Doctoral Thesis

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Affordance-based Design Review Method using Virtual Reality

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PREFACE

This thesis is submitted by the author to Shibaura Institute of Technology in partial fulfilment of the requirements for the Doctor's degree in Regional Environment System course. The studies were carried out between the period of 2019-2022 under supervision of Professor Michihiko Shinozaki in the Laboratory of Design Science in Architecture and Urban Studies, Department of Architecture, Graduate School of Engineering and Science, Shibaura Institute of Technology.

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Tokyo, September 2022

Fauzan Alfi Agirachman

“Then which of your Lord’s favours will you both deny?”
Q.S. 55:13

ABSTRACT

In the architectural design process, the architect visualizes his works to communicate their ideas to project stakeholders. So, they can understand what the architect's ideas are. The media technology used by an architect for visualization is developed and more sophisticated from time to time. One of them is immersive virtual reality (IVR) technology. It helps architects to develop spatial elements by intensifying spatial experiences that can be perceived by human senses in an immersive way, unlike other visualization media. Due to its spatial advantages and re-emerging in recent years, researchers in the architecture field explored VR technology for various purposes in the architectural design process. One of them is in the design review process. Unfortunately, most studies tended to utilize qualitative boolean responses only, such as good or bad. There is a need to adopt an approach that treats user perceptions in the design process. So, we adapt the affordance concept from ecological psychology study for a design review process.

This study aims to develop an affordance-based design review method in architectural design by utilizing immersive VR technology. It is at the intersection of architecture design, VR, and affordance study. This study was designed to develop an affordance-based review method framework, develop a VR system that supports the method, test out both method and VR system and evaluate the effectivity of VR system as the companion system for affordance-based design method process. The study was conducted in the scope of architectural education settings only and used a third-year architectural design studio course as a case study.

There are eight chapters in this study. Chapter 1 serves as the introduction to the study, including its background, motivations, problem statement, goals, objectives, scope, and structure. Chapter 2 presents the literature review for the study. It covers the virtual reality technology and affordance study in architecture. Chapter 3 covers how the affordance-based design review process is defined and works from defining the affordances into Affordance Structure Matrix (ASM) to data analysis processes, including the proposed Present-Disappear-Stagnant (PDS) Process.

Chapter 4 conducted a pilot study for a VR system as a proof of concept. It explored the user interaction inside a virtual environment (VE) with a Building Information

Modeling (BIM) model as a digital entity connected to a cloud-based database. Chapter 5 extended the prototype and brought its basic interaction model as the foundation of Virtual Reality Design Reviewer (VRDR) development. VRDR was designed to help students review their design works in the nuance of the architectural design studio course.

Chapter 6 exercised a simulation by utilizing VRDR in performing an affordance-based design review method to design works from a third-year architectural design studio course. In the simulation, three sets of data analysis were performed to find which design components of the reviewed design works achieved the studio objectives and which components must be improved, which affordances that are easy to be perceived with the non-VR and VR system, and the effectivity of VR system for performing design review process in terms of affordance ability to be perceived.

Chapter 7 extended the exercise of VRDR utilization by performing two parts of the study. Part 1 implemented VRDR in an ongoing design studio course with a student and a supervisor. Part 2 performed a confirmation study to affirm the result of Part 1. In conclusion, this study confirms that the affordance-based design review method using virtual reality helps students improve their design work by revealing the presence of positive and negative affordances in his work. It also reveals the differences between a student and supervisor in perceiving the affordances for reviewing design works. The comparison of media effectivity also confirmed the obligation of physical properties for perceiving affordances by users. Further discussion on practical workflow of the design review method and the advancement compared to other VR systems were explored in Chapter 8.

In the end, at Chapter 9, this study developed a framework of affordance-based design method using VR technology. It describes how the affordance-based design method is implemented in stages. Since it was tested only in educational settings, a future study may be performed to find the method’s effectivity in professional settings.

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CHAPTER 1
INTRODUCTION

1.1. Background and Motivation

In the architectural design process, visualization is one of the vital processes for an architect or architectural designer to communicate his ideas. *Visualization* illustrates ideas that have not been physically developed or are still visually abstract to other project stakeholders. The objective is that the stakeholders, either individually or communally, understand the ideas as clearly as possible. This communication process is essential to ensure that the proposed design is the best solution. Through the visualization process, every stakeholder will have a common understanding of the ideas presented. Although the communication process and presentation of architectural ideas seem full of rhetoric, the media technology used for architectural design visualization is one of the critical requirements to ensure the information is well-delivered (Lymer et al., 2009).

The technology of architectural visualization media is developed from time to time. The inception started from as simple as clay or paper to the rise of personal computers with computer-aided design (CAD) technology, which was commonly used in the 1980s until today. Although its presence was considered something revolutionary in its time, CAD is just a two-dimensional drawing production tool that was considered sophisticated at that time because architects can create a three-dimensional view of technical drawings (Carreiro & Pinto, 2013). In the late 1980s, Building Information Modeling (BIM) technology was also introduced as an architectural visualization technology that could integrate design information comprehensively. The model can be observed in three dimensions and be viewed from different points of view according to the communication needs.

At the beginning of the 21st century, computer graphics technology, which was rapidly developed, positively impacted the development of visualization media technology. The visualization outputs were more realistic than ever. One of the technologies that grabbed attention was immersive virtual reality (VR) technology.

This technology lets users explore and understand architectural designs more extensively beyond physical limitations in virtual environments (Vital, 2006). VR allows architectural designers to develop spatial elements by intensifying spatial experiences, unlike other visualization media. VR technology re-entered the end-user's market in early 2011 with more affordable devices with a more realistic virtual environment experience. In contrast to the year 2000, VR technology could not meet user expectations and unaffordable operational costs for end-users (Leigh et al., 2013; Sherman & Craig, 2003). This situation opened up opportunities for practitioners and academics in the field of architecture to explore the utilization of VR technology in architecture, especially in the design process (Ries, 2011) by using head-mounted display (HMD) devices (Figure 1.1).

Figure 1-1. A person wearing a virtual reality head-mounted display (HMD) device.

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To find out the state of the art, we performed an initial review of VR technology research trends in architecture. We mapped them into several topics. They are ranged from "the use of VR to analyze user behavior, form and space, building construction and its impact on the environment and building performance"(Globa et al., 2019; Kalantari et al., 2018; Morse & Soulos, 2019; Nagy et al., 2018; Nguyen et al., 2019; Rogers et al., 2019; Scorpio et al., 2021; Wang et al., 2019); "VR for collaborative and participatory design" (Chung et al., 2009; Dorta et al., 2019; Fabian Dembski et al., 2019; Fröst, 2002; Loyola et al., 2020; Nandavar et al., 2019; Oprean et al., 2018; Schubert et al., 2019); “VR for digital heritage preservation” (Bekele & Champion, 2019; Gaitatzes et al., 2001; Kalarat, 2014; Rua & Alvito, 2011; Souza, 2020); “VR as experimental design education tool” (Bartosh & Anzalone, 2019; Kieferle & Woessner, 2020; Kun Yuan et al., 2012); “VR as design canvas” (Castelo-Branco et al., 2019; Coppens et al., 2019; Rogers & Schnabel, 2018); until “the impacts of VR implementation to designers” (Boletsis & Cedergren, 2019; Chirico et al., 2018; Diemer et al., 2015; Ghani et al., 2012; Heydarian et al., 2014a; Higuera-Trujillo et al., 2017; Plechatá et al., 2019; Triberti et al., 2014).

Based on the description above, most of the research done has not touched the disruptive side of VR technology when it is included in the design review process in an ongoing architectural design process – especially in architectural education. In architectural education, the design review process generally involves students presenting the final design and getting feedback from supervisors, fellow students, or even professional architects who are invited to be judges (Lymer et al., 2009). What if a similar process was implemented using VR technology? Of course, ideally, all participants in the design review session should enter the same virtual environment. However, when asked to review the design, participants will tend to refer to qualitative expressions such as beautiful, less sturdy, etc. Some studies using a quantitative approach also utilize ratings choosing either good or bad (Kuliga et al., 2015).

Indeed, the goal of architectural design is to develop a design in which users can interact safely and productively and take into account the critical elements of human interaction, including perceptual abilities and motor control (Pagano et al., 2021). To review whether the architectural design that has been designed has achieved the final goal, an approach that treats user perceptions is needed in it. Ecological psychology approaches, particularly the concept of affordances, provide an empirical basis for this framework. Thus, the primary motivation of this study is to explore the adoption of the affordance concept from the realm of ecological psychology as an approach in the architectural design review method by utilizing VR technology as the visualization media.

In contact with architecture studies, the interest of affordances concept has brought several topics based on our reviews, such as research on enabling affordances in architectural education, affordance concept utilization as a design method, and user-driven designs. Meanwhile, in conjunction with VR studies, topics such as user-oriented design, medium performance, and comparison for perceiving affordance were also explored. As summed up in Figure 1-2, this study is situated at the intersection of VR, architecture, and affordances studies.

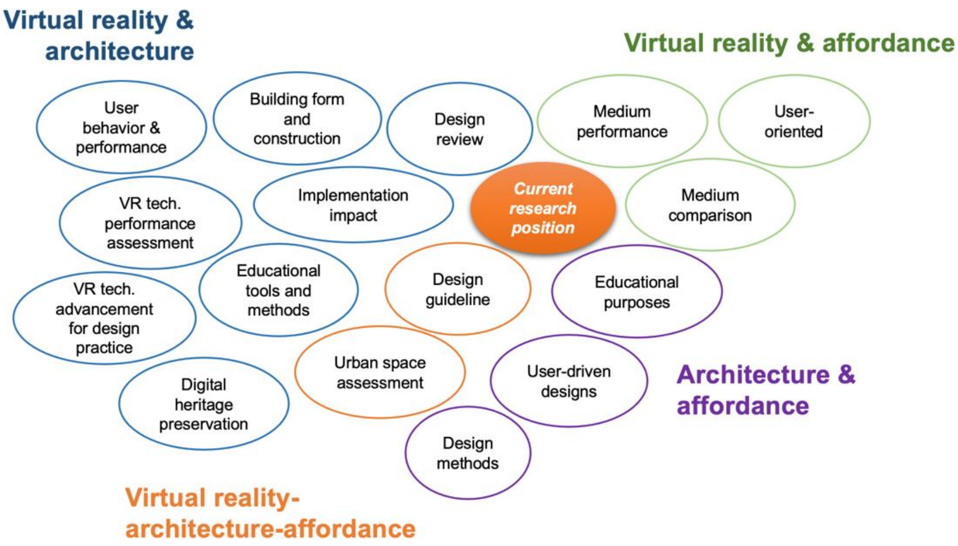

Figure 1-2. The research position in the virtual reality-architecture-affordance studies.

1.2. Problem Statement and Expectation

We learned that the trend of VR adaption in architectural design has increased in recent years due to increased interest in VR technical capability to let architects and other design stakeholders do initial previews or even perform initial reviews on the design itself. In the architecture education segment, adaptation efforts have been conducted by researchers and lecturers to use VR in the design studio, starting from the technical adaptation process (Aydin & Aktaş, 2020; Dvorak et al., 2005; Kamath et al., 2013; Tang, 2018; Tsou et al., 2017), pedagogy exploration (Al-Qawasmi, 2006), performing qualitative appraisal (Angulo, 2013, 2015) on the student works, collaborative learning (Rodriguez et al., 2018), and visualizing construction process (Bashabsheh et al., 2019). The efforts that have been made were still limited in the scope of technology application and have not touched yet the operational side of how VR can be used to improve the quality of architectural designs done by designers. The design review process in VR was still limited to vague qualitative variables and required further cognitive interpretation by architectural designers (Angulo, 2015; Kuliga et al., 2015). A more specific review method should be developed. A thorough approach is needed to do that so that architectural designers can review their designs more explicitly.

We explored the study of affordances concept from ecological psychology study and found that researchers have explored the possibilities of affordance concept adoption in architectural design. It was ranged from the analysis of affordances uses in architecture (Koutamanis, 2006) until the development of an affordance-based approach to architectural theory, design, and practice (Maier et al., 2009) that led to affordance-based design (ABD) approach that offers a shift in design thinking from functional-driven to user-driven (Maier & Fadel, 2009a, 2009b) and its operational method (Maier et al., 2008). After that, the adoption of ABD was performed by researchers to enhance the design process, which was focused on the designers (Gero & Kannengiesser, 2012; Gupta & Uma Maheswari, 2019; Masoudi et al., 2019a; Srivastava & Shu, 2012) and the design outputs (M. K. Kim, 2020; Maheswari et al., 2017; Wineman & Peponis, 2010). With that, the concept of affordance – especially the ABD, could be adopted as an approach for the design review method. Then, we looked through the study on the utilization of VR technology and affordances approach in architectural design. The studies were an exploration of affordance perception in VR to help architects understand the effects of designs on users (Regia-Corte et al., 2013) and for urban space assessment (Globa et al., 2019). Our review found that there is insufficient research on the triangulation of these topics, specifically in the architectural education and design review process, which becomes our focus.

On the other hand, this study was also motivated by the COVID-19 pandemic that was happened globally. The pandemic has forced architectural education institutions worldwide to arrange their academic activities differently. Institutions organize online classes, workshops, and design studios to avoid viral community transmission within students and supervisors. Unfortunately, both students and supervisors have difficulties in an architectural design studio, a hands-on practice, and assessment by nature (Allam et al., 2020). Students cannot present their design works appropriately in front of their screen, and it is hard for supervisors to engage with students' works without any direct hands-on session. It needs a technology that can bridge them gearing verbal presentation, discussion, and assessment in a learning process (Lymer et al., 2009). Looking at this phenomenon and the possibility of using VR technology, we see an urgency and opportunity to develop a method that can be used in architectural education during the pandemic – precisely, the design review method. We expect that this method helps students and supervisors when doing remote learning and could lead them into a new point of view from functional-based to user-oriented based on perceived affordances during student works review.

1.3. Research Goals and Objectives

This study aimed to develop an affordance-based design review method in architectural design by utilizing immersive virtual reality technology. In carrying out this study, the process of formulating a design review method framework using an affordance-based approach and the development of prototypes related to the virtual reality application used would be carried out.

Furthermore, a trial implementation of the design review method framework and virtual reality applications was carried out in educational settings. This was done to determine how effective the design review method and virtual reality application were in the architectural design review process. The trial was conducted in an ongoing architectural design studio course, including the building design iteration process that utilizes the design review method. Thus, it can be seen the effectivity of the affordance-based design review method based on the results of architectural design interations developed by the student. To obtain comparison results, a similar design review method was used by the student’s supervisor and further confirmation study was also carried out.

In principles, there are four objectives designed to achieve the study objectives, as follows:

a. To develop an affordance-based design review method framework that includes defining inventory input requirements, mapping affordances as a reference for the review process, and data analysis processes that produce output and feedback for designers

b. To develop a VR system that supports the affordance-based design review method process

c. To test out the VR system and the affordance-based design review method through the implementation in an ongoing design studio course, and

d. To evaluate the effectivity of VR system as the companion for affordance-based design review method by comparing with the non-VR media.

1.4. Scope of Study

This study was conducted in the scope of architectural education settings only. The case study was the third-year architectural design studio course and third year bachelor of architecture students in Bandung, Indonesia. As for the apparatus, we were using an immersive VR head-mounted display (HMD) device due to its portability and ease of use.

1.5. Structure of Study

This section explains the chapter organization of the thesis. It is mainly comprised of eight chapters with three highlights in between, as illustrated in Figure 1-2. The first chapter is the introduction to the thesis, followed by the literature reviews as the first highlight that includes the study of virtual reality technology utilization in architecture and the theory of affordance (Chapter 2). The second highlight is the methodology where we cover the affordance-based design concept adapted as design review method (Chapter 3) and the technical development of VR tool used in this study, including VR interaction model pilot study (Chapter 4) and the development of Virtual Reality Design Reviewer (VRDR) in Chapter 5. The last highlight is the implementation process, where we discuss the case study used for implementation and the result. It comprises the implementation of the affordance-based design review method on student works retrieved from the faculty archive

(Chapter 6) and in an ongoing design studio course (Chapter 7). In a separate chapter, we add in-depth discussion on practical workflow, technical advancement, and concept used in this study (Chapter 8). We conclude the research outcomes and findings with a framework of affordance-based design review method (Chapter 9).

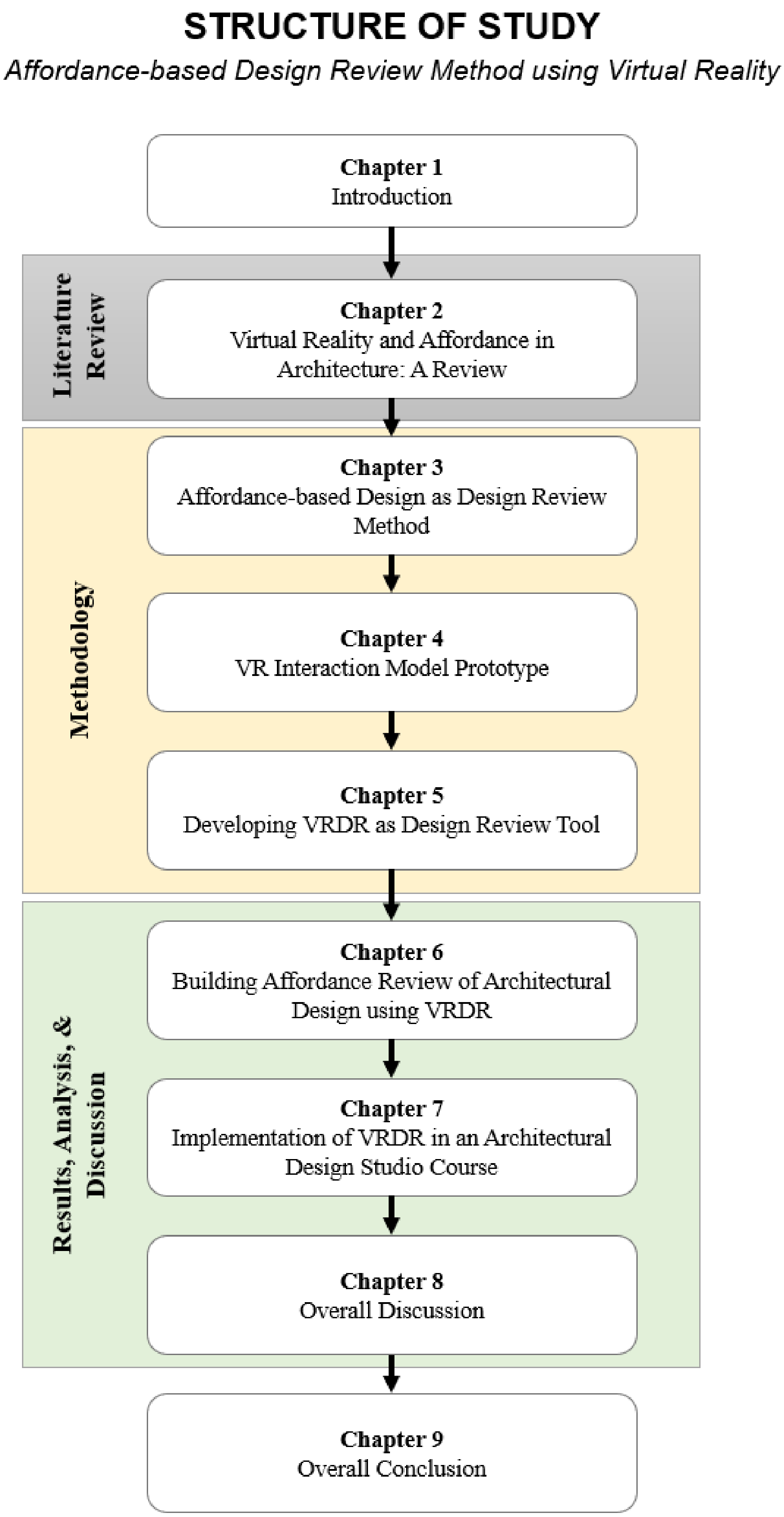

Figure 1-3. The structure of the thesis

CHAPTER 2
VIRTUAL REALITY AND AFFORDANCE IN ARCHITECTURE: A REVIEW

2.1. Introduction

Chapter 1 reviewed literatures supporting the study. It comprises two parts. In the first part, we reviewed a series of scientific articles related to VR technology in architectural design. We discussed VR technology as a tool to support the design review process, especially in educational settings. The review started with a brief introduction to virtual reality technology and its trend in architectural design studies. This section mainly discussed the VR technology was explored in the architectural design process and how the technology was shaped up for digitalization in architecture design, especially in educational settings. Furthermore, from a technical perspective, we also reviewed the VR platform selection used for the design review process that impacts the research that should be carried on.

In the second part, we reviewed the concept of affordances. The discussion began with the presence of the Theory of Affordance, which James Gibson coined in 1979, to develop theories, theses, and arguments of researchers in the study of Ecological Psychology around the concept of affordance, which continues to roll. The discussion continued to review the adoption of the affordance concept in the realm of design, especially in architecture, and various studies related to the affordance approach in the architectural design process. We also reviewed how the design review method can be carried out using an affordance-based approach and how to define the components of the design review to be operationalized in the architectural design process.

2.2. Virtual Reality as Architectural Design Review Tool

Virtual reality (VR), as defined by (Isdale, 1998), is an idea of how people "visualize, manipulate, and interact with computers and extremely complex data." It is formed as a three-dimensional spatial environment generated by a computer where human participates inside it in real-time (Isdale, 2003). VR is also defined as a medium for simulating a new reality. People interac

t with three-dimensional objects inside it using their senses to feel immersed in the shaped reality. (Gutiérrez A. et al., 2008; Sherman & Craig, 2003; Whyte & Nikolic, 2018). A virtual environment within VR is considered as immersive when users feel fully involved inside it as if they were involved in a real environment. This particular technological capability makes VR interesting to be explored further in the built environment, specifically in the scope of architectural design. Moreover, there is a new enthusiasm for the emergence of virtual reality technology which is now easily accessible and more familiar among end users.

2.2.1. The Virtual Reality

Virtual reality (VR) technology was started as multi-sensory real-world simulation in early of 1960s. A cinematographer named Norton Heiling developed a multi-sensory simulator system called Sensorama in 1962 (Gutiérrez A. et al., 2008). This system let a user to enjoy several driving situation using several kinds of vehicle such as bicycle, motorcycle, or helicopter. Sensorama (Figure 2-1, left side image) used a wide field of view optic to enable users seeing a 3D photographic view with a stereo sound, environment ambience, and fragrance generator. The user system could only become a passive observer since user could not interact with the generated environment inside.

Figure 2-1. Sensorama, Sketchpad, and "The Ultimate Display" are the first Virtual Reality systems. (Source from(Gutiérrez A. et al., 2008)

In 1963, Ivan Sutherland from Lincoln Laboratory of Massachussets Institute of Technology (MIT) developed “Sketchpad” (Figure 2-1, center side image) which later became the origin of computer-aided drawing (CAD) program. He described the system as “a man-machine graphical communication system” that helped users creating line drawing instead of typed statements for idea communication (I. E. Sutherland, 1963). Five years later, Sutherland developed a head-mounted display (HMD) device that could represent the left and right eyes views of a computer-generated 3D display (Figure 2-1, right side image). The device tracked the movement of the user’s head to match the displayed impression. This gives the user an illusion of being in a virtual environment. The HMD device was an embodiment of an article he authored in 1965 entitled “The Ultimate Display”. In the article, (I. Sutherland, 1965) described the concept of a screen where user could interact with objects in a world that did not follow the law of physical reality. Due to his achievement, Sutherland is well-known as the father of virtual reality system.

VR technology began to be commercialized in the early 1980s. In 1981, Silicon Graphics Inc. founded by a professor from Stanford University and also former student of Sutherland, Jim Clark together with his six students to produce high-performance graphic workstations. These machines were mostly still used in several VR development centers in the early of 2000s (Sherman & Craig, 2003)). Another company, VPL Research, which was founded by Jaron Lanier, was also developing VR system. Jaron is the one who coined the term of “virtual reality”. VPL Research developed DataGlove, a glove-based input device with HMD, and rendering software, until being acquired by Sun Microsystems in 1998.

