the digital walkthrough videos (DPB-DWV) with OSVE-IVR views. Second set of experiments have been used which include a collaborative virtual environment and aimed at measuring architectural communication by reviews and evaluation of students' projects through feedbacks (Experiment 1 and Experiment 4). Responses on spatial perception and feedback process was measured in ordinal (Likert) and nominal scale. In addition, the surveys also contained open-ended questions. However, only quantitative data were used to evaluate the outcomes, as qualitative answers were employed to validate responses proposed by the quantitative data.

The results obtained from the current study demonstrated that digital orthographic drawings as a conventional method for showcasing the design ideas are useful to understand the overall project layout and relations between volumes (Q301 and Q302 in Figure 4.12). On one hand, almost all students felt comfortable with seeing and evaluating the projects with on-screen virtual environment view. However, most significant advantage of this method seemed to be understanding the interior – exterior space connections and vertical relations of horizontal surfaces (Q405, Q410 in Figure 4.13). On the other hand, IVR view was significantly useful to figure out problems related with narrow areas and small volumes (Q513 in Figure 4.14). Additionally, to understand the human scale, the size of the structure, openings on the surfaces, their impacts for interior areas, interior design, and the furniture organizations IVR was a viable tool for students (Q502, Q507, and Q509 in Figure 4.14). Based on results, one can suggest that students understand and evaluate the designed volumes themselves more efficiently in OSVE and IVR views compared to digital orthographic drawings.

After the students' comfort with 3D digital models and use of them to design, evaluate and review projects were ensured; spatial perception in design studio projects was investigated with a comparison between DPB-DWV and OSVE-IVR views. Both in DPB-DWV and DOD systems, understanding the quantitative features about the projects such as dimensions, square meters, actual heights etc. and the organization of the project have been more efficient (Q901, Q918 in Figure 4.18). The outcomes of the experiment demonstrated students significantly preferred explorable 3D digital models over the DPB and DWV to understand various extend of the projects. In parallel, OSVE and IVR views were found to possess a high impact on understanding the idea about the project and how would it be like to be inside that volume (Q911 in Figure 4.18).

Another aspect of the current study was to measure effectiveness of collaborative feedback process in virtual environments. At the beginning of these experiments, almost all students indicated that CAD and/or BIM models were enough for other collaborators to evaluate their projects (Q1402 in Figure 4.37). To measure the efficiency of both giving and receiving reviews, set of questionnaires have been asked to students. Further investigations through the last experiment showed that students found virtual reviewing systems were significantly beneficial towards development of their projects. Our results suggest, providing feedback while indicating problems related with the project and models with them (Q1304 and Q1311 in Figure 4.36), and communicating through reviews in virtual environments were highly useful (Q1310 in Figure 4.36). Another major outcome was the high level of consensus has been reached on usefulness of received reviews through virtual environments. To students, these reviews were constructive for the development of their projects (Q1404 and Q1410 in Figure 4.37).

Further research is urgently required on this state-of-the-art technique and its imminent effects on how we deliver our education using this technology. The study recommend, the sample in future studies shall be extended to the instructors of the design studios as well as professionals. Such inclusion will effectively study the influences of virtual environments in architectural teaching and practice from a broader perspective. Different teaching methods, curriculum aims, personal skills and interests can differentiate the students' approaches to such innovative systems. Since architectural education is not handled within the same methods in every university, applying the same experiments in other universities with a different sample may results differently. Additionally, it needs to be noted that including physical and more virtual presentation methods would increase the scope of the research. Also, significant challenges in methodological aspects through conducting the current study have been faced. To overcome, the current study strongly argues that standard measurement techniques on spatial perception and collaboration must be proposed. These will ultimately eliminate the bias that may be inherit in the research process as well as these will ensure the ability to compare results obtained from different works.

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