Despite of the commercialization, VR HMD device was not ready to meet all expectations yet – from unstable hardware, slow computing process, and cybersickness phenomena being common problems among users at that time. So in the 1992, the VR interface paradigm switched from HMD-based into the CAVE system (as seen on Figure 2-2) which was demonstrated first at SIGGRAPH ’92 by the Electronic Visualization Lab or University of Illinois, Chicago. In constrast to HMD device, CAVE is a multi-user system that allows users to physically use their bodies and hands in the virtual environment and move freely within the boundaries.

Figure 2-2. CAVE VR system. (Sourced from (Leigh et al., 2013)

Several years later, in 2012, immersive VR technology was re-emerged into the end users' market with the release of Oculus Rift Development Kit 1.0 (DK1) released by Oculus VR (Figure 2-3). The Rift is a VR HMD device equipped with two OLED screens on both left and right eyes with 1080p high definition resolution. The rapid development of computer technology and the chip miniaturization carried out on smartphone development allows immersive VR HMD devices to be more sophisticated than the ones we saw in 1990s. The rise of VR industry marked with the acquisition of Oculus VR by Facebook. In 2021, Facebook changed the company name into Meta and brought the VR technology to the center stage for building a future network called "metaverse". Beside Meta, other companies have launched various versions of immersive VR HMD devices such as HTC Vive and Sony Playstation VR.

Figure 2-3. Oculus Rift Development Kit 1.0
(Credit: Sebastian Stabinger, CC BY 3.0 via Wikimedia Commons)

2.2.2. Trends of Virtual Reality Studies in Architecture

Throughout these decades, the trend of studies related to virtual reality technology in architecture has developed rapidly along with the technology adoption to the end-user. Most researchers explored how VR technology can be utilized in the design process and collaborate with stakeholders. As a technology, VR can produce an illusion of being in an environment acceptable to a user as a trusted place to exist with sufficient interactivity and perform various tasks efficiently and comfortably (Gutiérrez A. et al., 2008). Dagit III (1993) mentioned that five factors form VR experience

- immersion (the sensation of being around the user),
- presence (a feeling as if present in the generated environment),
- interactivity (engage with the generated environment),
- autonomy (freedom to act and explore), and
- collaboration.

Meanwhile, Sherman & Craig (2003) stated that the VR experience is shaped by four factors: the existence of a virtual world consisting of a collection of objects in the space with rules and relationships that govern them; immersion or the sensation of being in the environment including physical immersion, mental immersion, and a sense of presence; sensory feedback or feedback that can be felt directly by users with their senses; and interactivity that users can respond to through direct actions.

VR technology aims to provide "compelling, intuitively interactive and immersive experiences within virtual environments" (Whyte & Nikolic, 2018). In the built environment field, especially in architecture, VR technology is used to help designers and parties related to a design project understand the proposed design and construction projects across the phases. Not only used as passive and exploratory systems, but the VR system also can be used to bring more value-added information by extending the existing physical environment with new possibilities (Paranandi & Sarawgi, 2002).

VR technology offers many potentials on supporting architects' works, especially in some aspects that might not be expected before. Studies have shown that VR technology allows an architect to explore design alternatives that consider user personality traits (Banaei et al., 2020), do a usability study during conceptual design (de Klerk et al., 2019), determine the way architect designs façade geometry and associated sunlight patterns based on users' responses (Chamilothori et al., 2019), and provide a better spatial perception for better understanding on a spatial arrangement that architect explores (Paes et al., 2017). Naz et al. (2017) found that designers can use virtual environments as a vastly effective aesthetic tool that enables them to do space changing to trigger human emotional responses. So not only serves as a tool to evaluate a real-world spatial condition but VR can also be utilized to explore real-time space making as an aesthetic medium.

Researchers also examined the relation of VR technology to the architectural design process, education, collaboration, and practice with various stakeholders (Freitas & Ruschel, 2013). For example, for individuals who do not know architecture representation, VR helps them perceive a more accurate design project (Serpa & Eloy, 2020). It also enables designers to visualize relationships between architectural design, space layout, and thermal conditions, and at the same time, it facilitates better design feedback (Hosokawa et al., 2016). In addition, VR can create visualization sessions for design team members, thereby eliminating the need to travel (Johansson et al., 2014). Then, designers can simulate specific environment models and noise settings to validate a design with various user reactions (Moural et al., 2013). VR also provides in-time feedback to improve the design and even increase designers' understanding of the designed space (Angulo, 2013). Immersive VR can also help designers make "more informed and focused project decisions" (Coroado et al., 2015).

Furthermore, an architectural paradigm developed with a building information modeling (BIM) process can enhance an immersive VR environment. BIM combined with VR helps project stakeholders communicate (Sacks et al., 2018), share a common understanding of the design, and improve efficiency compared with a workflow without VR (Sampaio, 2018). BIM data imported to a virtual environment (VE) enables a designer to interact with his design with agility (Nadavar et al., 2018). Since current VR peripheral tools are more accessible and sophisticated, architectural designers can find various ways to deliver BIM information with VR (Sacks et al., 2018). Bringing BIM models inside a VE allows a user to have a real-life perception of the object.

2.2.3. Notions of Design Review Process in Educational Settings using Virtual Reality

In the architectural, engineering, and construction sectors, researchers have studied that the design review process has become one of the VR technology use cases. VR provides a more efficient design review process and helps stakeholders identify issues easier (Davila Delgado et al., 2020). VR is also able to assist architectural designers for space assessment ranging from spatial relationship, occupation comfort, visual and audio comfort (Berg and Vance, 2017; D'Cruz et al., 2014; Echevarria Sanchez et al., 2017; Liu and Kang, 2018; Sun et al., 2020). VR also can help non-designer to examine architectural design with ease (Serpa and Eloy, 2020). Even after the design development phase, VR can support stakeholders during the construction phase by improving communication between professionals, visualizing design review scenarios in construction, and analyzing building constructability (Bassanino et al., 2010; Boton, 2018; Dinis et al., 2020). Besides, VR usage for design evaluation in the operational phase is also explored. (Akanmu et al., 2020)

VR technology has a substantial capacity to be implemented for the design review process, especially in the architectural education setting. Wickens (1992) highlighted how the virtual reality itself as a concept "is created by an impressive, exciting technology that readily engages the user's interest." With that concept, VR opens an opportunity to those involved in the education business to improve or expand their learning environment. Bringing VR as an "instructional medium," Wickens saw some justification regarding additional cost from the technology. VR could give a motivational value or even show their users a different or even novel perspective. Also, there would be a "transfer of the learning environment" from physical to virtual environment, which should be supported with a "natural" interface.

Researchers developed VR systems and applied them to the design studio in various forms. For example, Dvorak et al. (2005) used a synchronized dual personal computer (PC) and stereoscopic projection for their system, Kamath et al. (2013) proposed a VR system with PC, projector, and 3D passive glasses, Angulo (2015) equipped her system with a head-mounted display (HMD) with spatial tracking capabilities. Bashabsheh et al., (2019) developed software based on VR technology for building construction courses. Those proposed systems were tested and showed that VR systems could help students understand their designs better, especially the relation between spaces and places. The system helped supervisors share their knowledge and detect hidden flaws in students' work.

Researchers also found that students get benefits that help their learning process understand the architectural space and design process using VR technology in architecture education. Dvorak et al. (2005) showed that VR helps increase students' speed and insight in learning architecture. They also found that VR is suitable for students to understand modeling and design faster because they focus on more prominent issues. Horne & Thompson (2008) explored the integration process of VR technology as visualization technology into the teaching process and sought responses from tutors on the integration. From the technical perspective, VR has been proved reliable and stable technology and helped them facilitate model exchange. They found that VR technology can extend students' learning processes and improve their motivation and awareness. VR provides "being there" with immersive interaction between students and their design works. It is considered vital because behavior, cognitive outcomes, and users' subjective experiences must be considered by the architectural designer when evaluating a building design using

VR (Kuliga et al., 2015). Tsou et al. (2017) proposed an integrated system supporting architectural design education, which lets users explore, discuss, and manipulate 3D objects within the virtual environment. Users operated the system using a VR controller, addressing many issues during the trial.

Regarding implementation into the curriculum, Aydin & Aktaş (2020) explored how VR technology can be brought into design education by developing a contextual curriculum. They found that digitalization in teaching design needed student response and contextual planning without seeing how advanced the types of equipment are. Even though it looked very technical, VR technology could be acceptable in design studios as a vital part of digital learning. However, it would happen with two catches: the compatibility between studio tasks and the VR tools themselves; and the students' interest and skills on VR experiences in prior.

2.2.4. Virtual Reality Platform Selection for Design Review Process

Researchers should pick a suitable VR system for their needs and research objectives to reach optimal performance. A VR system setup must mediate users with the virtual environments (VEs) they will experience. This system includes input and output devices with a range of hardware and software generating the graphics in which the VEs are displayed. According to the classification made by Brill in Biocca & Delaney (1995), VR systems are classified into six different systems. From all classified systems, we found out that there are three systems used in the various VR experiments and various research which the articles we reviewed in this study. They are window systems, immersive virtual reality systems, and cave systems.

First is the VR window system, "a computer screen provides a window or portal onto an interactive, 3-D virtual world." This system is a typical desktop VR system we can find today. Users need a desktop computer and sometimes 3-D glasses for stereoscopic effect for higher immersion. The second is an immersive virtual reality system. It is a system where a user wears a pair of displays that "fully immerse a number of the sense in computer-generated stimuli." Today, the options are between HMD devices, built-in stereoscopic displays, or the CAVE or Cave

Automatic Virtual Environment system. Users come into a space with a large screen surrounding a specific virtual environment that is almost continuously stitched.

When people decide which VR system they should use to accomplish their objectives or tasks, many factors come up in their minds, such as usability, portability, graphic performance, and cost affordability. Based on articles and their study results that we reviewed so far, we found two common factors in considering a VR system to pick. The first factor is user performance on accomplishing tasks. This factor covers how fast users can finish tasks that require spatial information to accomplish them, interaction mistakes that were occurred by the users, and the users' rate of tasks completion. The second factor is the degree of immersion and presence the system provides to the users. As described by Slater (2003), immersion refers to "the objective level of sensory fidelity" that a VR system provides, and presences refer to "a user's subjective psychological response to a VR system." Each VR system has a different hardware and software setup that affects how users are immersed and present in the displayed VEs.

2.2.4.1. User Performance on Accomplishing Tasks

As we reviewed the literature, each article focuses on measuring user performance on accomplished tasks using selected VR systems and provides mixed results that are interesting to discuss. For example, in a study done Pausch et al. (1997), they found out that users wearing HMD completed object searching tasks faster than those who used a stationary monitor and hand-based input interface. They were also substantially better at deciding when they had scanned the targeted room while they were told if any target existed. Meanwhile, users using the desktop system took 41% longer because they were re-examining areas they had already checked. They also found a positive transfer of training if users started using the HMD interface first and then moved to static displays. Contrarily, users felt a negative transfer of training when they performed the tasks using static displays first and moved to the HMD interface on the second chance. This study results also hint that HMD-equipped VR can assist users in remembering which objects they have and have not seen yet.

Another article that utilized HMD as the VR system (Ruddle et al., 1999) saw that their research participants could navigate buildings significantly faster and with a more accurate sense of relative straight-line distance when using HMD. By using behavioral analysis, the result showed that participants used the natural head-tracked interface from HMD while exploring the virtual environments (VEs) and spent less time on choosing a travel direction inside the VEs. Bowman & McMahan (2007) found that higher levels of immersion can contribute to improved interaction task performance, and users equipped with stereoscopic displays like HMD can do the task two times more quickly with eight times fewer errors made. Then, Lin et al. (2021) discovered that the VR-aided design process with an HMD system could reduce the operational difficulty for non-professional users, especially when participating in the design process. Nevertheless, contrary to other findings, Heydarian et al. (2014) found out that in their study, participants had some trouble navigating themselves inside the VE while using HMD. They mentioned that this issue could be resolved with more practice and training.

Some researchers were utilizing the desktop system as the VR system. For example, the research conducted by Figueroa et al. (2005) shows that users feel more comfortable and familiar with the PC system. So, they tend to make more interaction mistakes than other systems. Another study in a controlled experiment (Sousa Santos et al., 2009) shows that overall user performance was better when using the desktop setup. However, for those who seldom play games on a computer, users performed better when using the HMD.

Some articles mentioned their utilization of the CAVE system. Kieferle & Woessner (2015) developed a bidirectional link between design authoring software with CAVE VR system that can improve the design and construction process heavily after performing several project tests and various discussions with professionals in the AEC industry. Then, another study (Kasireddy et al., 2016) reveals that CAVE users gave the most accurate response. Those using Oculus HMD completed the task most efficiently. However, no correlation was observed between response accuracy and task completion efficiency. In a task where users need to navigate from one point to another, they could best perform it using Oculus HMD. In the end, the study found that CAVE works the best for performing tasks requiring users to correlate spatial information and extract them since users must stand and look around - just like users do in a building construction site. Oculus HMD works most efficiently since, by nature, users can finish the task without being distracted by any situation outside the VE shown to them. Cardboard HMD was also used in the study and chosen by users due to its lightweight setup and simple gaze-based interaction.

2.2.4.2. Degree of Immersion and Perception

From the perspective of immersion and perception, each VR system in the reviewed literature shows some advantages and disadvantages that the researcher should consider. For example, on the desktop system, Dorta (1996) developed a concept called Drafter Virtual Reality (DVR) that used QuickTime VR (QRTV) as the desktop system. His study shows that DVR maintained more personal touch compared to a rendering scene generated by a computer.

For the HMD system, according to the study performed by Bai, Rui-Yuan and Liu (1998), HMD-equipped VR systems were appropriate for users to capture factors such as approaching movement, lighting, glare, object proportion, material, and plane topography. Even though the capacity was minimal, the system is considered very effective. Meanwhile, Mizell et al. (2002) found that head-tracked immersive VR had statistically significant advantages compared to joystick-controlled display modes. This result demonstrates that immersion supports the experience at the highest level when the VE data is, in some sense, immersive and the surrounding geometries are visualized naturally.

Another study (Bowman & McMahan, 2007) demonstrates that immersive VR offers a different experience than 3D application interaction on desktop PCs or gaming consoles. Users inside an immersive VE act differently. A good immersive VE relies on the realistic experience provided to the users. A high level of sensory fidelity such as visual, auditory, and other senses are required to cue similar experiences with the real world. It must be as close as possible to match the real-world experience. Once the experience reaches a high level of immersion, it will produce a sense of presence. Immersion has positive effects on spatial understanding. Head tracking, stereoscopy, and wide field of range (FOR) need to work together to deliver positive effects. Users can give sensory feedback when interacting inside VE and communicating with other users with other prototyped haptic glove systems (Camacho et al., 2019).

According to Shu et al. (2018), users sensed a higher spatial presence and immersion while using HMD compared to the desktop system. Using the HMD system, users experienced more attention and more significant presence inside the VEs, and the movement they have done was closer to the real-life situation. However, despite higher presences with HMD, users tended to get motion sickness which caused them to feel dizzy. It is also found that involving VR technology in a course learning process improved users' spatial cognition and helped them understand spatial instruction (Merchant et al. in Huang et al., 2016). Another similar finding was found (de Vasconcelos et al., 2019). HMD system delivers a more immersive experience than CAVE due to its capability to block the visual perception of the physical world. Nevertheless, separating from the physical world might distract some use cases, such as collaborative works.

There are also some comparative studies between VR systems to see which system is sufficient for delivering immersive experience and bringing presence to users inside VEs. K. Kim et al. (2012) found that each VR technology had different effects on human emotional responses despite doing the same tasks in three different systems: desktop, HMD, and CAVE. The desktop system gives minor emotional changes to the users. In contrast, the CAVE system commenced the most considerable positive emotional impact, and the HMD system gave the most significant negative emotional impact to the users. Also, compared to its counterpart in the natural environment, immersive VE looks very appealing in terms of interior room setup. (Heydarian et al., 2014)

Horvat et al. (2019) also worked on a comparative study between interface on a desktop and HMD systems. They asked participants to review the 3D CAD model using both systems, mainly by performing model dimension measurement tasks. The result shows that HMD system-equipped VR enhances users' spatial perception of the models at different complexity levels. Users also might be able to recognize the model and estimate the model dimension if they were aware of its function. The differences between systems were distinct when participants were reviewing models with higher levels of complexity. Participants tend to have a lower relative error when using HMD than the desktop system.

In conclusion, each VR system has its advantages and disadvantages that affect users' performances, perception, and immersion capability when assessing space in the virtual environment. The desktop system is considered more familiar for a specific group of people in user performance and allows users to make interaction mistakes. It is also more feasible on passive or lesser active tasks. Meanwhile, the HMD system favors faster user performance with minimal distractions and fewer errors, and the CAVE system provides the highest accuracy of users' responses. Regarding the degree of immersion and presence, the HMD system provides a higher sense of spatial presence and immersion but with a catch that the displayed VEs should deliver users' high expectations of a more immersive experience. The desktop system can provide similar performance with immersive setup in VEs with less complex visualization. We should pay attention to the virtual environment design to maximize the chosen system capability and reach optimum user experience and performance.

2.3. Affordances

Ecological psychology study was raised in the 1970s as an alternative theory that considered perception a cognitive process. This study examined how meaningful information related to the three-dimensional world does not disappear but is conveyed through the sensing system. Ecological psychology started from analyzing the elements that make up the environment to the supporting information such as light elements for the sense of sight and acoustic elements for the sense of hearing. Then, treating perception and motor control as a reciprocal unitary (Turvey, 1990; Warren, 2006) which serves as the basis for understanding how affordances provoke specific actions, attitudes and interactions are more likely to occur (Rietveld and Kiverstein, 2014; Withagen et al., 2012; 2017). Because affordances can provoke user action, a well-designed environment will support users in selecting various affordances and eliminate the need to use their cognitive abilities.

It is why there is a possibility for an architect or architecture designer to utilize affordances during the design process – precisely the design review stage.

2.3.1. The Concept and Its Development

In his seminal work entitled “The Theory of Affordance”, Gibson (1979) described affordances as the relationship between the features offered by the environment and the ability of individual surroundings to take advantage of the environment. Therefore, affordances are neither in the individual nor in the environment. Humans, as an individual, recognize each affordance as a relational property deriving from the relationship between them. For example, stairs can help a human move from one height level to another. At the same time, stairs can also cause humans to fall or get injured. Thus, simultaneously, objects in the environment affordance both desirable (positive) and undesired (negative) affordance. Each desired and undesired affordance must be easily perceived from the individual's environment.

Furthermore, Gibson mentioned that the affordance perception does not need information processing or internal representation. An individual perceives an affordance directly, adjusting to the learning process he has taken. This process is not based on individual relative properties but rather on the interacted object-relational properties. The recognition process is occurred both subjectively by the user and objectively by the object. Users perceive an affordance relative to their body capabilities (Warren, 1984; Warren & Whang, 1987) and potential action (Heft, 2003). Individuals recognize action opportunities for affordances and perceive what actions users can take with the object. That means there is a certain degree of information where the user can specify affordance. Perceptual information provided by the object specifies affordances.

Inspired by Gibson, Norman (1988) introduced affordances to product design and later inspired the field of human-interaction design as the set of action opportunities provided by a product. With his seminal work entitled "The Psychology of Everyday Things – which was revised later as "The Design of Everyday Things,” Norman (2013) collected the anxieties that users face when interacting with objects they use every day. This situation was described (Srivastava & Shu, 2012) as an affordance-based error that describes the discontinuity between the designer's motive and the user's perception Norman (1999) also developed the notion of perceived affordances as the actions the users perceived to be possible with an object and made them contrast with natural affordances, defined as actions that are possible with the object.

For many experts and researchers in ecological psychology, the concept of affordance initiated by Norman is in contrast to the concept presented by Gibson (Brown & Blessing, 2005; Chemero, 2018; Koutamanis, 2006; Masoudi et al., 2019b; McGrenere & Ho, 2000a; Osiurak et al., 2017). Gibson claimed that affordance is independent of the experience and culture of the individual or user. In many cases, however, individual actions and interactions arguably presupposed the individual's previous experiences with the same environment. Unlike Gibson, who associated affordances with an individual's ability to act, Norman emphasized them on the individual's perceptual and mental abilities. Even in his book, Norman (2013) conceptualizes affordances depending on three kinds of behavioral constraints: physical, logical, and cultural. Physical constraints are closely related to real affordances. These logical constraints use reasoning to determine the alternatives and cultural constraints based on conventions shared by a certain cultural group. In short, Gibson's affordance should be a direct one, while Norman's affordance needs a cognitive effort by an individual. The discourse related to the conception of affordances continued and branched.

Tucker & Ellis (1998) saw affordances not as properties of the environment but as motor attributes directly included in an object's visual representation. The association of individual action properties with visual properties of an object represented the individual's mental situation (Symes et al., 2007). Tucker & Ellis (2001) also found that the object-size affect – the effect of the fit between the type of the response and the object's size – is relatively transient and quickly dissipated. Indeed, the object-size effect can also occur with the expression of words or when objects are out of reach. To overcome this difference, they distinguished between extrinsic (location and orientation) and intrinsic (size and shape) properties of an object through simple grip experiments (Jeannerod, 1981; Tucker & Ellis, 2004). The intrinsic properties of objects are contained in the user's motor knowledge stored from past experiences and integrated with the representation of the object itself. These "intrinsic micro-affordances" are derived from the visual structure of objects. This idea was also confirmed with the findings (Borghi & Riggio, 2015) where affordances represent the individual's brain for possible interactions with the object.

2.3.2. Affordances in Architecture

The concept of affordance provides an alternative way for an architectural designer to view a design by emphasizing the relationship between the environment and its users. This relationship is similar between the building form and the end-users behavior as part of the building function. By using an affordance-based approach, architectural designers put their design vision into account by identifying the affordances.

Pagano et al. (2021) reviewed how the concept of affordances, in particular, should be preferred in the architecture dan design scene. The main goal of architectural design is to produce an artifact with which people can interact productively and safely. The scope of interaction between humans includes motor control and human perception. Relatively, the relationship between humans and their environment needs to be defined. It can be done quantitatively with the concept of affordances. It supports the definition of user interaction with objects and built space with minimal usage interpretation requirements. So, the design will become more inclusive since it allows the end-users to perceive the design without further cognitive elaboration and mental representation effort.

McGrenere & Ho (2000) also mentioned that to reach a design's goal, the object itself, an architectural designer must determine mandatory affordances that a design must provide. Also, he should maximize the clarity of information, describing the affordances and the ease of dealing with them. Information, such as the physical properties of the design and artificial signs, helps users specify the affordances for performing required tasks (L.-H. Chen et al., 2007). It is in line with the concept of direct perception expressed by Gibson (1979). In order to reduce users' cognitive efforts, the architectural designer should have the affordances being perceived from their designs as quickly and directly as possible. He must eliminate the need to add signifiers or other information to direct users to the affordances presence.

In more depth, Koutamanis (2006) explained how architectural designers' affordances of building components and spaces define how users interact with the building design. Koutamanis followed the concept of affordance, which Norman coined in each building component and space. According to him, affordances in architecture promise to handle functionality and usability solid, direct, and transparently. Thus, architects and architectural designers can deal with design problems intuitively. In addition, identifying affordances in architectural designs is helpful for architects to understand various aspects of users, including cognitive, perceptual, and mobility abilities of various users. Thus, affordance studies conducted by architects can produce architectural designs beyond user-profiles stereotypes and generalizations of choice. Architectural design becomes more flexible and adaptable according to the intended affordances.

The affordances of building components are derived from defined functional and structural constraints. Affordances from building components have a similar scale and user interaction with most objects. However, architectural design demands a greater functional scope. It is needed for greater flexibility based on two levels of abstraction, namely the spatial level and the interaction with the building component itself (Tweed, 2001). The spatial level is significant for formulating usage expectations and design goals, including recognizing visual clues to maintain the affordances that will be offered. This aspect must inform the user directly and without having to guess the designer's intentions for the design he makes.

Then, the affordances of spaces are derived from the everyday use of space and spatial prerequisites. In contrast to building components, spaces deviate from the general example of most affordances studies. They offer a less tangible form that allows the mapping of functions by each individual. In addition, spatial elements do not have a clear or solid interface. Spatial elements require a higher degree of abstraction because of their flexibility and adaptability to user activities. The process of abstraction from spatial elements can be done by looking at the spatial level, which refers to the internal structure of the patterns and relationships between spaces and the level of interaction associated with mapping these patterns. Generally, architects and architectural designers use design precedents or information considered valid to explain spatial patterns. By mapping the pattern and boundaries of the room in the form of a design, architects can recognize the affordances of spatial elements well. However, the relationship between form, function, and the intended affordances requires knowledge and experience of qualified architectural design practice. Even so, there are still many design solutions that can be formulated according to the basic understanding of each spatial element.

As the result of the architectural design process, buildings should not require a manual to explain how to use them, which is in line with Gibson's affordance as "direct perception." Although there are differences in cultures, affordances in buildings should support general intended functions. So, it is possible to evaluate the architectural design and the refinement of referring to affordances by their nature, such as recognizing the spatial affordance of a museum design (Wineman & Peponis, 2010) or optimizing residential design (Bitaraf et al., 2021).

CHAPTER 3
AFFORDANCE-BASED DESIGN AS DESIGN REVIEW METHOD

3.1. Introduction

Adapting the concept of affordances as part of the architectural design process is not new (Gibson, 1976; Tweed, 2001; Warren, 1995). However, few studies have addressed affordance-based design for architecture, although this approach has been applied in various disciplines, such as engineering, industrial design, and human interface design (Kim 2020). There are three main propositions of affordances application to architectural design, as proposed by (Maier et al., 2009):

1. It is related to architectural theory. Affordances can be used as a conceptual framework to understand the relationship between humans and the built environment from time to time, especially regarding the form, function, and meaning of architectural elements.
2. It is related to architectural design. The affordances allow an everyday theoretical basis of architectural design to improve the design process by offering a common language of communication with other design project stakeholders.
3. It is related to architectural practice. The concept of affordance can be used as a design review tool to explore the relationship between the initial design achievements and the final design results.

This study focused on exploring the third prepositions of using affordances in architecture, which is the design review method using an affordance-based design approach. So, similar design mistakes can be avoided to happen again. This Chapter reviewed how the design review method can be carried out using an affordance-based approach and how to define the components of the design review to be operationalized in the architectural design process.

3.2. Design Review Method using Affordance-based Design Approach

The framework of affordance-based design, developed by Maier & Fadel (2009a), started with a basic idea of having affordances of a building since we considered a building an artifact. The affordances were determined by the users' needs and the artifact's structure (spatial elements and building components). At the same time, the design process can recognize or even eliminate harmful affordances from the building design and develop or maintain the intended positive affordances. The resulting design will be formed from the expected affordances to support the desired user behavior and avoid the undesired affordances. Using an affordance-based design approach during the design process, architects identify which affordance should and should not appear in their designs by maximizing the presence of positive affordances and minimizing the presence of negative affordances. The presence and absence of both positive and negative affordances measure a design's success.

Since its inception published as Maier's Ph.D. dissertation (Maier, 2005), affordance-based design framework was initially studied with product designs as case studies such as bottle opener, light bulb, shopping cart, and vacuum cleaner. Furthermore, researchers in product design studies explored the concept for analyzing the smart speakers' affordance affection to specialized group of people (Wu et al., 2022), cognitive reduction in a compact digital camera (Chen et al., 2021), conceptual design for a robot vacuum cleaner (Liu et al., 2021), and many more ((Brown et al., 2015; M. Chen et al., 2020). Other studies such as packaging design (Fuente et al., 2014), education/pedagogical methods (Thompson, 2021; Tsering Wangyal et al., 2019), user interaction (Y. V. Chen et al., 2016; Lucaites et al., 2017), and business systems (Hamida et al., 2016) were also exploring the adaption of affordance-based design concept.

The framework is visualized as Designers-Artifacts-User system (DAU system) in Figure 3-1 developed by (Maier & Fadel (2009a). The framework offers two distinct classes of affordances suitable for both architectural and surrounding environmental elements: artifact–user affordance (AUA) and artifact–artifact affordance (AAA). AUA is defined as "the usual affordances of interest exist between artifacts and users" (Maier et al., 2009). The affordance expresses a potential behavior, but that behavior does not have to be manifested. User behavior can occur between the artifact and the user that the user or the artifact cannot manifest alone. In this context, the artifact is the building design, and users are the expected occupants. AUA mapping helps know the potential use of buildings as artifacts for their use. Architects can define AUA as an interaction between the user and the artifact where the artifact offers an affordance to the user. It is indivisible from Gibson's original concept of affordance, where affordance always expresses a relationship between the individual and his environment.

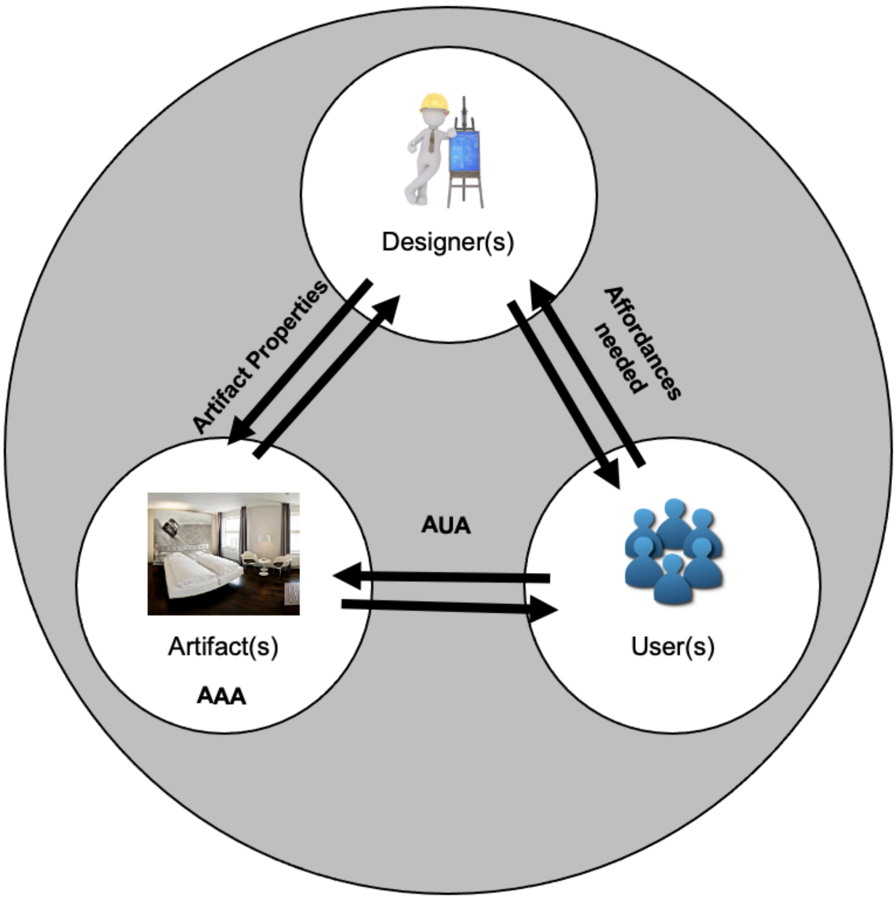

Figure 3-1. Affodances related interaction within a DAU system.

Re-created from Maier & Fadel (2009a).

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Meanwhile, Artifact-Artifact Affordances (AAA) exist between two artifacts. These express that a behavior is possible to be performed by an artifact toward the other artifact. Designers could identify what kind of afforded behaviors by the artifacts. These behaviors should satisfy physical laws which should be already understood by architectural designers who have a basis of design knowledge. For example, the affordance of holding the load exists in both structural beams and columns. In addition, these affordances classes should consider direct perception for minimal cognitive processing. The classes also should consider artifacts' intrinsic units (such as size and shape) for measuring affordances quality and analyzing the critical items of the design (Masoudi et al., 2019a).

The architect defines the structure of the building components and their spatial elements, and the affordances they can offer, be it AUA or AAA. Designers should note that AUA should disclose relationships that are directly beneficial to users, and AAAs should disclose relationships that are indirectly beneficial to building users. In turn, affordance determines how a system in an artifact behaves. Also, affordances should be intended to be perceived directly without any cognitive effort (direct perception) to increase its usability. But, as a designer, certain knowledge should be acquired first to define “intrinsic unit related to user characteristics and artifact’s properties” to let anyone as a user to have affordances with direct perceptions.

3.3. Defining Design Review Components

With the affordance-based design framework, the affordances definition process requires architectural designers who have the expertise or knowledge related to the context of the designer building. It includes knowledge of which activities users can and cannot do in the building and everything that the building itself can and cannot. To review whether a design has the particular desired affordances to support a specific behavior and avoid individual behavior, the team used the Affordance Structure Matrix (Maier et al., 2008). There are four groups of affordances in the ASM: positive AUA (+AUA), negative AUA (−AUA), positive AAA (+AAA), and negative AAA (−AAA). In this study, we used a simplified version of the ASM, in which the "roof" and "side" parts are not included since intradomain relationships are not considered in this study.

In the design review process, the concept of affordances clearly can be adopted for evaluating design works. An architect can learn and use affordances to determine appropriate goals he wants to achieve as the final product, as Maier et al. (2009) described. Affordances can be used to understand failures and unintentional design consequences, including unexpected human behavior. A design that affords users to do intended behavior and activities by an architect is considered a successful design. Especially when an architect can review and confirm different intended affordances for different users existed in their design. It can be recognized from a large building or room-scale to a small interior scale, such as a ramp or door handle.

The desired studio outcome should have and not have from each design objective as an affordance structure. The affordances are identified from design objectives mentioned in the design brief using a predetermination strategy (Maier & Fadel, 2007). This strategy starts by determining artifact-user affordances (AUA) and artifact-artifact affordances (AAA). In short, AUA defines a relationship between a built environment and a human user situated in it. While in AAA, affordance defines a relationship between an element and other elements in their respective built environment where behavior can exist in it. All identified affordances were mapped in the form of Affordance Structure Matrix (ASM) developed by Maier et al. (2008). For this study, the team used a simplified version of the ASM, in which the "roof" and "side" parts are not included, as seen in Figure 3-2, since intradomain relationships are not considered in this study. The Matrix is used as a design review companion tool and combined with media used for design review. Furthermore, the process of affordances identification is explained in Chapter 6.

Affordance Structure Matrix			Room										Building Component									
			Retail	Atrium	Café	Gym	Karaoke	Minimarket	Toilet (Ladies)	Toilet (Gents)	Toilet (Disabled)	Circulation Area	Slab	Str. Column	Str. Beam	Ramp	Solid Wall	Glass Wall	Railing	Stairs	Ceiling	Facade
+AUA	G1	Safety in activities																				
	G2	Comfort in activites																				
	G3	Suitability of activities with the function of space																				
−AUA	H1	Getting in an accident																				
	H2	Getting lost in the building																				
+AAA	J1	Ability to support the load																				
	J2	Natural ventilation																				
−AAA	K1	Chances of getting hot easily																				
	K2	Excessive glare																				

Figure 3-2. Affordance Structure Matrix (ASM)

3.4. Data Analysis Process

This section covered data analysis processes used in this study. We used correspondence and hierarchical analysis methods to analyze the relationship between affordances and design components; and the relationship between affordances and the medium used for the design review process. We also adopted paired statistical *t*-test to perform a medium effectivity comparison. We proposed a new data analysis process called PDS Process for this Chapter. It was derived from the theory of affordances and distribution analysis to find which better design option depends on the presence and disappearance of perceived positive and negative affordances.

3.4.1. Affordances vs. Design Components

We performed correspondence and hierarchical clustering analysis methods between affordances and design component groups using JMP software to find the relationship between perceived affordances and reviewed design components. The analysis output is presented in the dendrogram, as seen in Figure 3-3. Each dendrogram is clustered in different colors based on Cubic Clustering Criterion calculated by JMP software. Then, we mapped the clusters based on the media used. So, we can determine whether each affordance pair is perceived using single media (NVR or VR) or double medium (NVR and VR). A single media perceives an affordance pair – NVR or VR – when an affordance and a design component are paired inside a dendrogram of the NVR or VR. If the same pair is paired inside both dendrogram of NVR and VR, both mediums perceive the pair.

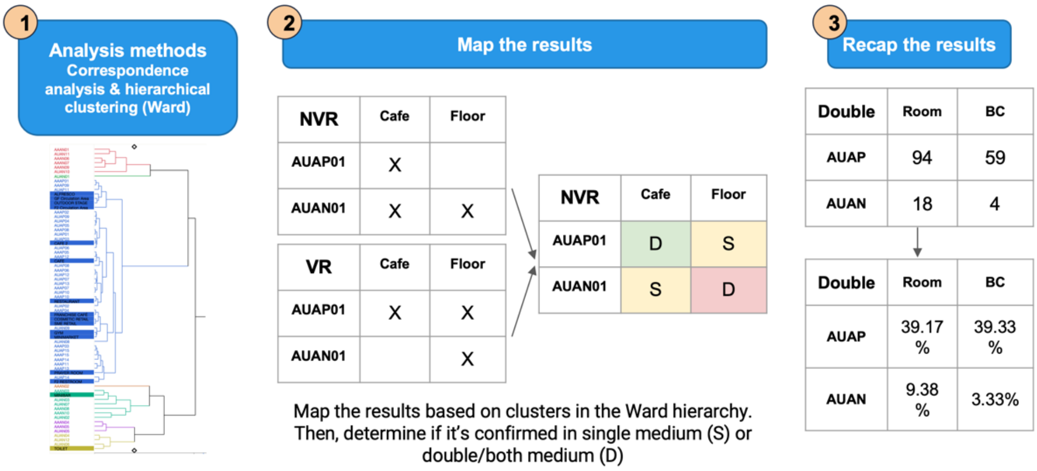


Figure 3-3. Correspondence and hierarchical clustering analysis method between affordances and design component groups.

3.4.2. Affordances vs. Medium

We perform correspondence and hierarchical clustering analysis between affordances and medium used during the study to find the relationship between perceived affordances and medium. This data analysis process aims to discover the relationship between affordances and medium for a design review in different design component groups. Then, we determine the medium compatibility on assisting participants in perceiving affordance in each design project. Same as the previous section, we used JMP software to process the data. The analysis output is presented in the dendrogram, as seen in Figure 3-4. Each dendrogram is clustered in different colors based on Cubic Clustering Criterion calculated by JMP software. We mapped the clusters based on the media used within each design component group and calculated the distribution of confirmed affordances on both design options in the design projects.

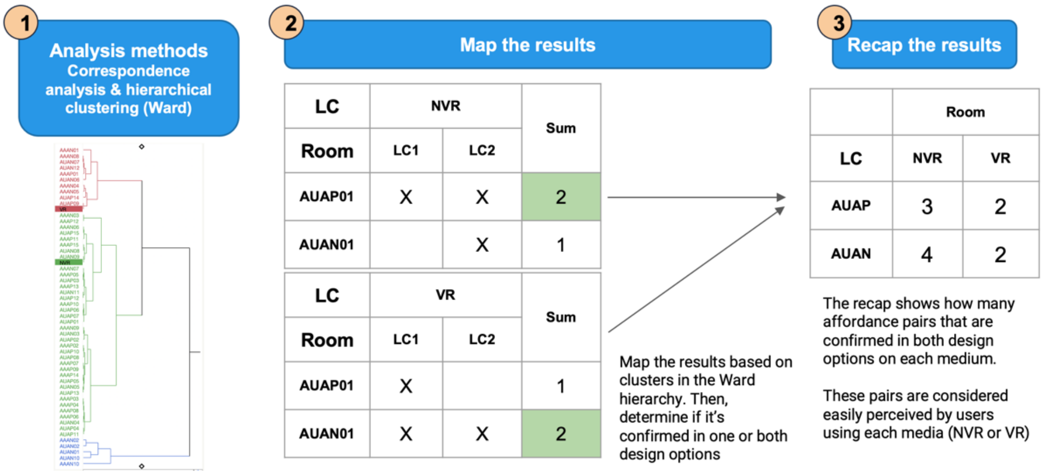
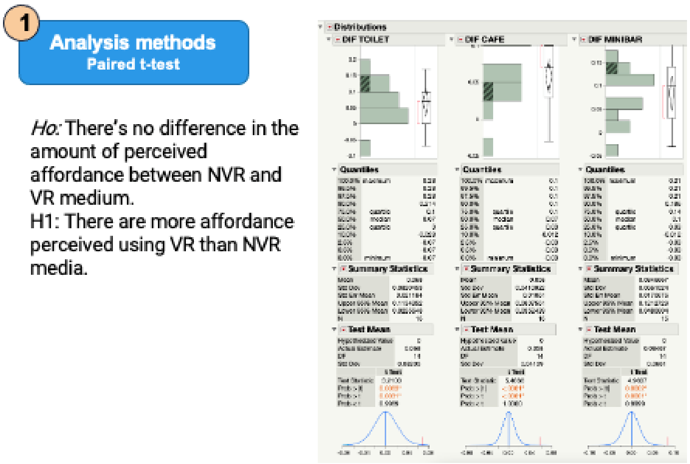


Figure 3-4. Correspondence and hierarchical clustering analysis between affordances and medium

3.4.3. Medium Effectivity Comparison

To find how effective the medium was used for the design review process, we performed paired t-tests comparing design review results using NVR and VR medium. Paired t-test was conducted on each affordance-design component pair. The null hypothesis we used for the test is "there is no difference in the amount of perceived affordance between NVR and VR medium.". If the null hypothesis is rejected, more affordances are perceived using VR than NVR media. We summarized the *p*-value from all tests categorized based on affordance groups in all design options. Then, we calculated the distribution of pairs that have a significant *p*-value. The analysis process flow is visualized in Figure 3-5.



2 Recap all the p-values

NVR–VR	Room	
	Toilet	Cafe
AUAP	0.207	0.395
AUAN	0.178	0.893
AAAP	0.056	0.0018*
AAAN	0.091	0.237

LC1–LC2	Room	
	Toilet	Cafe
AUAP	0.0063*	<.0001*
AUAN	0.0005*	0.0028*
AAAP	<.0001*	0.0033*
AAAN	0.0083*	0.0307*

Figure 3-5. Paired t-tests comparing design review result that is using NVR and VR medium

3.4.4. PDS Process

When Gibson (1979) presented affordance as a set of action opportunities provided by an object, he sparked a possibility for an individual to perceive what type of action he could do. He treats affordance as “direct perception.” Perceptual information provided by objects, which specifies affordance, is vital to help users as living beings decide the required tasks (L.-H. Chen et al., 2007). To ensure that the building can be appropriately occupied by its users, an architect and architectural designer should design a building with enough perceptual information. They have adequate knowledge to measure if a building design has sufficient information or not for planned affordances being specified by users. Ordinary users might not realize that particular affordances exist since they depend on the presence of some living being that could perceive them (Chemero, 2018). So, an architect and architecture designer should be aware that those affordances in a building design are present or disappear. We propose a data analysis process for an affordance-based design review process called the PDS process.

PDS itself stands for Present, Disappeared, and Stagnant. This process counts how many perceived affordances in the latest iteration of an object are currently present and disappeared compared to the object’s previous iteration. It also calculates how many perceived affordances whose presence is still stagnant, present, and disappeared in two compared iterations. This process can be used to compare two design iterations between an original design and a revised design in architectural design. Compared to the original design,

1. an affordance that is now present in the revised design marked as "Present" or "P,"
2. an affordance that is now disappeared in the revised design marked as "Disappeared" or "D,"
3. an affordance that is still present in the revised design marked as "stagnantly present" or "S1", and
4. an affordance still disappeared in the revised design marked as "stagnantly disappeared" or "S0".

This process must be performed with perceived positive and negative affordances. So, the designer can use the PDS process to measure if the revised design is better or worse based on the amount of perceived positive and negative affordances. First, we sum up the perceived positive and negative affordances in percentages based on their PDS marks in Table 3-1 below.

Table 3-1. PDS Calculation for Positive and Negative Index

Objective	Affordance Group	P	D	S0	S1
OBJ1	A-P	∑ A-P (P)	∑ A-P (D)	∑ A-P (S0)	∑ A-P (S1)
	A-N	∑ A-N (P)	∑ A-N (D)	∑ A-N (S0)	∑ A-N (S1)

To determine whether a design's tendency is improved or not based on the number of perceived affordances, we create indexes named Positive Index (PI) and Negative Index (NI). Both are expressed with the following equations:

1. **Positive Index (PI) =** ∑ A-P (P) + ∑ A-N (D) + ∑ A-N (S0) + ∑ A-P (S1)

   Positive Index (PI) is a sum of percentages of present positive affordances, disappeared negative affordances, stagnantly disappeared negative affordances, and stagnantly present positive affordances. This index shows the tendency of a revised design or a design iteration to be positively enhanced.

2. **Negative Index (NI) =** $\sum$ A-N (P) + $\sum$ A-P (D) + $\sum$ A-P (S0) + $\sum$ A-N (S1)

   Negative Index (NI) is a sum of percentages of present negative affordances, disappeared positive affordances, stagnantly disappeared positive affordances, and stagnantly present negative affordances. This index shows the tendency of a revised design or a design iteration to be negatively revised.

Then, to find out the improvement between two design iterations based on the amount of added perceived affordances, we propose other indexes named Imprv. (+) and Imprv. (–). These indexes might also help us to know if the tool or media we utilize for the design review process is helpful or not. Both are expressed with the following equations:

1. **Imprv(+) =** $\sum$ A-P (P) + $\sum$ A-N (D)

   Imprv(+) is a sum of percentages of present positive affordances and disappeared negative affordances. This index shows the improvement of a design iteration towards the positive direction.

2. **Imprv(–) =** $\sum$ A-N (P) + $\sum$ A-P (D)

   Imprv(–) is a sum of percentages of present negative affordances and disappeared positive affordances. This index shows the improvement of a design iteration towards the negative direction.

CHAPTER 4
VR INTERACTION MODEL PROTOTYPE:
A PILOT STUDY

4.1. Introduction

This chapter explains our exploration of user interaction inside a virtual environment (VE) with a Building Information Modeling (BIM) model as a digital entity of a building connected with its physical entity simulated with a cloud-based database. We chose the BIM model as the entity inside the VE because, by its core, it enables the architect to create accurate virtual models of a building and constructs it digitally (Sacks et al., 2018). BIM has been significantly developed for years and adopted by practices worldwide. Many studies have shown many benefits that BIM can provide for architects such as generating various design alternatives through spatial analysis and optimizing them based on costs (Hyun et al., 2018), creating environmental assessment on design (Rezaei et al., 2019), or even improving building safety through multiple dimensions modeling or well known as nD modeling (Martínez-Aires et al., 2018).

Both BIM and VR technology can enhance and assist architects and architectural designers. While at the same time, an architect can use those technologies with an approach called Digital Twin, which is used mainly in manufacturing and engineering (Batty, 2018). Digital Twin is a digital representation of physical objects in the real world that enables comprehensive data exchanges and contains information describing its counterparts in the real world (Dembski, 2019). With BIM's capability to embed various information inside a digitized architectural building model and VR capability to provide an immersive virtual life-size built environment, it is an opportunity to explore what kind of interactions possibly can be done with BIM and VR technology to support the architect during the design process and even related stakeholders handling the building design as digital twin entities.

At the end of this Chapter, we developed a prototype as a proof of concept – using a simulated data stream coming from an IoT device attached to building components. With this prototype, we expected to find new possibilities on developing a VR technology system for helping architects' design decisions in the earlier phase of the building lifecycle. Our goal is to have a basic interaction model between the user and the connected BIM model within the VE.

4.2. Methodology

This study used simulation research to replicate real-world settings and objects and mimic the situation (Groat & Wang, 2013). We used a module of Architecture Program building in Institut Teknologi Bandung as the case study. We used device and software to develop the prototype that supports BIM model authoring and immersive VR technology. For the VR device, we used Oculus Quest – a VR head-mounted device (HMD) with hand motion controllers – and a high-end personal computer with a dedicated graphics processing unit (GPU). While on the software side, we used Unity game engine software with C# scripts for required object interaction events inside the VE, Revit for BIM model authoring, and Firebase for a cloud-based real-time database.

This prototyping study limited the scope into two aspects: user exploration and database connection within the VE. We examine how users interact with a BIM model inside a VE connected to a cloud-based real-time database. A real-time database is commonly used for IoT devices to store various data captured with various sensors. Since it was a prototype, we limited the database by providing hardcoded values. These values were similar to those produced by IoT devices, such as Arduino, ESP8266-based system on chip (SoC), and various plugged sensors connected to the Raspberry Pi single-board computer. The computer can be placed inside a building – acted as the physical counterpart of the VR model – providing real-time data to the real-time database. Types of data used in this study are boolean (i.e., door/window opening state) and float (i.e., lighting intensity or indoor temperature). With these data, the model can utilize them for specific events such as showing the current status of a building component, visualizing a thermal situation in a room, or replacing any building component inside the VR model to match the actual situation.

4.3. Connected Digital Twin as Interaction Model

To reach the study goal, we built a Connected Digital Twins (CDT) model prototype and conducted a simulation with it. The prototype consisted of a BIM model inside a VE using immersive VR. We connected the model to a real-time database that simulated IoT devices' presence. It supplied information about the status or situation of the building or room. Sensors and actuators attached to the IoT devices would capture that information and send them to the database, as illustrated in Figure 4-1.

4.3.1. Prototype Concept Framework

Parts of the prototype concept framework consist of a BIM model, VR interaction, and real-time database connection, with each specification, explained further below.

4.3.1.1. BIM Model

We developed the case study building into a BIM model using Autodesk Revit software. The model is based on as-built drawings of the building. We picked a small part of the building, the faculty staff workspace, for this study.

The BIM model was created under a Level of Development (LoD) determined by the researcher to ensure the content clarity and reliability of the BIM model. Building components in the model used LoD 300 specification based on 2019 BIMForum specification to recognize the components and its parameter in the VE easily. A BIM model with LoD represented the building graphically as an object with a measured and accurate space, size, location, and orientation. So, the BIM model visually represents the actual existing building in the VE.

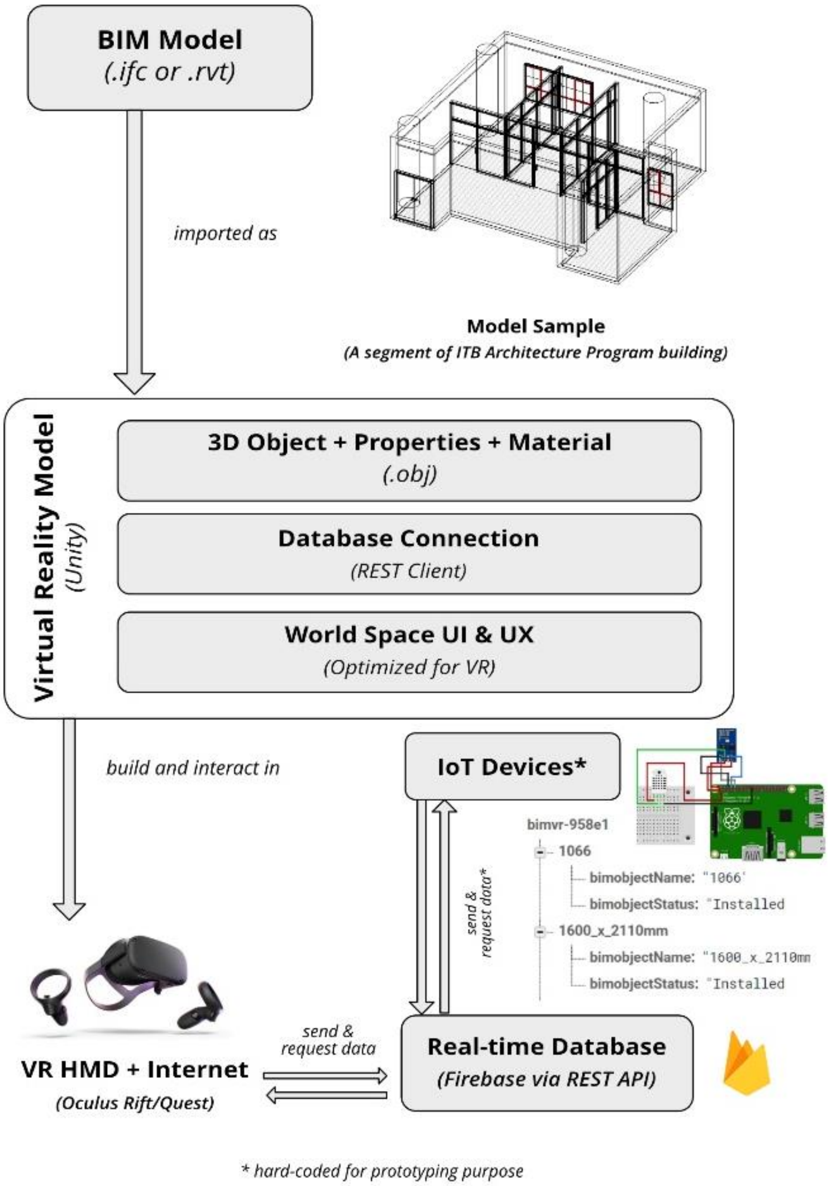


Figure 4-1. Connected Digital Twin Concept Framework

Once it was completed, we prepared the BIM model to be exported into the Unity game engine and developed the interactions inside Unity, as seen in Figure 4-2. In this process, maintaining information consistency within the model is considered essential. We converted it into two file types: the model geometry and material information in an OBJ format, and building property parameters, such as component name, size, and material name, are exported as C# script. The model geometry was separated based on the family and component type to maintain instance independence.

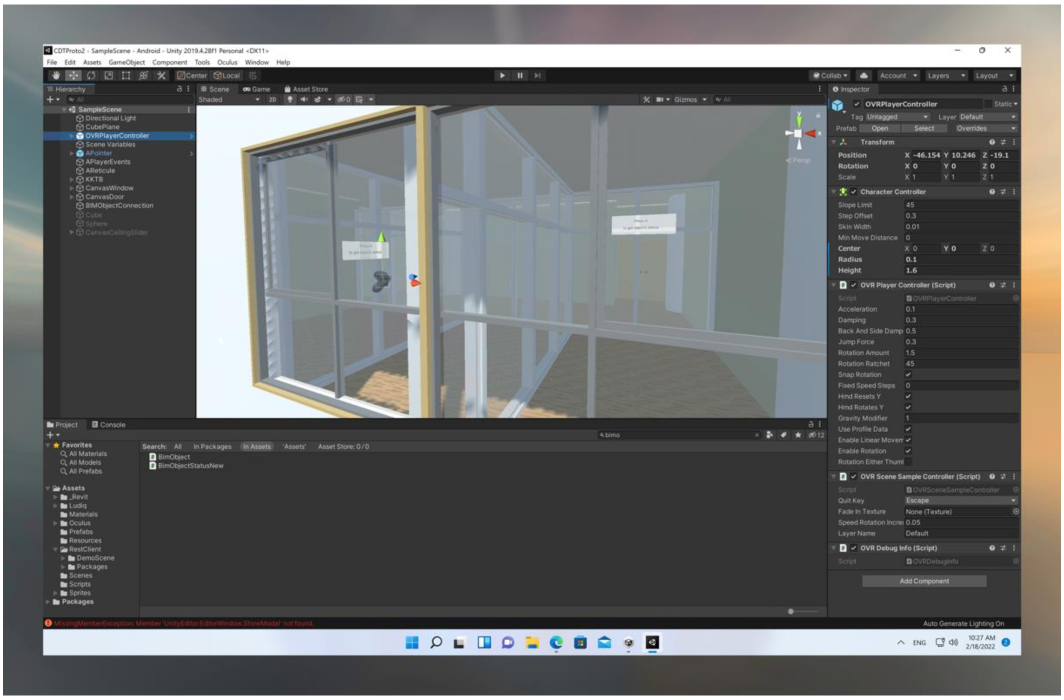


Figure 4-2. BIM model with scripts inside Unity game engine

4.3.1.2. VR User Interaction

User needs specific hardware to explore and interact with objects inside a virtual environment. We used Oculus Quest HMD and Oculus Touch motion handheld controllers in this study. Using the device, users can do fundamental interactions and activities such as walking, sightseeing, and touching objects inside the virtual environment. Those interactions were developed inside the Unity game engine using C# programming scripts and virtual objects called GameObjects. Each GameObjects represented interfaces, characters, events manager, and database handler needed for the interaction.

This study had three categories of GameObjects: event manager, interface, and database manager. GameObjects under the interface category mean these objects would interact directly with a user within the environment. The event manager handles all or selected events happening in a virtual environment. The database manager handles the connection between the virtual environment and the database in the cloud. Table 4-1 describes all GameObjects and their functions.

Table 4-1. GameObjects and their functions in the prototype

GameObject	Function
Events Manager	
APlayerEvents	Handles VR HMD controller input events
Interface	
OVRPlayerController	The avatar represents a user in the virtual environment, controlled using the VR HMD controllers.
APointer	As ray cast pointer for a user to interact with building components, moved by the VR HMD controllers.
AReticule	As cursor for the pointer ray at APointer
KKTB	The building design model is used as the case study, whereas the interactable building component is equipped with "Interactable.cs" custom C# script
Directional Light	As the default sunlight in a Unity scene
CubePlane	Act as the ground plane
Database Manager	
BIMObjectConnection (contains BimObject.cs and BimObjectStatusNew.cs)	Manage the connection between the real-time database and the virtual environment, including posting and retrieving parameter values using the RESTClient package.

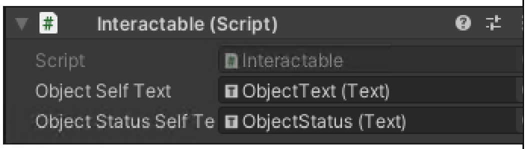
Fundamental interactions we developed were building component selection and triggers for loading information from the database. All related objects with these interactions are described in Table 4-2. For object selection, we used the ray casting process to show a pointer line with APointer and hit a selectable object – for example, a door. When the ray cast hits the door, a user can execute the event trigger by pressing a button on the motion controller. Then, the prototype will pull the latest requested information about the door from the database and show it on a tag named CanvasObject above or near the clicked object. To ensure that the clicked object is linked with the correct value, we embedded a C# script named Interactable.cs, and it was linked with its CanvasObject. From a scripting point of view, all classes and events for the prototype were written using a single responsibility principle. Each class has its responsibility for a single part of functions in the application (Martin, 2000). So, it is possible to add new interactions and event triggers in the future.

Table 4-2. Interactables objects in the prototype

Description	Preview
CanvasObject	
a. ObjectText ObjectText contains the parameter value of building component's type name as string. b. ObjectStatus ObjectStatus contains the parameter value of building component's status as string.	
Building Components (Door or Window) – Layer: Interactable	

<table>
<tr><th>Description</th><th>Preview</th></tr>
<tr><td>

Interactable.cs (C# Script)



A custom C# script connects a building component and a CanvasObject as its tag. Inside, the script is linked with ObjectText and ObjectStatus on each CanvasObject.

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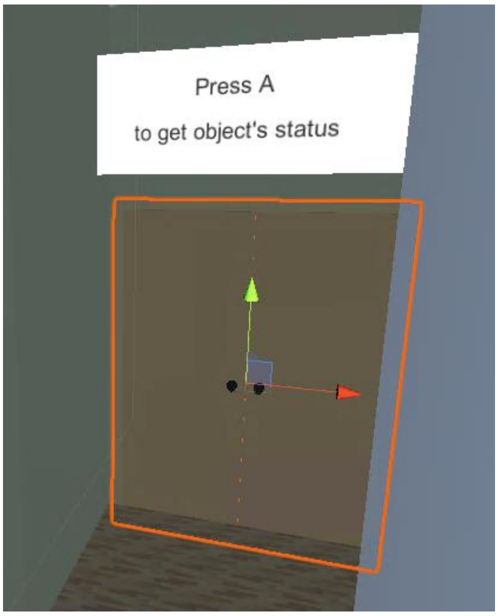

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</table>

4.3.1.3. Real-time Database Connection

A real-time database system used in this study provides real-time processing on handling data from the building to the BIM model rapidly (Lindström, 2008). Unlike the traditional database system, a real-time database can get, pull, and acquire data as quickly as an application requested while maintaining its consistency.

This study used Firebase to store and sync the component parameters data, as seen in Figure 4-3. All data were stored as JavaScript Object Notation (JSON) objects and synced between the BIM model and the database. We added a Representational State Transfer (REST) client inside the prototype for handling the database connection. A "put" method is added in a C# script named BimObjectStatusNew.cs to store new data values linked to a building component in the BIM model to the database simulating a data input workflow from IoT devices attached to the building. Once the connection is established, the BIM model can store and get parameter values from the database.

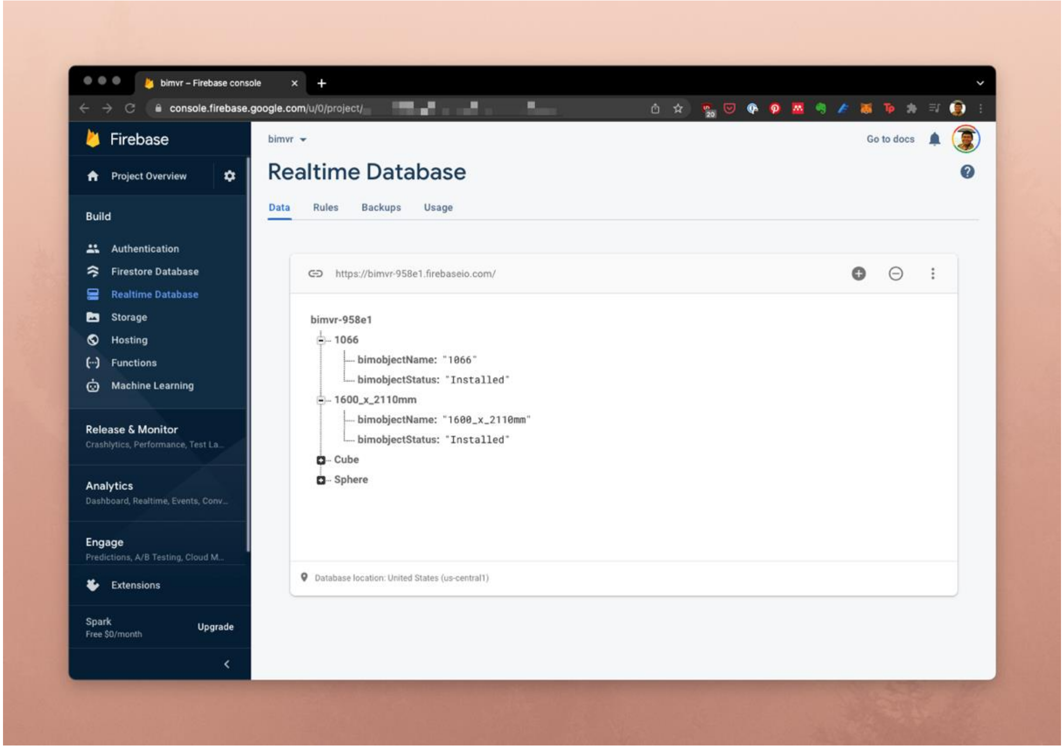


Figure 4-3. Firebase real-time database, simulating the presence of physical entities in the prototype

4.3.2. Experiment Scenario

The experiment scenario was prepared in this study to fulfill the goal. The scenario consists of two sections. First is the front-end flow for the user interaction within the virtual environment. The second is back-end flow to connect the BIM model inside the virtual environment and real-time database. Both flows were in the workflow and not separated, as illustrated in Figure 4-4. Before the experiment starts, the user must first wear the HMD and motion controllers. Then, the user launched the prototype application inside to bring the user inside the CDT model with a 1:1 scale. A white pointer line appeared and worked as a pointer for selecting objects or building components inside. The user can explore the model by toggling the thumb pad to move around the environment.

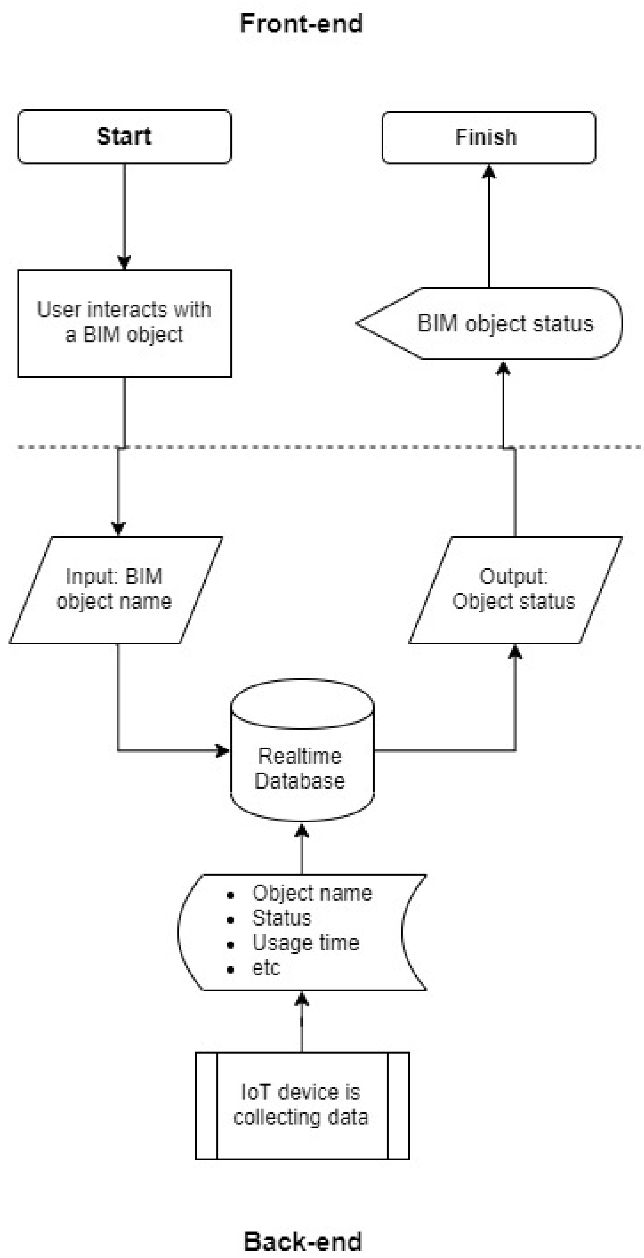


Figure 4-4. Experiment scenario flowchart

Inside the application, two-building components are already connected to the database: a door and a window. Each object had two parameters: type name and status, whose values were stored in the real-time database. Those parameter values were shown on a floating user interface (UI) near or above the related object. To pull or get the latest value, the user must point the line to the object and click a button on the motion controller. Then on the back-end side, the application would request the parameter value from the database and pull it onto the UI label, as shown in Figure 4-5.

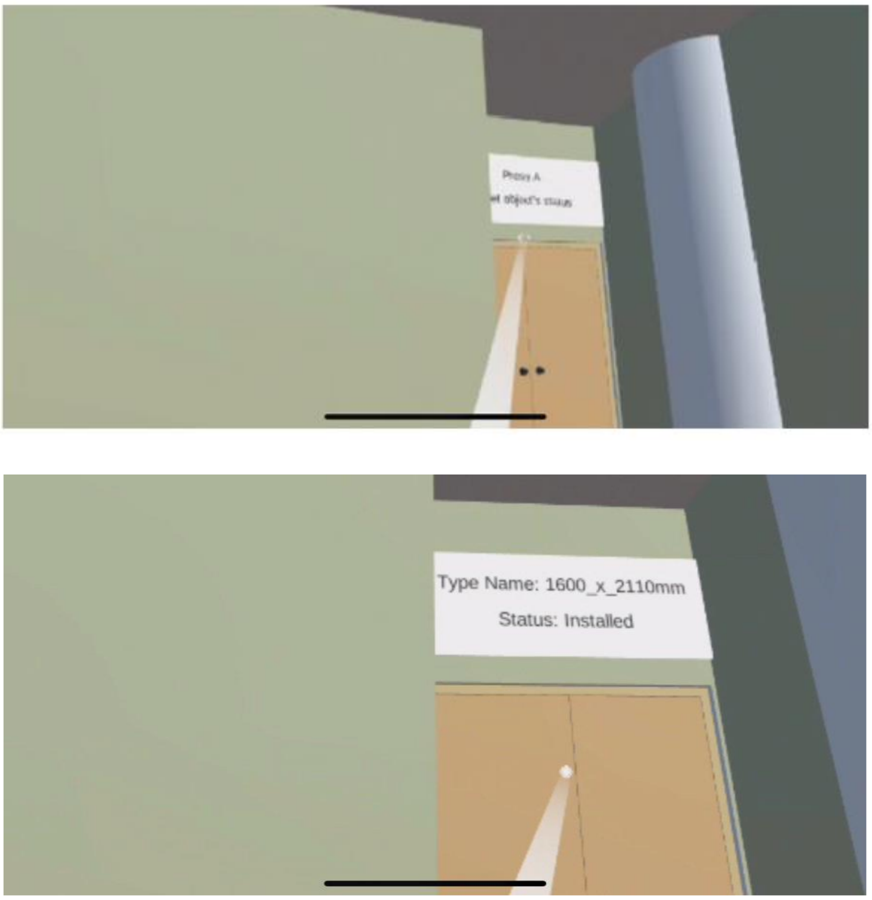


Figure 4-5. Floating label in VR before (top) and after (bottom) requesting data values from the database.

During the experiment, an additional scenario was added where the user was requesting the parameter or data value while the value was updated manually in the database. The scenario was conducted to check the connection consistency between the object and stored data value. The user pointed and triggered the event on both objects, and each of their labels showed different values, as shown in Figure 4-4. Different value on the "Status" parameter was written on both objects. This condition proved that the connection between the CDT model; the real-time database worked well and had a consistent behavior.

Figure 4-6. Floating label in VR before (top) and after (bottom) updating data value manually to the database.

4.4. Discussion

This section discusses findings after building the prototype and conducting the experiment with the scenario explained above. First, a BIM model can be visualized and presented in a virtual environment with building components' parameters are still attached to the geometry. Each building component instance has retained essential properties, such as component type name, width, height, and material visual representation. That information can be considered sufficient to be used in this prototype. This condition makes it possible to link any building component instance from a BIM model and add some additional functions in the Unity editor environment. The need for additional BIM parameters in each geometry depends on the case scenario performed in the Unity environment. Second, user interaction created in the experiment opens a possibility to connect the CDT model with the building or physical model in a virtual environment. Primarily, we will use these interactions as the foundation for the design review tool we explain in the next chapter. Also, the same interaction can be used for other cases such as remote building inspection or analyzing collected data as a lesson learned input for building renovation design. Tighter integration between the CDT model and the building can be developed later in other studies.

The prototype has some limitations. The information stored and synced in the real-time database is text-based information such as component name, category, and working status. The same text-based information is also shown inside the virtual environment. Also, the user can only select and request information on selected building components. Additional changes to the BIM model cannot be added to the virtual environment in real-time. The model importing process must be started to get the latest BIM model in the virtual environment.

We also compare the prototype with Unity Reflect, a software developed by Unity Technologies to bring a BIM model from a design authoring software into the Unity editor environment. It has an advantage in linking BIM software and Unity itself in real-time. So, any changes inside the BIM model will be automatically added to Unity, where the virtual environment is developed. Meanwhile, the prototype connects the BIM model inside Unity with a cloud-based real-time database and visualizes it inside a VR environment. The opportunity to observe any differences in the building using interactions inside a virtual environment is an advantage of the prototype compared to Unity Reflect.

4.5. Conclusion

This study concludes that the user interactions developed inside the prototype opens a possibility on connecting a BIM model with external data sources. Parameter values from building components can be supplied by IoT devices attached to the related components inside the building. Also by having a building model visualized inside a VR environment, people can inspect the building condition in an immersive experience without actually inside the building. The study in this chapter is mostly situated in the maintenance/operational and post-occupancy phase of a building. We are going to utilize basic interactions and scenario prototypes in the next chapter for building a VR application for design in the early phases of the architectural design process.

CHAPTER 5
DEVELOPING VRDR AS DESIGN REVIEW TOOL

5.1. Introduction

Chapter 4 developed the interaction model prototype as a proof of concept where a BIM model geometry representation inside a VE connected to a cloud-based database. This Chapter brought the prototype and extended it further into a VR system utilizing information inside the architectural design model as a design review tool. As a result, we developed a game-engine-based VR system called Virtual Reality Design Reviewer or VRDR for reviewing architectural design studio outcomes. It was designed to help students understand and evaluate their designs in an architectural design studio course.

This study uses simulation research as the research method (Groat & Wang, 2013) by reconstructing architectural designs into a real-world setting as a virtual environment and driving individual perceptions of anyone interacting inside. We were working with building designs which are the outcomes of architectural design studio, retrieved from the faculty archive. As the design models were created as BIM models, we used the information content to enhance the user experience inside the virtual environment. For this Chapter, we aim to offer VRDR as a VR system for reviewing studio design outcomes based on the objectives assigned in the design brief using the affordance-based design approach. We focus on explaining the development of VRDR itself in this Chapter. We cover the affordance-based design review process using VRDR in Chapter 6.

5.2. Development of VRDR

This section explains how we developed a game engine-based VR system called Virtual Reality Design Reviewer (VRDR), as seen in Figure 5-1. The system was developed using Unity game engine technology and optimized for standalone VR head-mounted displays such as Oculus Quest. We decided to have VRDR run without a need for high-end personal computer (PC) specifications. VRDR lets the user himself explore design studio outcomes in a BIM model inside a VE.

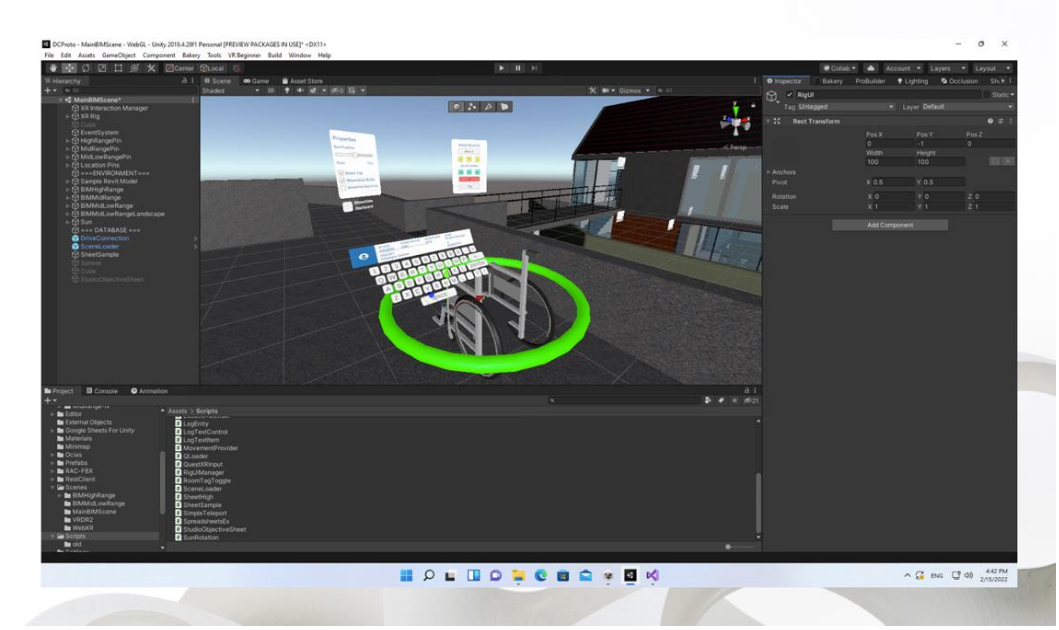


Figure 5-1. VRDR in the Unity game engine

5.2.1. System Layers

VRDR consists of three system layers: BIM models as 3D geometric and building instance parameter data sources; design review as a decision-making process, user interface (UI), and user experience (UX) layers, as shown in Figure 5-2. First, as mentioned above, all design studio outcomes used in this study are modeled as a BIM model. Three-dimensional geometries from the BIM model were imported into the .obj file and optimized for VR. We extracted essential parameters from several instances, such as name, area, and volume, to add an informative layer to UI and UX layers. More explanation on how those models and parameters are used in VRDR will be discussed in the following subsection. Second, we put design evaluation as the decision-making process of an architectural design at the center of VRDR. The design evaluation process will focus on building affordance as the main design evaluation component. The third is the UI/UX layers, consisting of three sublayers:

- multisensory & Spatio-temporal aspects of a VR system
- architecture design studio nuances in a VE
- positioning students and supervisors as system users

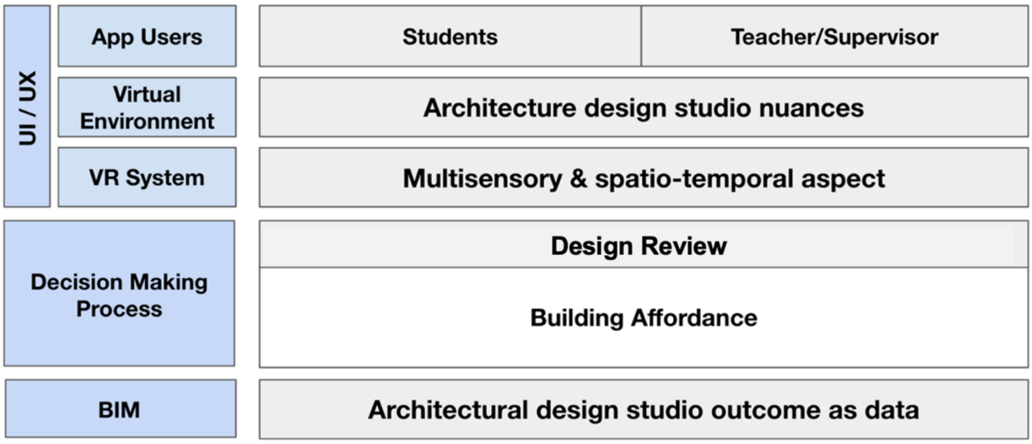


Figure 5-2. The system layers of VRDR

5.2.2. System Framework

VRDR system framework contained three main parts: Common Data Environment (CDE) of the BIM model, VR model itself, and a standalone VR HMD device connected to the Internet, as shown in Figure 5-3. CDE worked as the back-end arrangement for VRDR. VR model contained optimized 3D objects with embedded material textures and properties from the BIM model, database connector using RESTful client, and a world space-based user interface and experience (UI/UX) to enable users to explore the model using VRDR. Compared to the previous prototype, the additional capabilities of the UI/UX will be discussed further in the next section. Once the VR model was ready, it was deployed to the VR HMD device. It must be connected to the Internet to hook up with the CDE database.

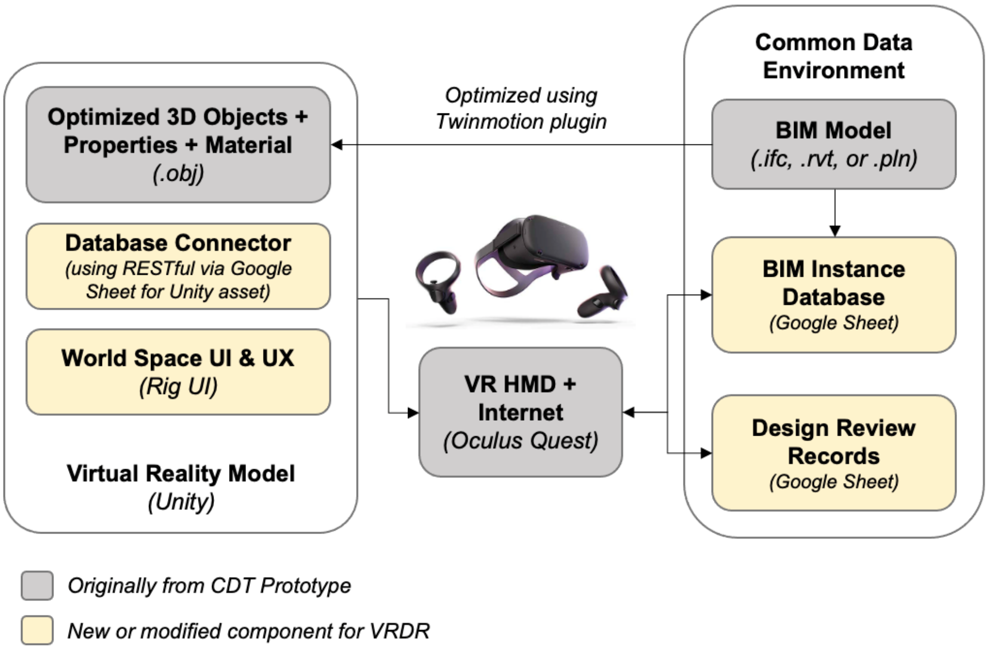
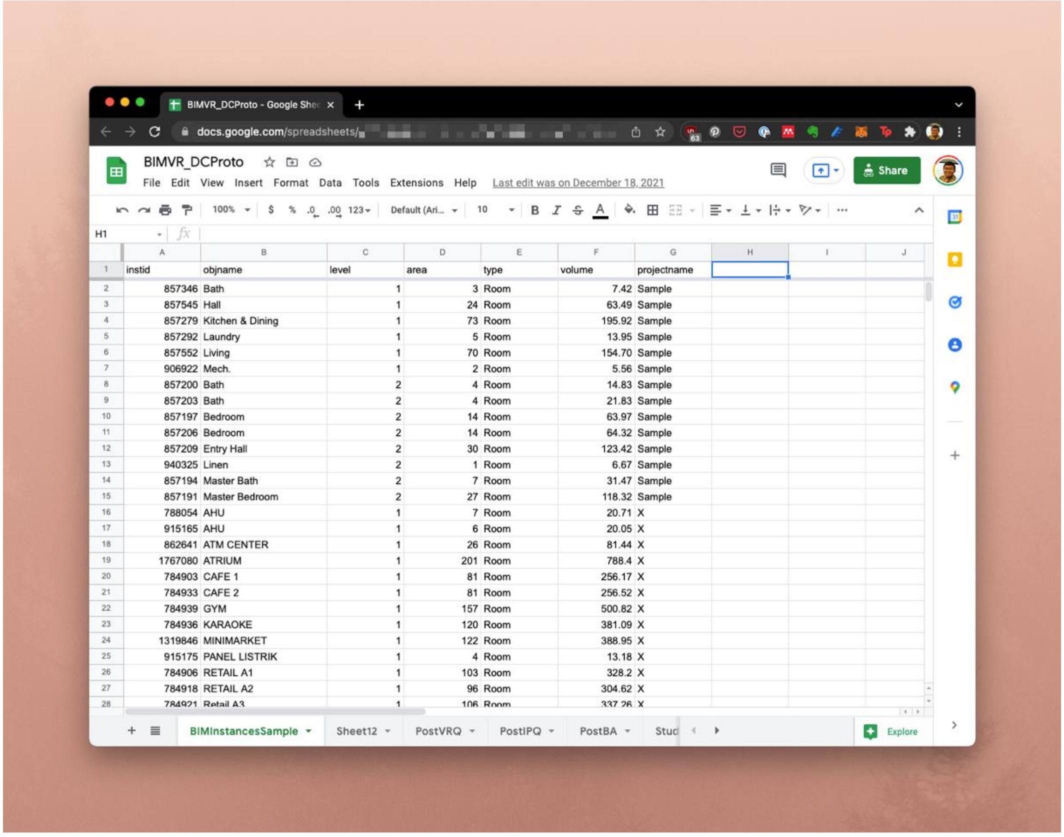


Figure 5-3. The system framework of VRDR

5.2.2.1. Common Data Environment (CDE)

CDE or BIM repository collects and manages all BIM-based information and objects of individual projects (Sacks et al., 2018). We used a custom arrangement of cloud services and storage modified from the prototype in Chapter 4. As seen in Figure 5-4, the components with yellow color are the modified components from the CDT prototype in Chapter 4. Inside, there are the BIM models themselves in their native formats, such as RVT for Revit or PLN for ArchiCAD project or openBIM format of IFC; the BIM instance database where all extracted parameter values from BIM model stored; and the design review records database. Compared to the prototype where we used Firebase for the database, we used Google Sheets instead in VRDR since it is more familiar to use by end-users, as seen in Figure 5-4.



	instid	objname	level	area	type	volume	projectname
2	857346	Bath	1	3	Room	7.42	Sample
3	857545	Hall	1	24	Room	63.49	Sample
4	857279	Kitchen & Dining	1	73	Room	195.92	Sample
5	857292	Laundry	1	5	Room	13.95	Sample
6	857552	Living	1	70	Room	154.70	Sample
7	906922	Mech.	1	2	Room	5.56	Sample
8	857200	Bath	2	4	Room	14.83	Sample
9	857203	Bath	2	4	Room	21.83	Sample
10	857197	Bedroom	2	14	Room	63.97	Sample
11	857206	Bedroom	2	14	Room	64.32	Sample
12	857209	Entry Hall	2	30	Room	123.42	Sample
13	940325	Linen	2	1	Room	6.67	Sample
14	857194	Master Bath	2	7	Room	31.47	Sample
15	857191	Master Bedroom	2	27	Room	118.32	Sample
16	788054	AHU	1	7	Room	20.71	X
17	915165	AHU	1	6	Room	20.05	X
18	862641	ATM CENTER	1	26	Room	81.44	X
19	1767080	ATRIUM	1	201	Room	788.4	X
20	784903	CAFE 1	1	81	Room	256.17	X
21	784933	CAFE 2	1	81	Room	256.52	X
22	784939	GYM	1	157	Room	500.82	X
23	784936	KARAOKE	1	120	Room	381.09	X
24	1319846	MINIMARKET	1	122	Room	388.95	X
25	915175	PANEL LISTRIK	1	4	Room	13.18	X
26	784906	RETAIL A1	1	103	Room	328.2	X
27	784918	RETAIL A2	1	96	Room	304.62	X
28	784921	Retail A3	1	106	Room	337.26	X

Figure 5-4. Google Sheets as database, storing all parameter values of BIM models and design review records

5.2.2.2. VR Model Preparation

After preparing the CDE, we developed the VR model in VRDR by exporting the three-dimensional objects from the BIM models, including their materials, as seen in Figures 5-5. The objects were optimized by reducing their Level of Detail (LoD) and numbers of triangulations. This step is crucial to maintain the VR real-time rendering performance done by the HMD device. It is also helpful to reduce the motion sickness of a user when using the VRDR system. Unique object identifiers such as object identification numbers were also extracted from the BIM models to VRDR to link the object with the instance database set up in the CDE. So, each object could fetch related information from the database. Since we used Google Sheet, we changed the database connector to Google Sheet for Unity asset, utilizing the similar RESTful mechanism and JSON files translation.

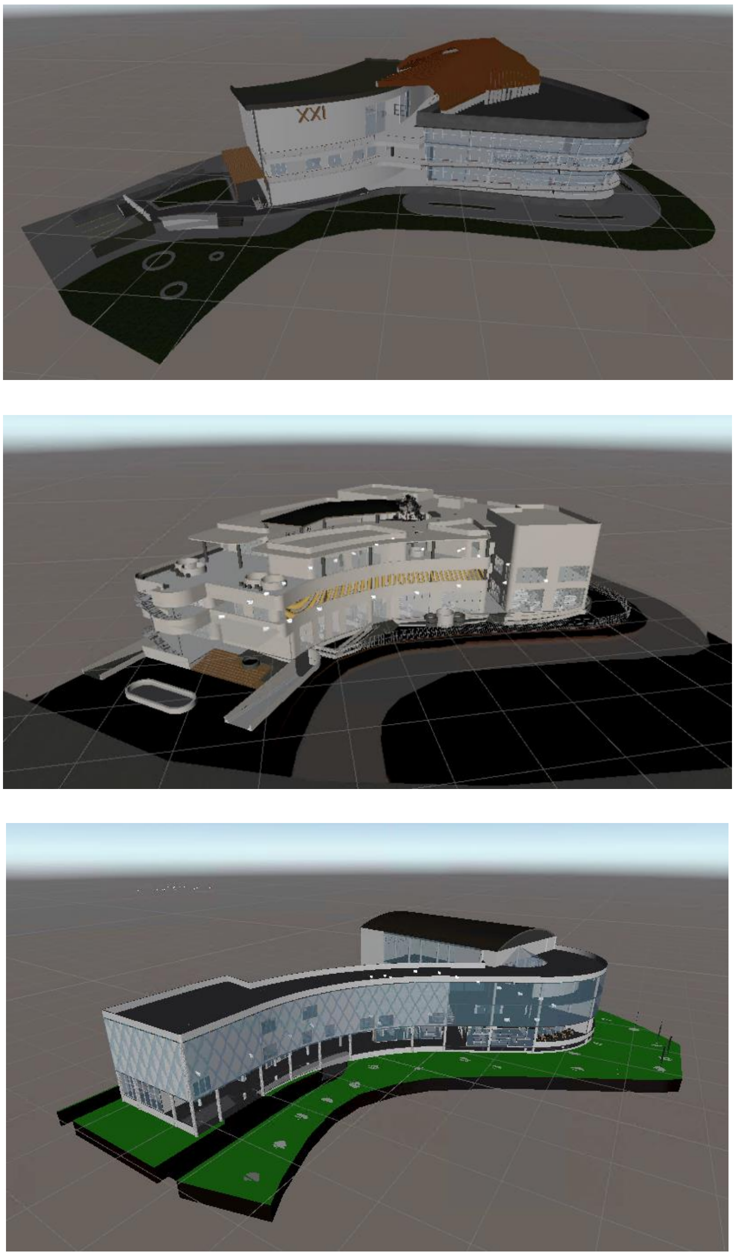


Figure 5-5. Optimized BIM models inside the VR scene of VRDR

5.2.2.3. UI/UX Development

Then, we developed the UI inside VRDR, named XR Rig, to help users interact with the models, both general and specific tools for the design review process, as seen in Figure 5-6. Standard tools, such as input keyboard, show and hide buttons, environment adaptor panel; and project information panel, were placed in front of the user avatar for easier reachability. Specific tools such as object tags were placed near their respective object instance; questionnaire panel and scene switcher were placed in the exact location along with the standard tools. The questionnaire panel was designed to let the user load questions and record feedback to the CDE database. So, we can retrieve the evaluation response faster regardless of the VRDR user. The detail of interfaces in the XR Rig are described further in Table 5-1.

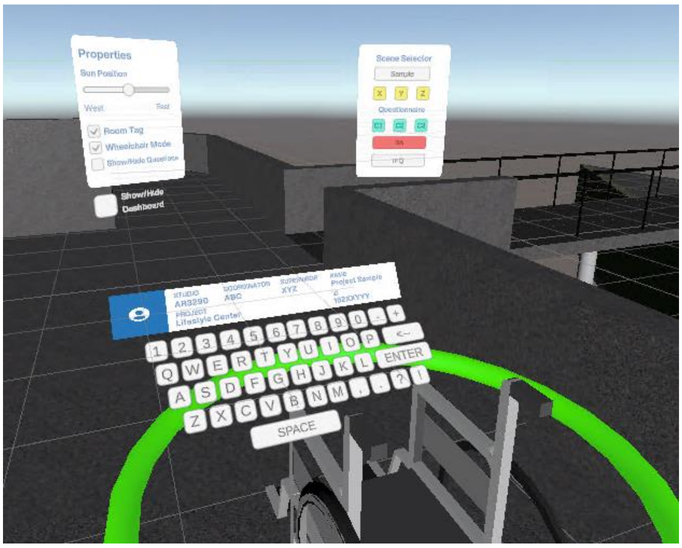
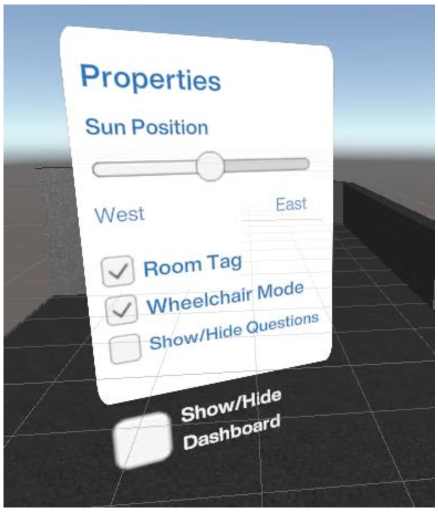
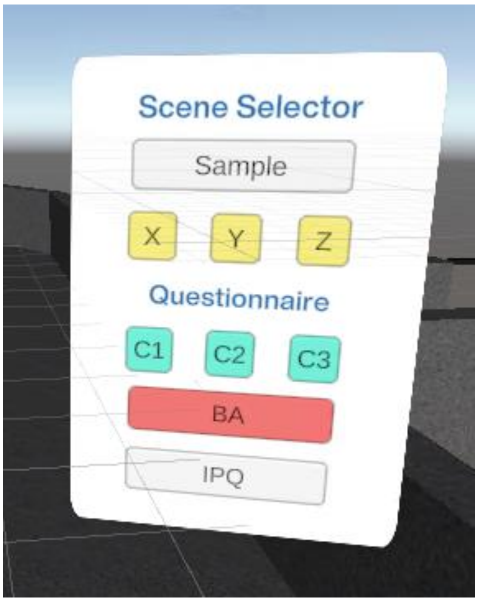


Figure 5-6. XR Rig in VRDR

Table 5-1. List of interfaces inside XR Rig of VRDR

Description	**Preview**
RigLCanvas	
a. Sun Position (SunSlider) SunSlider helps the user move the DirectionalLight position to check the building design shading and shadow. b. Room Tag (RoomTagToggle) RoomTagToogle helps the user on showing or hiding the Room Tag or RoomCanvas.	

Description	**Preview**
c. Wheelchair Mode (DifableToggle) DifableToggle helps users activate or deactivate wheelchair mode. This mode was considered a part of the exploration and is not discussed in this Thesis. d. Show/Hide Questions (QToggle) QToggle toggles the visibility of a list of questions related to the design review and data collection process. e. Show/Hide Dashboard (RigUI Toggle) RigUI Toggle toggles the visibility of the whole "dashboard components" in front of the avatar.	
RigRCanvas	

Description	**Preview**
a. Scene Selector (SceneBtn) SceneBtn helps the user to teleport from one location point to another point, depending on the design project that the user reviews, using SimpleTeleport.cs b. Questionnaire (SceneBtnC) SceneBtnC toggles the visibility of the questions list based on the design project that the user reviews.	
RigDownCanvas	
a. Project Information This UI canvas contains general information about the design project where the user currently is. b. QWERTY Keyboard A typical QWERTY keyboard, made for a VR environment. It is powered with KeyDetector.cs script.	
RoomCanvas	

<table>
<tr><th>Description</th><th>Preview</th></tr>
<tr><td>

a. Room Name (RoomNamePinText)

This object contains the parameter value of the room’s name as a string value.

b. Room Area (RoomAreaPinText)

This object contains the parameter value of the room’s area as a float value.

c. Room Volume (RoomVolPinText)

This object contains the parameter value of the room’s volume as a float value.

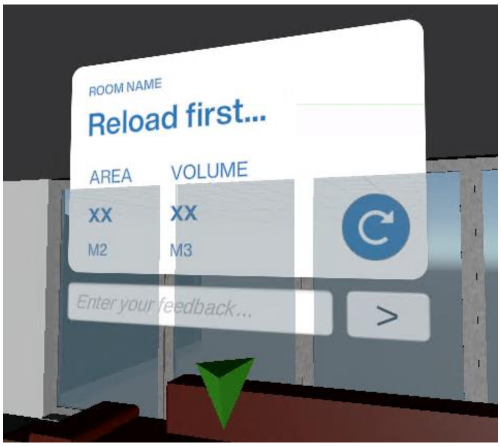
d. Load Button (LoadButton)

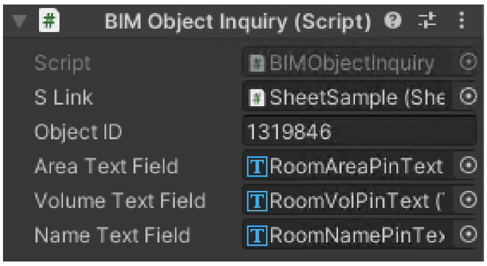
LoadButton triggers DriveConnection to load parameter values of a particular room component, using BIMObjectInquiry.cs script.

e. Feedback Field (FeedbackInputField)

FeedbackInputField lets the user type his feedback on the room using the prepared QWERTY keyboard.

</td><td>

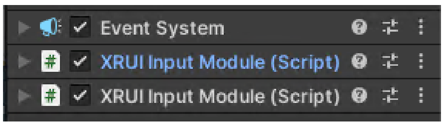


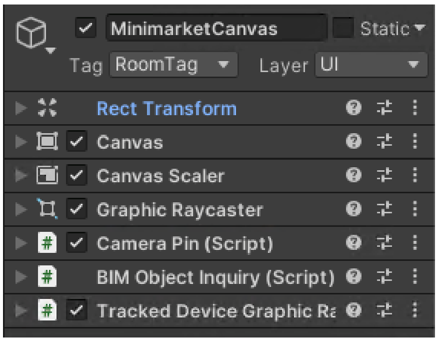
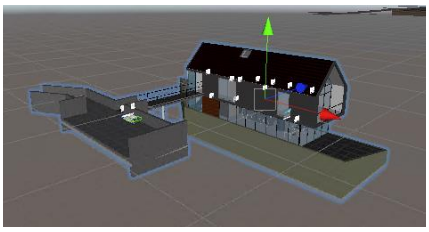


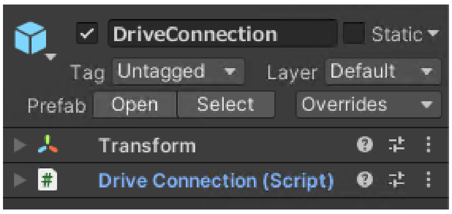
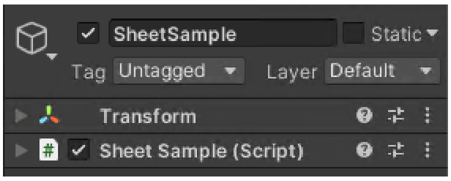
</td></tr>
</table>

Similar to the prototype in the previous Chapter, VRDR was built with various GameObjects representing the interfaces, characters, event managers, and database handler needed for the UX. There are four categories of GameObjects inside VRDR: event manager, interface, environment, and database manager. We decided to use XR Interaction Manager from the XR Interaction Toolkit asset released by Unity as a beta in the event manager. This asset becomes the fundamental of essential user interaction inside the virtual environment. Also, in the database manager category, we put DriveConnection and SheetSample from Google Sheet for Unity asset to manage and maintain the data connection between the database in the Google Sheet and VRDR. All GameObjects and their functions inside VRDR are explained more in Table 5-2.

Table 5-2. List of GameObjects and their functions in VRDR

GameObject	**Function**
Event Manager	
XR Interaction Manager 	This component facilitates interaction between interactors (user avatar) and interactable GameObject (design model and tags). It is part of the XR Interaction Toolkit released by Unity.
EventSystem 	The component handles UI events to process input and update individual active canvases.
Interface	
ProjectNamePin 	A collection of RoomCanvas for the room components in a particular project under ProjectName

GameObject	**Function**
RoomCanvas 	A UI canvas showing parameters of room components (room name, area, and volume), connected with the database
XR Rig 	The avatar represents the user in the virtual environment, controlled using the VR HMD controller and equipped with supporting interfaces (RigLCanvas, RigRCanvas, and RigDownCanvas). This component is a modified version of XRRig, part of the XR Interaction Toolkit sample project.
Environment	
Sample Revit Model 	This model is the infamous Revit Sample Project, optimized for VR and used for testing/tutorial by users before exploring VRDR even further.
BIM[ProjectName]	This object is the building design model used as the case study, later being reviewed by users using the affordance-based design approach.
Sun / Directional Light	As the default sunlight in the Unity scene
Database Manager	

<table>
<tr><th>GameObject</th><th>Function</th></tr>
<tr><td>DriveConnection

</td><td>Manage the connection between the database in Google Sheets and the virtual environment using RESTful API, including posting and retrieving parameter values. This object is a part of Google Sheets for Unity asset.</td></tr>
<tr><td>SheetSample

</td><td>A game object with SheetSample.cs script that serves on defining the data structure and inquiry classes and activating the DriveConnection</td></tr>
</table>

5.2.3. Data Transmission Workflow

Furthermore, this section discusses the data transmission workflow in the VRDR system. The workflow explains how the data transmits from the BIM model of reviewed design to the VRDR system including the data flow to the data analysis process, as illustrated in Figure 5-7.

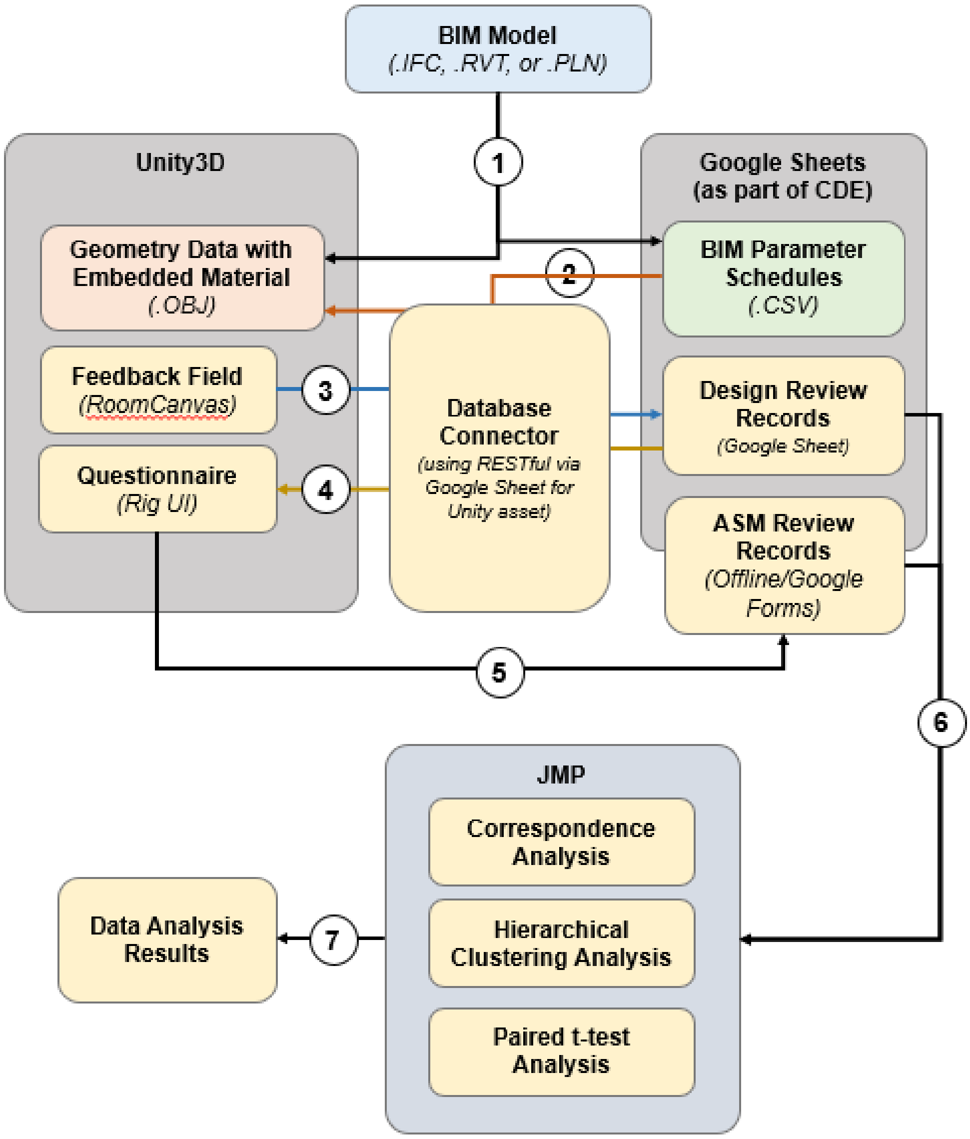


Figure 5-7. Data Transmission Workflow from BIM Data to VRDR System

There are seven processes in the workflow, explained as follows:

1. BIM model was extracted into two data parts: geometry data with embedded material (as OBJ files) exported to Unity and BIM parameter

schedules (as CSV files) exported to Google Sheet which is part of the CDE.
2. The parameter database in the Google Sheet is linked through Database Connector.
3. FeedbackField (RoomCanvas) is linked to Design Review Record database through Database Connector.
4. Questionnaire (Rig UI) is linked to Design Review Record database through Database Connector.
5. Questionnaire asked to the participants through printed materials and Google Form. All responses were gathered in the Google Sheets.
6. Both records from Design Review Records and ASM Review Records were retrieved and prepared to be processed using JMP.
7. The data analysis method was processed using JMP and analyzed further.

5.3. Discussion

VRDR system combines immersive VR technology and the power of embedded information inside the 3D geometries of a BIM model. It enables the student to get a sense of how his design would be built virtually on a scale of 1:1. By adding information layers from the extracted BIM database, the student can gain more spatial awareness of which area he is currently exploring. It is like playing a first-person video game, but the environment he explores is the building and site design he created by himself. In VRDR, students can evaluate if their designs afford the building users to perform activities mentioned in the TOR document of the design studio. The discussion section covers how the VRDR system works; the original features that make it distinctive, the advantages and disadvantages of the current systems, and opportunities that should be addressed in future studies.

VRDR system offers original features that make it distinctive from others. The system has a RESTful client and API built-in connection to the Google Sheet database, enabling structured and unstructured data connection. A structured data connection is needed to access structured databases such as the instance database, containing instance name, width, length, and location. Unstructured data connection availability lets us have a feedback feature where users can type textual feedback, send it to the CDE, and be accessed with other users for review.

There are advantages and disadvantages of the current VRDR system that we can identify. The VR model linked to the CDE database in the cloud lets the student update the model information directly inside the virtual environment or outside with a separate dashboard. This advantage opens an opportunity to elaborate on the design authoring modification process. The student can change specific building components or properties and record all changes to the CDE database. Students can send notes or feedback in text by typing them in the room tag panel and recording it as part of their design logbook. Since the current system is in single-player mode, only one student or user can interact with the VR model at a time. Multi-player mode within the VRDR system is an opportunity in a future study. It would be helpful for students and even supervisors to evaluate design outcomes together in real-time.

5.4. Conclusion

VRDR system enables students to utilize VR technology to evaluate their design outcomes, specifically in building affordances. Using an affordance-based design approach, students can use VRDR to evaluate if building affordances based on the design studio objectives have existed in their design works. As the outcomes were created as BIM models, students can get additional information about their design, such as room properties. The instance database provided information in the CDE and linked to each 3D geometry inside the virtual environment.

In Chapter 6, we will proceed to the analysis process of results recorded by the system. After that, further development of the system will be discussed based on the analysis result. The authors will determine any differences between non-VR and VR system-equipped design evaluation processes, including the advantages and disadvantages of both methods. In the end, we can get more insights into how the VR system can improve students' design works.

CHAPTER 6

AFFORDANCE-BASED DESIGN REVIEW PROCESS USING VRDR

6.1. Introduction

Chapter 5 described VRDR as the architectural design assessment tool with building affordances as the parameters. This Chapter will exercise how affordance-based design approach is used for the architectural design review process, especially in the educational context, by using VRDR. We identified the affordances referred to the studio objectives and Student Performance Criteria (SPC) set in the design studio brief. The affordances were mapped into Affordance Structure Matrix (ASM) with design components that will be reviewed: spatial entities – represented with rooms – and building components. We experimented with third-year students of the architecture program, where each of them evaluated student works using ASM with two different media: non-VR (NVR) and VR.

In this Chapter, we hypothesized that first, the media used for design review process might affect how each participant perceived affordances in each design and then led to the review result. Each of the media, NVR and VR, provides different experience to the participants on how they feel immersed onto each design work and perceive affordances. Second, with its immersive spatial capability compared to NVR, we expected that VR is more effective on helping participants to perceive affordances from spatial entities. Third, in the mean time, we also expected that each of design components might or might not perceived equally on both media. If an affordance is confirmed on both media, it is highly chanced that the affordance is actually present. The architectural designer could take action to the design component paired with that affordance. Lastly, by having an affordance confirmed to be perceived on specific media across all design works, we expected that the affordance is highly compatible with the media. If a participant wants to review that particular affordance presence, it is suggested to use the compatible media for review. With those hypotheses in mind, we explored the relationship between perceived affordances and design components of reviewed design works and perceived affordances and media used for review. We also compared the effectivity of NVR and VR media (VRDR) on perceiving affordance to find out if VRDR is more effective than NVR media. Then, it is followed by a discussion on the data analysis results and the chapter conclusion as a reflection for the future study.

6.2. Research Methods

We used simulation and correlational research strategies (Groat & Wang, 2013). We developed a game engine-based VR system and invited participants to perform a design review simulation using VRDR by wearing a VR head-mounted display (HMD) and exploring the virtual environment (VE). We used student design works from a third-year architectural design studio in the system for simulation. The designs represented three different score levels graded by the supervisors: high, middle, and low. All works were developed as BIM models. So, we could used the embedded parameters and properties to enhance the building information inside the VE. Beside that, each student was also required to submit a physical model of the final design in a scale of 1:500 using a monochromatic-colored material. Nevertheless, the requirement of building physical model during the design process is not explicitly written in the design brief.

In responding to the hypotheses, this study focused on three areas. The first area was the relationship between affordances perceived by participants and design components of each design. The objective of the first area was to discover what kind of feedback participants could give to the designer for design improvement. The second area was the relationship between affordances perceived by participants and the media they used to perform design reviews. The last area was the effectivity comparison between NVR and VR media. The objective was to determine which media is more effective in helping participants perceive affordances during the design review process.

During the design review simulation, each participant must complete the ASM by recognizing any perceived building affordance. We prepared the ASM before the simulation began. The ASM contained four types of affordances: +AUAs, −AUA,

+AAAs, and −AAAs. We defined them from studio objectives and performance criteria taken from the design studio brief.

6.2.1. Participants

The participants in the simulation experiment were third-year architectural design students. We assumed that third-year students have sufficient spatial reading skills to perceive affordances that can appear in the design component being evaluated and are familiar with BIM and the essential use of BIM-based design authoring tools. Fifty students (20-24 years old; 38.5% were 22) participated in the simulation (46.2% had never used a VR HMD device; 53.8% were myopic, and 42.3% did not suffer from any visual impairment). The simulation was conducted during the COVID-19 pandemic; therefore, all participants were required to follow health protocol measures, such as washing their hands, wearing a face mask and a disposable eye mask, and practicing physical distancing when performing the simulation. According to the Japanese Ethical Guidelines for Medical and Health Research Involving Human Subjects and the principles of the Declaration of Helsinki, the simulation was carried out. The participants provided informed consent.

6.2.2. Data collection and analysis processes

The data collection process comprised two phases: Phase A and Phase B. In Phase A or “NVR prior to VR” phase, each participant evaluated each design work by examining printed documentation, such as preliminary design drawings (floor plans, elevations, and sections), concept posters with interior and exterior perspective renderings, and an on-screen BIM model before they engage with VR media. Then in Phase B, or “NVR followed by VR,” participants explored all design works in the VR system by wearing a VR HMD (Figure 6-2). All participants engaged in the NVR condition before participating in the VR condition. It took up to 50 minutes for each participant to complete both phases.

Figure 6-1. Participants explored the VE wearing HMD.

After the data collection process was completed, we performed three types of data analysis on the collected data to achieve the study's objective:

1. Correspondence analysis was performed to determine the association between the categories of two nominal variables, such as between the perceived affordances and the media used for design evaluation.
2. Hierarchical clustering was performed for group categories of variables based on their similarity scores determined during the correspondence analysis.
3. A paired *t*-test was administered to determine any differences between Phase A and Phase B.

6.2.3. VR system

In the previous chapter, we developed a game engine-based VR system called the VR Design Reviewer (VRDR), as shown in Figure 6-1. The system was developed using Unity and was optimized for Oculus Quest as a standalone VR HMD. The VRDR system comprises three main parts: the VR model, the BIM common data environment (CDE), and the VR HMD. There are optimized BIM models of design studio works, seen in Figure 5-5, with embedded properties inside the VR model, including a representational state transfer (RESTful) client as the data connector to BIM CDE and a world space front-end interface to enable users to interact with the BIM models. As back-end infrastructure, the CDE contains the parameters and values of BIM model instance components. The CDE was designed as a cloud-based environment. The system was then deployed to the HMD and connected to the Internet.

Figure 6-2. Virtual Reality Design Reviewer (VRDR)

Participants used VRDR system to review presented design studio works as VR model during the Phase B data collection process. They must wear the HMD to use and experience VRDR. At first, they can see the dashboard user interface in front of them. On the left side, there is the “Properties” canvas where they can move the sun position and show or hide certain user interface elements. On the right side, there is the “Scene Selector” canvas where participants can teleport from one design studio model to another model and also show or hide the questionnaire they must respond as part of the simulation. In another way, participants can also take off the HMD for a while and respond the questionnaires in a separate screen or printed materials. On the lower side, there is the information panel about the design studio work they currently reviewed and custom keyboard as input tool.

Participants can explore the VR model by moving around using the analog stick on the left controller. Inside each of the model, there are room tags floating around. Each room tag shows the information related to the room or spatial entity where it resides such as room name, room area in meter square and room volume in meter cubic. All these information are taken directly from database in the CDE. There is also a feedback input right below each room tag. Participants can submit their feedback on each room by typing it using the available keyboard. The feedback, then, will be submitted to the CDE database and can be exported for report.

6.3. Identifying and Mapping Affordances

6.3.1. ASM arrangement from design brief

To complete the design studio course, a student must satisfy the seven objectives and eight student performance criteria (SPC). The course objectives were formulated based on the goals of the curriculum, whereas the SPCs were based on the accreditation board's quality standard (Korea Architectural Accrediting Board, 2018). However, affordances could only be extracted from four of the seven objectives and five of the eight criteria in this study. The remaining objectives and criteria are related to the students' presentation techniques and working attitudes. Using content analysis, we assigned all defined affordances into four types (+AUA, −AUA, +AAA, and −AAA). Note that any given affordance may appear in different objectives and SPC (Table 6-1 and 6-2).

After affordances were identified, the team placed them on the left side of the ASM, and design components (rooms and building components), were placed at the top side. The "Rooms" group was identified from the architectural space program decided in the design brief. The "Building Components" group was selected because these building components are the minimum required component to be designed by a student based on the level of drawing detail assigned in the design brief. Each participant was asked to consider if they perceived each affordance provided by each design component during both data collection phases. The respondent placed a tick mark on the matrix if an affordance was perceived. The arrange ASM can be seen on Table 6-3.

Table 6-1. Design objectives with related affordances

Points	+AUA	−AUA	+AAA	−AAA
		Objectives		
Arranging architectural programs includes the study of project initiatives, user studies, and precedent studies	Safety in activities	Getting in an accident	Integration between the site and building	Chance of getting hot easily
	Comfort in activities	Getting lost in the building	Weather protection	Getting wet when it is raining
	Suitability of activities with the function of space	Difficulty in attaining space		
	Ease of exploring rooms	Giving a feeling of tightness		
	Ease of disaster evacuations	Excessive glare		
	Sufficient capacity			
	Ease of building for the disabled population			

Points	+AUA	−AUA	+AAA	−AAA
Arranging various spatial zoning alternatives on the site, which guide the building design process through the site analysis	Ease of moving from space to space	Getting in an accident	Integration between the site and building	Chance of getting hot easily
	Ease of exploring rooms	Difficulty in attaining space		
	Ease of disaster evacuations	Excessive glare		
	Ease of space accessibility			
	Ease of building for the disabled population			
Making a schematic design as a schematic plan that shows the spatial organization and a sketch of architectural ideas to visualize the building's three-dimensional form	N/A			
Developing a building form/space composition by following the aesthetic principles, considering the site's context and its integration with the previously prepared spatial organization	Suitability of activities with the function of space	Getting lost in the building	Integration between the site and building	Getting wet when it is raining
	Ease of moving from space to space	Giving a feeling of tightness		

Points	**+AUA**	**−AUA**	**+AAA**	**−AAA**
	Ease of exploring rooms			
	Aesthetic of the space			
Developing buildings' preliminary designs by considering the aspects of their construction, function, and beauty	Safety in activities	Getting in an accident	Ability to support the load	Fragile/collapses easily
	Comfort in activities	Giving a feeling of tightness		
	Aesthetic of the space	Excessive glare		
	Suitability of activities with the function of space			
Presenting the design submission according to the preliminary design drawing standard	N/A			
Establishing a positive learning attitude during the design process	N/A			

N/A = not applicable

Table 6-2. SPCs with related affordances

Student Performance Criteria (SPC)				
Points	**+AUA**	**−AUA**	**+AAA**	**−AAA**
Ability to formulate architectural programs that guide the functional design of buildings	Safety in activities	Getting in an accident	Ability to support the load	Getting wet when it is rain
	Comfort in activities	Getting lost in the building	Weather protection	
	Activities suitability with the function of space	Difficulty in attaining space		
	Ease of space accessibility	Giving a feeling of tightness		
	Sufficient capacity	Excessive glare		
Competency in understanding the principles of visual aesthetics and applying them for two- and three-dimensional architectural designs	Aesthetic of the space			

Student Performance Criteria (SPC)

Points	+AUA	−AUA	+AAA	−AAA
Ability to design architecture comprehensively based on environmental and sustainability considerations and utilize concepts generated from user analysis and environmental context	Suitability of activities with the function of space	Getting in an accident	Natural ventilation	Chance of getting hot easily
	Ease of disaster evacuations		Natural lighting	
			Weather protection	
Ability to choose materials, components, and building structure systems that are integrated into building designs	Suitability of the activities with the function of space	Getting in an accident	Able to support the load	Chance of getting hot easily
	Ease of disaster evacuations			
Capable of designing with the "barrier-free" principle for persons with disabilities and the elderly	Safety in activities	Getting in an accident		Fragile/collapses easily
	Ease of building for the disabled population	Unfriendly for disabled user		

Student Performance Criteria (SPC)				
Points	**+AUA**	**−AUA**	**+AAA**	**−AAA**
Ability to visualize architectural ideas using various media and information technologies to demonstrate that the design process is being conducted		N/A		
Competently present architectural drawings that follow the preliminary standards		N/A		
Ability to recognize the importance of a positive attitude and work collectively to achieve the best results		N/A		

N/A = not applicable

Table 6-3. Arranged Affordance Structure Matrix (ASM)

Affordance Structure Matrix			Room										Building Component									
			Retail	Atrium	Café	Gym	Karaoke	Minimarket	Toilet (Ladies)	Toilet (Gents)	Toilet (Disabled)	Circulation Area	Slab	Str.	Str. Beam	Ramp	Solid Wall	Glass Wall	Railing	Stairs	Ceiling	Facade
+AUA	G1	Safety in activities																				
	G2	Comfort in activites																				
	G3	Suitability of activities with the function of space																				
	G4	Ease of moving from space to space																				
	G5	Ease of exploring rooms																				
	G6	Aesthetics of the space																				
	G7	Ease of disaster evacuations																				
	G8	Ease of space accessibility																				
	G9	Ease of building for the disabled population																				
	G10	Sufficient capacity																				
-AUA	H1	Getting in an accident																				
	H2	Getting lost in the building																				
	H3	Difficulty in attaining space																				
	H4	Unfriendly for disabled user																				
	H5	Giving a feeling of tightness																				
	H6	Excessive glare																				
+AAA	J1	Ability to support the load																				
	J2	Natural ventilation																				
	J3	Natural lighting																				
	J4	Integration between site and building																				
	J5	Weather protection																				
-AAA	K1	Chances of getting hot easily																				
	K2	Fragile/collapses easily																				
	K3	Getting wet while it is raining																				

6.3.2. ASM results

The matrices for Phase A and B were counted separately. Perceived affordances were calculated according to affordance types, design submission, and design components (Table 6-4).

Table 6-4. Summary of ASM results

Affordance Structure Matrix			Project X				Project Y				Project Z			
			Room (NVR)	Room (VR)	Building Component (NVR)	Building Component (VR)	Room (NVR)	Room (VR)	Building Component (NVR)	Building Component (VR)	Room (NVR)	Room (VR)	Building Component (NVR)	Building Component (VR)
+AUA	G1	Safety in activities	77%	79%	31%	31%	76%	67%	22%	27%	68%	71%	21%	27%
	G2	Comfort in activites	75%	70%	24%	23%	73%	62%	17%	21%	71%	71%	13%	18%
	G3	Suitability of activities with the function of space	78%	80%	19%	19%	81%	67%	13%	16%	71%	74%	8%	13%
	G4	Ease of moving from space to space	58%	59%	16%	17%	73%	66%	10%	14%	53%	52%	8%	15%
	G5	Ease of exploring rooms	60%	56%	15%	18%	70%	64%	9%	12%	53%	53%	6%	14%
	G6	Aesthetics of the space	49%	48%	17%	21%	49%	46%	11%	17%	32%	35%	9%	16%
	G7	Ease of disaster evacuations	58%	55%	15%	19%	72%	67%	9%	14%	46%	49%	6%	13%
	G8	Ease of space accessibility	61%	58%	15%	18%	81%	75%	9%	14%	49%	49%	7%	13%
	G9	Ease of building for the disabled population	45%	42%	12%	15%	44%	49%	11%	16%	37%	37%	10%	14%
	G10	Sufficient capacity	63%	66%	11%	17%	58%	65%	9%	17%	57%	60%	9%	13%
-AUA	H1	Getting in an accident	5%	6%	4%	8%	5%	5%	3%	5%	5%	6%	2%	6%
	H2	Getting lost in the building	9%	9%	1%	1%	3%	6%	1%	1%	9%	12%	2%	2%
	H3	Difficulty in attaining space	17%	18%	2%	3%	6%	8%	1%	2%	18%	18%	2%	3%
	H4	Unfriendly for disabled user	11%	16%	3%	7%	21%	14%	3%	5%	15%	18%	2%	6%
	H5	Giving a feeling of tightness	23%	21%	2%	3%	13%	11%	2%	3%	15%	16%	3%	4%
	H6	Excessive glare	22%	13%	5%	4%	5%	6%	4%	2%	9%	8%	3%	3%
+AAA	J1	Ability to support the load	30%	28%	38%	38%	28%	31%	31%	36%	31%	30%	30%	39%
	J2	Natural ventilation	39%	39%	12%	14%	39%	42%	9%	14%	30%	33%	9%	14%
	J3	Natural lighting	49%	50%	13%	14%	52%	50%	12%	16%	39%	39%	10%	16%
	J4	Integration between site and building	42%	43%	17%	18%	44%	47%	15%	16%	39%	40%	11%	16%
	J5	Weather protection	48%	40%	18%	20%	51%	46%	11%	16%	42%	35%	12%	18%
-AAA	K1	Chances of getting hot easily	17%	15%	5%	4%	11%	10%	2%	3%	17%	18%	3%	3%
	K2	Fragile/collapses easily	1%	2%	3%	5%	0%	1%	2%	3%	1%	0%	4%	3%
	K3	Getting wet while it is raining	13%	8%	3%	3%	9%	10%	6%	6%	10%	12%	5%	4%

The matrix identifies how many affordances in the design studio submissions were perceived by the participants in different design component groups and media between NVR and VR. Each number represents the average percentage of participants who perceived an affordance on different media. For example, in "Project X," 77% of participants perceived the "safety in activities" affordance from rooms using the NVR media and 79% from those using the VR media for the evaluation process.

6.4. Data Analysis

6.4.1. Relationship between affordances and design components

This section analyzed the relationship between affordances and design components using correspondence and hierarchical analysis methods configured as dendrograms. This relationship explained perceived affordance proximity to the design components evaluated by the participants using either the NVR or VR media. Then, we compared the relationship result on different media and design components for all design works. We found that the media type affects the associative relationship of affordances and the reviewed design components. In Project X, 18 of 24 affordances (75%) were associated with rooms differently between the NVR and VR media, and 20 of 24 affordances (83.3%) were associated with building components differently between media. In Project Y, 22 of 24 affordances (91.7%) were associated with rooms differently, and 23 of 24 affordances (95.8%) were associated with building components differently between media. In Project Z, 13 of 24 affordances (54.17%) were associated with rooms differently, and 21 of 24 affordances (87.5%) were associated with building components differently between media.

Some affordances were not associated with any room or building component in NVR or VR media. For example, in Project X with the NVR media, affordances of "getting in an accident" (H1) and "getting wet while it is raining" (K3) are not associated with any room. Affordances of "getting in an accident" (H1), "getting wet while it is raining" (K3), "unfriendly for disabled user" (H4), "difficulty in attaining space" (H3), "getting lost in the building" (H2), and "giving a feeling of tightness" (H5) were not associated with any building component in Project X. We expected that because, by definition, those affordances were more relatable with rooms as spatial entities than building components. In Project Z, the affordance of "fragile/collapse easily" (K2) during Phase B (VR) is not associated with any room, and affordance of "getting we while it is raining" (K3) is not associated with any building component. In addition, in Project X and Y, the affordance of "fragile/collapse easily" (K2) was not associated with any room in the NVR or VR phase. This situation meant that the participants could perceive affordances of a fragile building when evaluating rooms in Projects X and Y regardless of which media was used for the design review.

In addition, some affordances not associated with any design component in one media were associated with design components in the other media. For example, in Project X, the affordance of "getting wet while it is raining" (K3), which was not associated with any room in the NVR media, is associated with the atrium and circulation area in the VR media. In Project Y, affordances of "getting in an accident" (H1), "getting lost in the building" (H2), and "getting wet while it is raining" (K3) was not associated with any room in the NVR media, are associated with the circulation area in the VR media. In Project Z, the affordance of "fragile/collapses easily" (K2) associated with the café room in the NVR media loses all associations in the VR media.

Specific findings between rooms and the building components group were also found. For example, in rooms, the dendrograms shown in Figure 6-3 demonstrate that participants perceived the same affordances in many specified rooms when using the VR media. In Project Y, affordances of "difficulty in attaining space" (H3), "unfriendly for disabled user" (H4), "giving a feeling of tightness" (H5), and "chances of getting hot easily" (K1) were perceived in all lavatories in the NVR media. However, those affordances could only be perceived in the lavatory for men and women in the VR media. In building components, the affordance of "ability to support the load" (J1) was associated with the slab, structural columns, and structural beams in all projects and all media. This finding suggested that the slab, structural columns, and structural beams made users easily perceive the affordance of "ability to support the load" (J1).

The researchers compared similar results between NVR and VR medium on all design submissions. In Project X, 18 of 24 affordances (75%) were perceived in different Rooms, and 20 of 24 affordances (83.3%) were perceived in different Building Components. In Project Y, 22 of 24 affordances (91.7%) were perceived in different Rooms, and 23 of 24 affordances (95.8%) were perceived in different Building Components. In Project Z, 13 of 24 affordances (54.17%) were perceived in different Rooms, and 21 of 24 affordances (87.5%) were perceived in different Building Components.

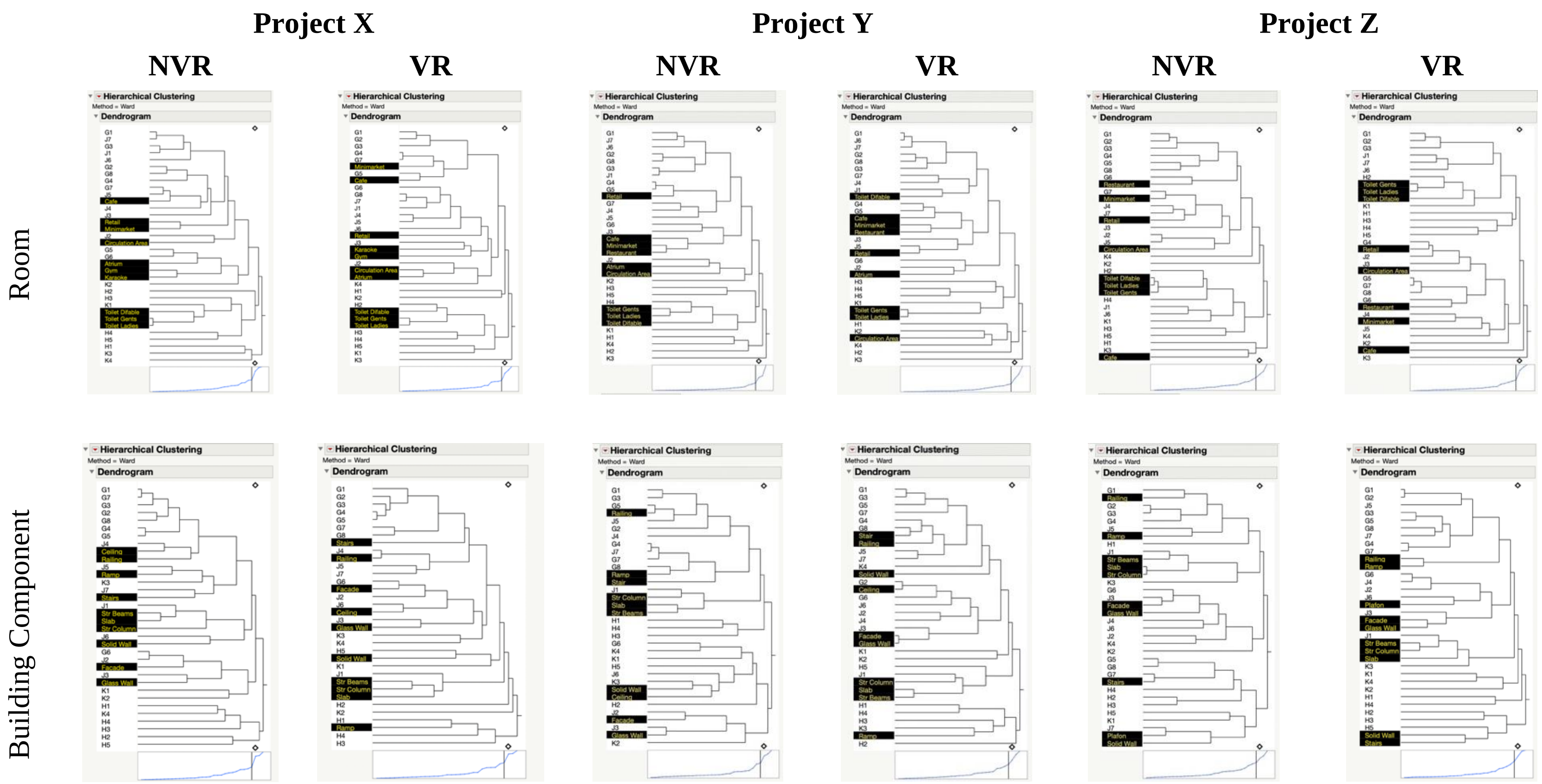


Figure 6-3. Dendrograms of hierarchical clustering analysis of the relationship between affordances and design components.

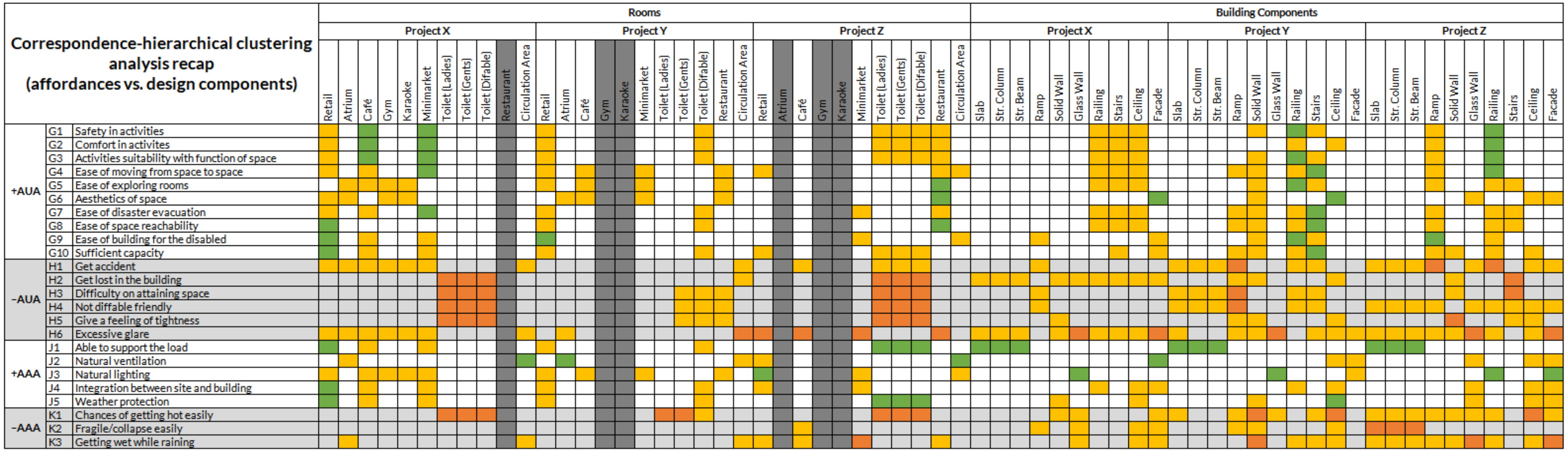
The results of the analysis are summarized in Table 6-5. It shows the affordances confirmed to have been perceived by users in both the NVR and VR media. Different colors in the table represent positive and negative affordances perceived using either NVR and VR media, one of the media, or none.

The results indicate how many affordances can be provided by each design component to the participants and how well each design submission achieves the design objectives based on the perceived affordances. Three conditions determine the achievement of a design objective:

a. When an affordance exists in a design component in both media, the design component achieves its objective if it is a positive affordance. If it is a negative affordance, a problem is found, which should be resolved immediately.
b. If an affordance does not exist in a design component in both media, the element has not yet achieved the design objective if it is a positive affordance. No problem is found in the design component if it is a negative affordance.
c. When an affordance exists in a design component in one media, the student (as the architectural designer) should consider improving the design.

Table 6-5. Correspondence–hierarchical clustering analysis summary

(affordances versus design components)



Notes:
Confirmed both in NVR and VR (+)
Confirmed both in NVR and VR (–)
Confirmed either in NVR and VR
Not perceived

According to the above conditions, the result confirmed that all three design submissions achieved several design objectives and potential improvements. For example, in Project X, the building structure is perceived as solid, with some building components that require attention (K2). The café offers users safety and comfort for activities (G1, G2) because it can be used for its intended function (G3). Retail spaces can be reached by users easily (G8) with site-building integration (J4) and easy access for persons with disabilities (G9). In addition, retail spaces provide adequate support for internal structural loads (J1) and protection from adverse weather conditions (J5). The circulation area is perceived to provide natural ventilation (J2). For lavatories (bathrooms), the student (as the designer) should rework these rooms because they are difficult to reach (H3), inhospitable for users with disabilities (H4), can give a feeling of tightness (H5), and can get hot quickly (K1). In addition, the main structure that supports lavatories can support the expected load (J1). Both glass walls and building facades should also be redesigned because these components afford excessive glare to users (H6).

Retail spaces provide easy access for users with disabilities (G9), noting that the disabled population was not tested explicitly in this study. In Project Y, the building structure is perceived as solid, with some building components that require attention (J1, K2). The atrium was perceived to provide natural ventilation (J2), and the stairs in the building allow users to move between spaces quickly (G4, G8), especially when evacuating during a disaster (G7) with sufficient capacity (G10). Railings also help keep users safe (G1, G3, G5), especially people with disabilities (G4). In terms of design improvement, the student should carefully consider the lavatories and ceiling, which can get hot quickly (K1), and ramps, which can potentially harm users (H1, H3), especially persons with disabilities (H4).

In Project Z, the building structure is also perceived as solid (J1) but tends to collapse easily (K2). Participants also perceive that they can easily reach and explore the restaurant (G5, G8), and the restaurant provides space aesthetic to them (G6). The restaurant, café, minimarket, and retail spaces also introduce excessive glare to users (H6) due to the heavy use of glass walls. In addition, railings are perceived to keep users safe (G1, G2, G3, G4) and potentially get them in an accident (H1). Solid walls in the building cause a feeling of tightness to users (H5), and all lavatories afford weather protection (J5) but are inhospitable for users with disabilities (H5) and introduce a feeling of tightness (H5). All confirmed items are based on the affordances that satisfy the conditions (a) and (b). Students should consider each result to improve their designs.

6.4.2. Relationship between affordances and media

The relationship between affordances and the media used for the design review process in different design component groups was analyzed using the correspondence and hierarchical clustering analysis methods and visualized as dendrograms (Figure 6-4). In the building component group, all 24 affordances (100%) could be perceived by participants. Regarding composition, 50%–62.5% of the affordances were perceived in the VR media. 37.5%–50% were perceived in the NVR media (depending on the design works). However, in the room group, only 19–21 of the affordances (79.2%–83.3%) can be perceived by participants when using either the NVR or VR media. This finding demonstrated that participants could perceive the affordances of building components (i.e., walls, columns, and beams) faster than those of rooms (i.e., retail space, café, and lavatory).

The consistency of the affordances identified in rooms and building components with the NVR and VR media were examined for all design submissions. In the room group, affordances of "ease of exploring rooms" (G5), "ease of space accessibility" (G8), and "weather protection" (J5) were perceived consistently in the NVR media. In contrast, affordances of "safety in activities" (G1), "suitability of activities with the function of the space" (G3), "natural ventilation" (J2), and "integration between site and building" (J4) were perceived regularly in the VR media. Meanwhile, in the building component group, affordances of "safety in activities" (G1), "getting lost in the building" (H2), "chances of getting hot easily" (K1), "excessive glare" (H6), and "getting we while it is raining" (K3) were perceived consistently in the NVR media. Affordances of "ease of exploring rooms" (G5), "aesthetics of the space" (G6), "ease of disaster evacuation" (G7), "ease of space accessibility" (G8), "getting in an accident" (H1), "unfriendly for disabled user" (H4), "ease of building for the disabled population" (G9), and "sufficient capacity" (G10) were sensed regularly in the VR media. Affordances consistently perceived from the room group were positive. The building component group well perceived both positive and negative affordances. This condition indicated that each media considered had sufficient information clarity to help participants undertaking those mentioned affordances, whether in the room or building component group.

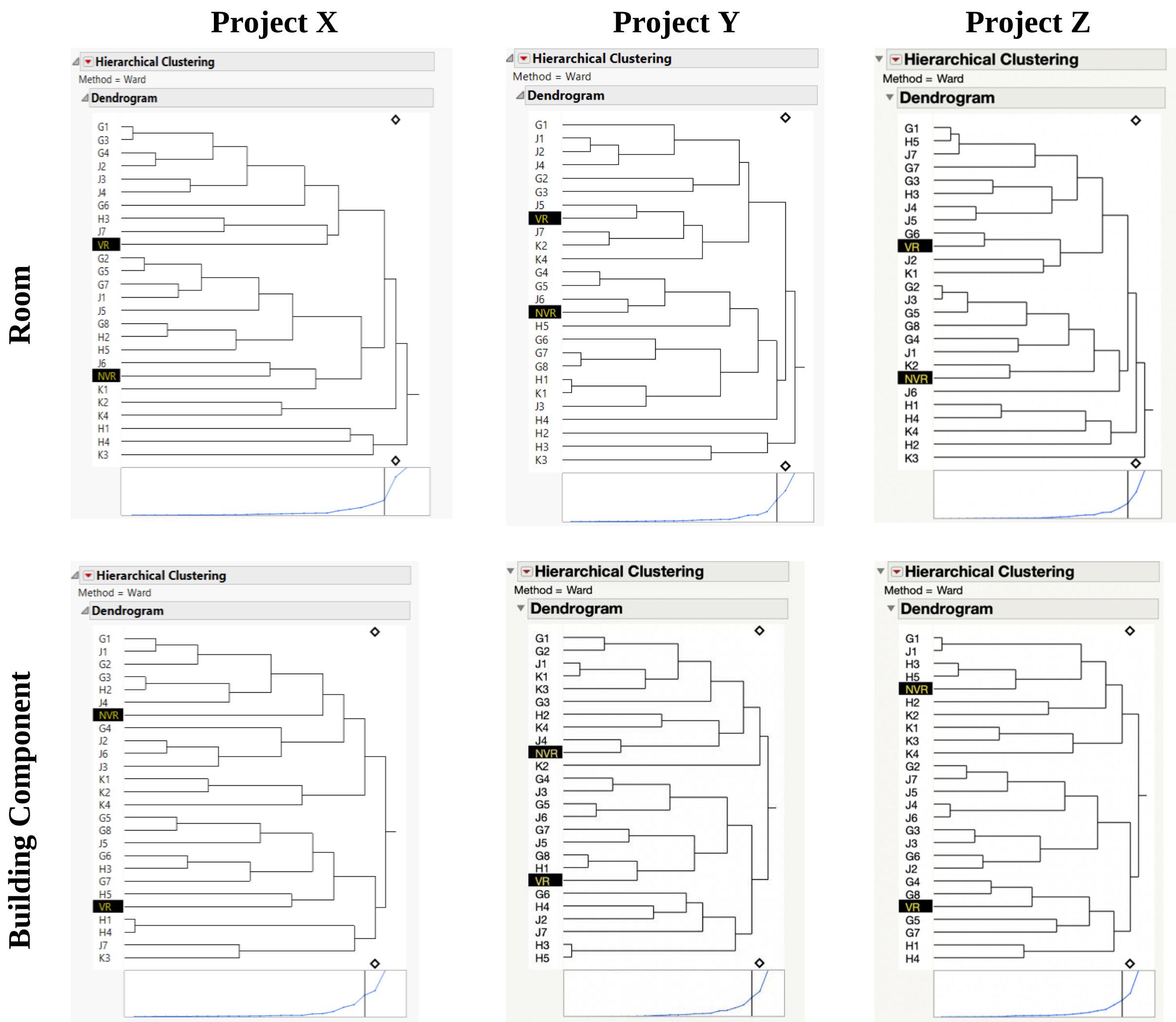


Figure 6-4. Dendrograms from hierarchical clustering analysis of affordances and media relationship in rooms and the building components group.

The relationship between affordances and media showed the media's capability in helping users perceive affordances from the design works (Table 6-6). When participants evaluated rooms, affordances of "ease of room exploration" (G5), reaching the space (G8), and "weather protection" (J5) were associated more with the NVR media than the VR media. The team suspects that this phenomenon occurred because the spatial information required to perceive both affordances G5 and G8 was more clearly perceived in the NVR media than in the VR media. Meanwhile, by using the VR media, users could easily perceive affordances of the safety in performing activities (G1), activities that were suitable for space's function (G3), natural ventilation (J2), and integration between the site and building (J4). This finding is unique because, logically, the affordances of G5 and G8 should be quickly taking advantage of VR spatial capability where participants can freely explore space inside, and it is more immersive than the NVR media.

For building components in the NVR media, users easily perceive the safety in executing activities (G1), becoming lost in the building (H2), the chance of getting hot quickly (K1), excessive glare (H6), and getting wet during rainy weather affordances. In the VR media, users perceived affordances of the ease of exploring rooms (G5), aesthetics (G6), simplicity of disaster evacuations (G7), space reachability (G8), the possibility of having an accident (H1), inhospitable for users with disabilities (H4), ease of motion for users with disabilities (G9), and sufficient capacity (G10). These findings may help determine which media should be used to evaluate specific affordances.

Table 6-6. Summary of correspondence–hierarchical clustering analysis (affordances versus media).

Correspondence-hierarchical clustering analysis recap (affordances vs. medium)			Rooms								Building Components							
			NVR				VR				NVR				VR			
			Project X	Project Y	Project Z	Summary	Project X	Project Y	Project Z	Summary	Project X	Project Y	Project Z	Summary	Project X	Project Y	Project Z	Summary
+AUA	G1	Safety in activities				0	v	v	v	**3**	v	v	v	**3**				0
	G2	Comfort in activites	v		v	2		v		1	v	v		2			v	1
	G3	Suitability of activities with the function of space				0	v	v	v	**3**	v	v		2			v	1
	G4	Ease of moving from space to space		v	v	2	v			1	v			1		v	v	2
	G5	Ease of exploring rooms	v	v	v	**3**				0				0	v	v	v	**3**
	G6	Aesthetics of the space		v		1	v		v	2				0	v	v	v	**3**
	G7	Ease of disaster evacuations	v	v		2			v	1				0	v	v	v	**3**
	G8	Ease of space accessibility	v	v	v	**3**				0				0	v	v	v	**3**
	G9	Ease of building for the disabled population	v			1		v	v	2				0	v	v	v	**3**
	G10	Sufficient capacity				0	v		v	2				0	v	v	v	**3**
-AUA	H1	Getting in an accident		v		1				0				0	v	v	v	**3**
	H2	Getting lost in the building	v			1				0	v	v	v	**3**				0
	H3	Difficulty in attaining space				0	v		v	2			v	1	v	v		2
	H4	Not diffable friendly		v		1				0				0	v	v	v	**3**
	H5	Giving a feeling of tightness	v	v		2			v	1			v	1	v	v		2
	H6	Excessive glare			v	1		v		1	v	v	v	**3**				0
+AAA	J1	Ability to support the load	v		v	2		v		1		v	v	2	v			1
	J2	Natural ventilation				0	v	v	v	**3**	v			1		v	v	2
	J3	Natural lighting		v	v	2	v			1	v			1		v	v	2
	J4	Integrating between the site and building				0	v	v	v	**3**	v	v		2			v	1
	J6	Weather protection	v	v	v	**3**				0	v			1		v	v	2
-AAA	K1	Chances of getting hot easily	v	v		2			v	1	v	v	v	**3**				0
	K2	Fragile/collapses easily				0				0		v	v	2	v			1
	K3	Getting wet while it is raining				0		v		1	v	v	v	**3**				0
		Freq	10	11	8	3	9	9	11	4	12	10	9	5	12	14	15	8
		Percentages	41,67%	45,83%	33,33%		37,50%	37,50%	45,83%		50,00%	41,67%	37,50%		50,00%	58,33%	62,50%	

6.4.3. Comparison of media effectivity

This section employed two analysis methods to study the effectivity of the NVR and VR media for the design evaluation process. First, correspondence and hierarchical cluster analysis were performed to find relationships between the design components and the media and identify which components were connected to one media (Figure 6-5). Then, we performed a paired statistical *t*-test analysis to compare the NVR and VR media in terms of perceived affordances for each design component. The resulting *p*-values, which indicate the probability of obtaining the paired t-test result under the null hypothesis, are shown in Table 6-7 for rooms and Table 6-8 for building components.

More building components were associated with the VR media based on the results. Some rooms and building components were consistently associated with one medium across all design submissions. All lavatories were consistently associated with the NVR media in the room group, whereas the circulation area was consistently associated with the VR media. The glass wall, structural column, façade, and ramp were regularly correlated with the NVR media in the building component group. In contrast, the structural beams, ceiling, and slab were consistently associated in the VR media.

To obtain more detailed findings, the team examined the paired *t*-test results. In this test, the following null hypothesis was considered: "there is no difference in the amount of perceived affordance between VR and NVR media." If the null hypothesis is rejected, the alternative hypothesis is accepted, "there are more affordances perceived in the VR media than in the NVR media." In Tables 6-5 and 6-6, the highlighted numbers show that the highlighted pairs reject the null hypothesis, meaning more affordances are perceived using the VR media than the NVR media. Based on the presented data, more pairs of design components and affordance groups are significantly effective to be perceived with VR in the building component group than in the room group. For example, in Project X, there are four pairs in the room group and 11 pairs in the building component group. In Project Y, there are 17 pairs in only the building component group. In Project Z, there are five pairs in the room group and 20 pairs in the building component group.

The highlighted pairs appear more in the building component group than the room group. Specifically, most highlighted pairs are associated with positive affordance, and all pairs associated with AUA+ tend to be significantly more likely to use VR than NVR. The opposite result occurred in the room group. In other words, most affordances–design component pairs in the room group are significantly more effective when using NVR. Only a handful of affordances–design component pairs were significantly effective when using VR.

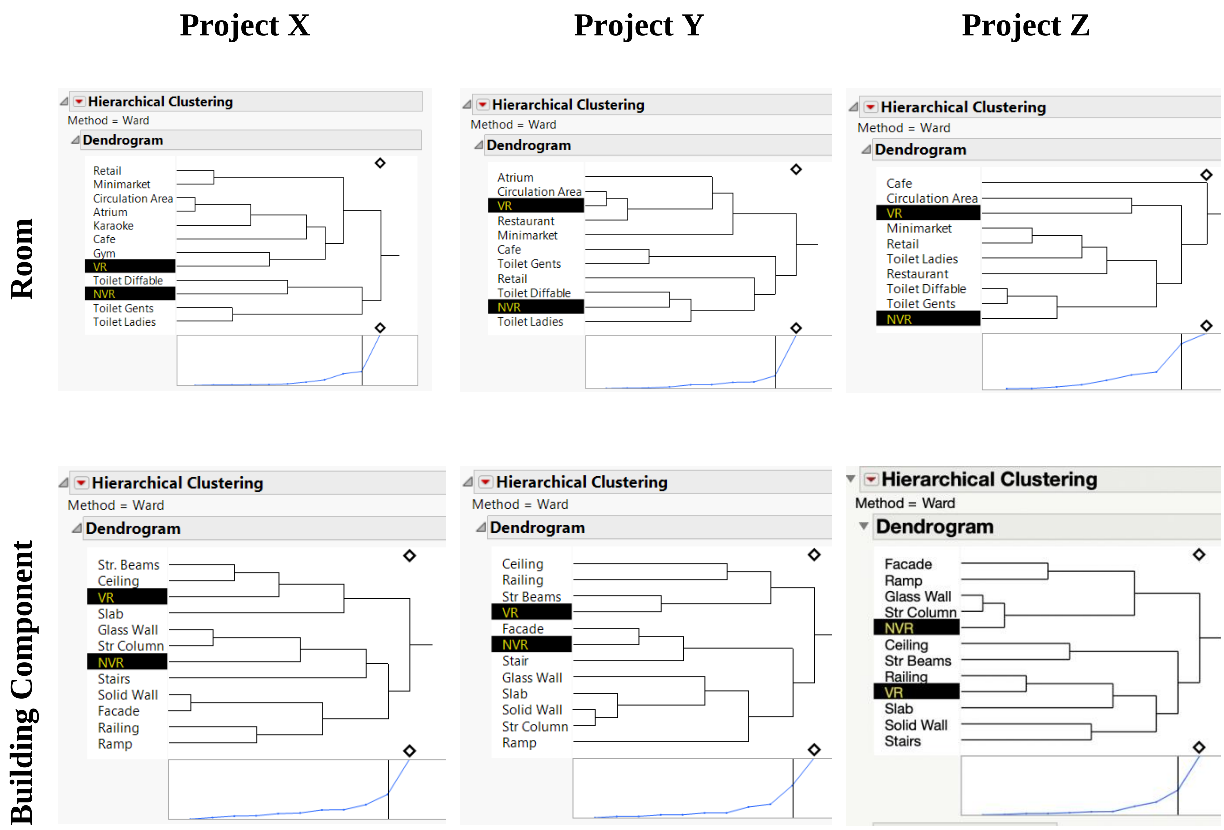


Figure 6-5. Dendrograms from hierarchical clustering analysis of design components and media relationship in different design component groups.

Table 6-7. P-values of paired t-test analysis results for each room

	Paired t-test Results (p-value)	Room										
		Retail	Atrium	Café	Gym	Karaoke	Minimarket	Toilet (Ladies)	Toilet (Gents)	Toilet (Diffable)	Restaurant	Circulation Area
PROJECT X	AUA+	0.08	0.06	0.19	0.003	0.05	0.82	0.001	0.001	0.003	N/A	0.67
	AUA-	0.12	0.76	0.67	0.06	0.37	0.06	0.47	0.46	0.21	N/A	0.16
	AAA+	0.14	0.30	0.11	0.79	0.85	0.59	0.85	0.62	0.70	N/A	0.23
	AAA-	0.23	0.23	0.53	0.42	0.42	0.74	0.42	0.42	0.74	N/A	0.68
PROJECT Y	AUA+	0.23	0.31	0.85	N/A	N/A	0.41	0.24	0.70	0.12	0.47	0.40
	AUA-	0.91	0.81	0.59	N/A	N/A	0.50	0.29	0.31	1.00	0.57	0.33
	AAA+	0.09	0.37	0.26	N/A	N/A	0.16	0.56	0.88	0.66	0.63	0.06
	AAA-	0.74	0.23	0.74	N/A	N/A	0.42	0.74	0.42	0.63	0.18	0.23
PROJECT Z	AUA+	0.002	N/A	0.68	N/A	N/A	0.015	0.15	0.40	0.19	0.06	0.015
	AUA-	0.06	N/A	0.61	N/A	N/A	0.49	0.033	0.09	0.08	0.70	0.002
	AAA+	0.49	N/A	0.62	N/A	N/A	0.81	0.18	0.11	0.51	0.89	0.07
	AAA-	0.42	N/A	1.00	N/A	N/A	0.27	0.23	0.23	0.42	0.42	0.27

Table 6-8. P-values of paired t-test analysis results for each building component.

Paired t-test Results (NVR vs. VR)		Building Component									
		Slab	Str. Column	Str. Beam	Ramp	Solid Wall	Glass Wall	Railing	Stairs	Ceiling	Facade
PROJECT X	AUA+	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	0.0002	0.0002	0.0006	<.0001*
	AUA-	0.36	0.61	0.38	0.15	0.36	1.00	0.23	0.03	1.00	0.70
	AAA+	0.24	0.27	0.14	0.34	0.10	0.59	0.07	1.00	0.37	0.85
	AAA-	0.23	N/A	0.74	0.53	0.42	0.74	0.42	0.74	0.18	0.53
PROJECT Y	AUA+	0.001	0.002	<.0001*	0.034	<.0001*	<.0001*	<.0001*	0.025	<.0001*	0.009
	AUA-	0.20	0.04	0.10	0.14	0.30	0.28	0.11	0.24	0.17	0.36
	AAA+	0.004	0.14	0.052	0.004	0.13	0.18	0.007	0.011	0.001	0.13
	AAA-	0.42	0.42	0.42	0.42	0.42	N/A	0.42	1.00	1.00	0.74
PROJECT Z	AUA+	<.0001*	<.0001*	<.0001*	0.013	<.0001*	<.0001*	0.027	<.0001*	<.0001*	<.0001*
	AUA-	0.36	1.00	0.08	0.16	1.00	0.17	0.14	0.04	N/A	0.36
	AAA+	0.023	0.005	0.027	0.001	0.058	0.004	0.011	0.020	0.000	0.000
	AAA-	0.42	N/A	0.42	1.00	1.00	0.07	N/A	0.42	N/A	0.18

6.5. Discussion

In the previous section, three sets of data analyses were explained. First, the relationship between affordances and design components in the NVR and VR media was investigated to observe the proximity of perceived affordances to the design components evaluated by the participants. The results demonstrate that the selection of the media affects the correlative association relationship between affordances and the evaluated design component. Suppose a design component has a correlative association relationship with an affordance. In that case, the design component provides the associated affordance. This correlative association relationship can be confirmed in the design evaluation process using one media (NVR or VR) or both media (NVR and VR). An affordance might not have a correlative relationship with any design component, indicating that no evaluated design component provides that affordance. This finding confirmed the third hypothesis stated earlier regarding the presence of affordance on both media as a sign that the affordance is actually present in the reviewed design works.

Affordance polarity in the correlative association relationships also can help students improve or revise their designs. If a positive affordance is associated with a design component, the design component achieves the expected design objectives. If the associated affordance is negative, the students must revise the associated design components. Therefore, the relationship analysis between affordance and design components in NVR and VR media can help students determine which design components have achieved the design objectives and which components must be improved.

An architectural design model can be more easily perceived using direct perception if the information content required by the user is sufficient to execute the design evaluation process. The results of the second data analysis indicate that the room exploration (G5), reaching space (G8), and weather protection (J5) affordances are more associated with the NVR media than the VR media. Logically, these affordances should be easier to perceive using VR than NVR by utilizing immersive spatial exploration capabilities in the VE. This finding is in contrary with second hypothesis where we expect VR is more effective on perceiving those affordances.

We suspect that the information content required by the user to evaluate the design works could be provided more easily on NVR compared to VR. By using NVR, the user can move from one document to another or from one model view to another to obtain the required information. In VR, the user is presented with three-dimensional spatial information. They must perform motoric actions, such as pressing a button or sticking on the controller for exploring the room. Users can perform design evaluations with minimal or no cognitive effort; otherwise, users must perform a more extensive cognitive activity.

In addition, the result of second data analysis confirms the last hypothesis we stated previously. As recapped in Table 6-6, we found the presences of several affordances across all design works in a specific media, either NVR or VR. These affordances are considered more compatible with the specific media. We suggest that if a designer wants to pursue a specific affordance presence, it is better for him to use the compatible media for review process.

Lastly, the results of the third data analysis demonstrate that the more perceived affordances of the building component, especially positive affordances, are significantly more using the VR media than the affordances of rooms. The results confirms the first hypothesis we stated in the beginning of the Chapter. Although at the same time, we surprised that it is in contrary with the second hypothesis where VR should be more effective on perceiving affordances in the room components. In line with the ecological psychology approach on affordance, building components, e.g., walls, columns, and beams, have specific apparent physical properties. This condition makes building components provide affordances, and users can perceive these affordances more readily than rooms that do not have apparent physical properties. Spatially, the physical properties of rooms can be defined more clearly by placing unique interior components in each room. Thus, rooms can provide the expected affordances. These results demonstrate that rooms with unique interior components with programmed functions, such as lavatories, retail space, and gyms, can be more readily perceived by users compared to other rooms.

This study has several limitations. We asked all participants to perform the simulation in the same sequence. They started evaluating the design using NVR media before VR media (Phase A). They then continued to evaluate the same design using VR media directly after NVR or "NVR followed by VR" (Phase B). The sequencing protocol used in the study might influence how participants perceived affordances during Phase B because they have prior knowledge during Phase A. Later in the future, additional study with a counterbalanced design, in which half of the participants perform the simulation with NVR media then VR media, and the other half perform the simulation with VR media first. NVR media should be done to see if the simulation sequence might influence how they perceive the affordances. Another limitation of the study is that the participants only evaluated the ground floor or the first floor of each design. This consideration was taken to simplify the simulation, and also, the ground floors of all designs have a similar architecture spatial program. This study also exposes a limitation of VRDR as the VR media has less information clarity of the design. So, the degree of information clarity in VRDR must be enriched to make affordances designed by the students as an architectural designer can be easily perceived directly.

6.6. Conclusion

This chapter investigated a method to review design works from an architectural design studio course authored as BIM models with an affordance-based design approach using two phases: "NVR prior to VR" and "NVR followed by VR." VRDR employed the information content of the BIM model to provide the user with complementary information about the target architectural design. Simulation participants evaluated three design studio works by examining the perceived affordances in NVR and VR using the ASM. The results were mapped and analyzed using correspondence–hierarchical clustering analysis and paired t-tests.

This study focused on the relationship between affordances and design components, the relationship between affordances and the media, and media effectivity comparison. The first analysis results showed that students could identify which design component should be improved and revised based on associated positive and negative affordances by examining the relationship between affordances and design components. The second analysis demonstrated that affordances could be perceived easier using direct perception if the media used for the evaluation had sufficient amounts of the required information. The results of the third analysis demonstrated that more affordances provided by building components (primarily positive affordances) could be recognized using VR compared to NVR. In addition, fewer affordances provided by spatial entities (e.g., rooms) can be perceived using VR media due to the insufficient level of information in VR compared to NVR. The limitations of this study suggest the need for having a counterbalanced design study with different simulation sequences to see the impact of media on the perception of affordances.

The next chapter will further study to confirm the findings by applying the evaluation method to a continuous design studio workflow involving a pair of student and supervisor. We can observe the gradual changes of perceived affordance from an architectural design until the student finalizes the design.

CHAPTER 7
IMPLEMENTATION OF VRDR IN AN ARCHITECTURAL DESIGN STUDIO COURSE

7.1. Introduction

Furthermore, after the development of VRDR and the trial of VRDR implementation as a design review tool in Chapters 5 and 6, Chapter 7 continues the trial of using VRDR with a case study, namely an ongoing architectural design studio course. In the first part, this Chapter will explain what the architectural design studio course used as a VRDR test case study looks like and how VRDR will be used in the design studio course.

We divide this Chapter into two parts, as follows:

1. VRDR Implementation in an On-going Design Studio

   In this part, we asked a pair of student and supervisor in an ongoing architectural design studio course to use VRDR for reviewing the student's design submissions. The student used the review result as feedback to improve the design. After the student completed the design revision process, both student and supervisor used VRDR once more to do another design review process to know whether the design was improved based on the affordance-based design point of view.

2. Confirmation Study

   To confirm the result from Part 1, we performed a confirmation study with third-year architectural design bachelor students as participants. We assumed that the students have sufficient spatial reading skills to perceive affordances in the evaluated design. Similar to Chapter 6, we used two different mediums for the affordance-based design review process: NVR and VR, and compared both mediums. We can compare the results to determine whether VRDR is effective for the affordance-based design review process.

7.2. Case Study: Third-year Architectural Design Studio Course in Bandung

This section introduced the case study that we used to implement an affordance-based design review method using VRDR in an ongoing architectural design process. The case study was the third-year architectural design studio course in the Study Program of Bachelor in Architecture at Institut Teknologi Bandung, Indonesia. The studio course consisted of two design projects that students must finish: Lifestyle Center and Apartment.

7.2.1. First Project: Lifestyle Center

In the first project, students designed a Lifestyle Center (LC) building facility located in the city of Bandung. This project stressed the place-making issue by developing a safe and comfortable place for the people of Bandung with facilities such as retail spaces, convenience stores or minimarket, ATM center, cafe, restaurant, and supporting facilities. The overall site area was approximately ± 6,200 m^2, including the site used for the second project, as seen in Figure 7-1. Furthermore, the course expected students to design a building through form and spatial composition and integrate them with site context, functional, and constructability aspects through this project. The course coordinator formulated studio objectives – derived from the goals of the curriculum and Student Performance Criteria (SPC) – based on the accreditation quality standard that students must fulfill to help supervisors measure student achievements. For final design submission, each student must submit a physical design study model in a scale of 1:200 using monochrome-colored materials.

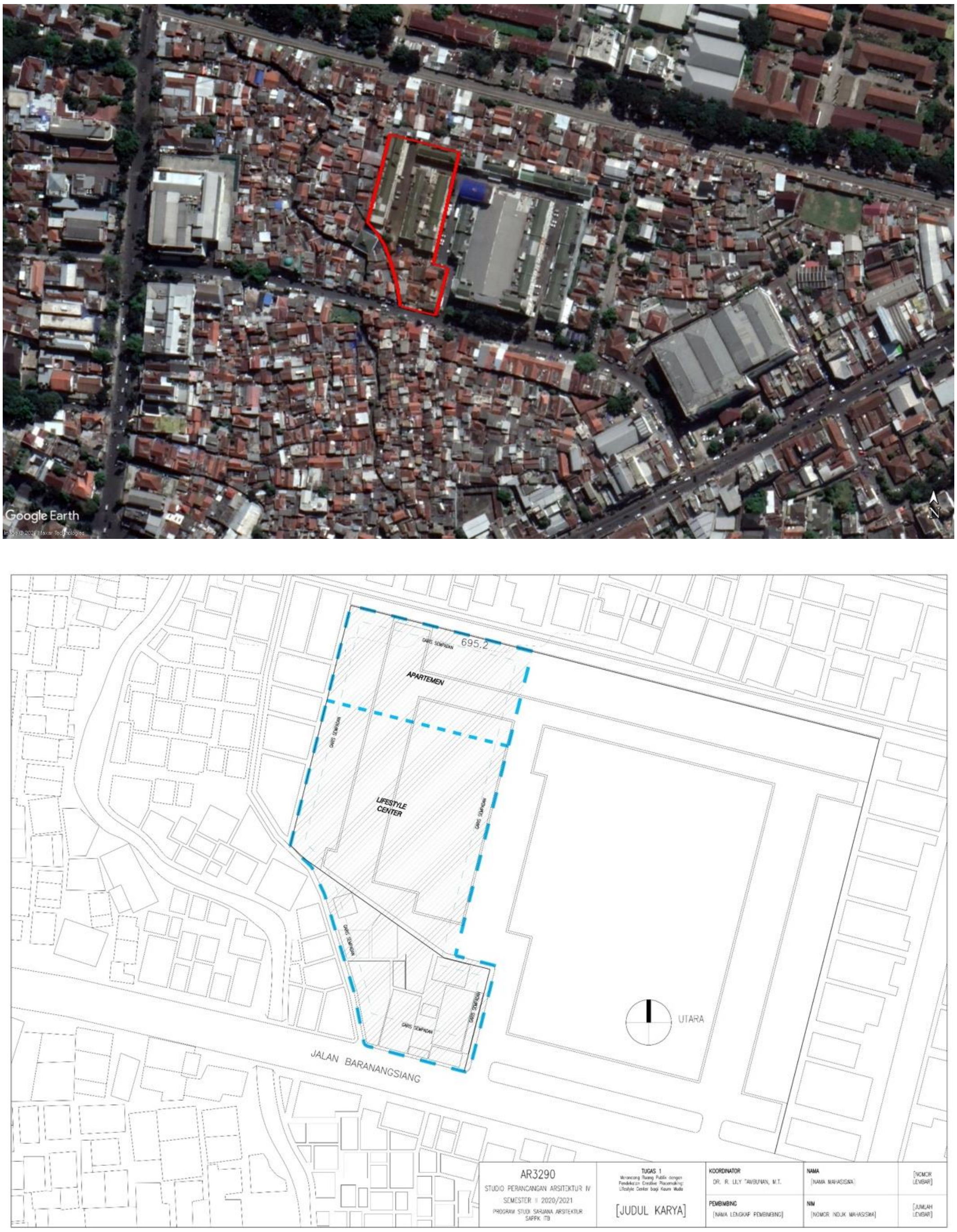


Figure 7-1. Site aerial view (top) and site plan (bottom) used for the design studio projects. (Image source, top: Google Earth)

7.2.1.1. Studio Objectives

The studio objectives that each student in this project must achieve were as follows:

1. Able to develop the architectural program, including site studies, user studies, and precedent studies, to formulate design goals and objectives,

spatial programs, relationships between spaces, and initial ideas or concepts that can provide a picture of the success of the designed building.

2. Able to develop alternative spatial zoning on the site that guides the building design through the site analysis process, including building regulations, site context analysis, site access analysis, site topography analysis, and site potential analysis.

3. Able to develop schematic designs that show spatial organization and ideas in a 3D form.

4. Able to develop the form or spatial composition of a building following aesthetic principles by considering the site context and integration with spatial organization prepared previously.

5. Able to develop preliminary designs of the building by considering constructability and function ability.

6. Able to present the design outputs graphically according to preliminary design drawing standards.

7. Able to develop positive learning attitudes during the design process.

7.2.1.2. Student Performance Criteria (SPCs)

In the first project, there were Student Performance Criteria (SPCs) that must be achieved by each student, as follows:

1. Able to formulate an architectural program that guides the functional design of the building.

2. Able to understand the principles of visual aesthetics and apply them in the form of two- and three-dimensional architectural design.

3. Able to design architecture comprehensively based on environmental and sustainability aspects and utilize concepts generated from user analysis and environmental context.

4. Able to pick building materials, components, and structural systems integrated with the design.

5. Able to design architecture with the principle of “barrier-free” design for the elderly and persons with disabilities.
6. Able to present architectural ideas graphically by utilizing various media and information technology to show how the design process was carried out.
7. Able to present architectural drawings according to preliminary design drawing standards.
8. Able to realize the importance of a positive attitude and working collectively to achieve the best result.

7.2.2. Second Project: Apartment

The students designed a mid-rise apartment (APT) eight floors tall for the second project. The building site was located on the northern side of the first project, as seen previously in Figure 7-1. The building was designed primarily to respond to the housing needs of the people of Bandung. Students should consider learning occupants’ behavior when designing vertical dwellings.

The main competency that students must master is designing a building as a system. So, the design focused on combining the structural module with a typical spatial module and designing a structural system by paying attention to the standard spatial layout, circulation for building safety, and the aspect of mechanical/electrical utilities that support the building. This approach was suitable for developing a high-rise or midrise building with typical spaces, such as apartments. It also helped students design the building based on specific and relevant rules and integrate functional and constructability requirements as the main design focus. For final design submission, each student can submit a physical design study model in a custom scale (depends on the visualization needs) using monochrome-colored materials. Unlike the First Project, the submission of physical model is optional.

7.2.2.1. Studio Objectives

The studio objectives that each student in the second project must achieve were as follows:

1. Able to design an eight-floor midrise apartment with additional two floors of basement
2. Able to draft conceptual and schematic design in the form of building mass studies that follow the detailed urban design guideline and a schematic plan showing the layout of typical rooms, circulation area, shared spaces, and services area
3. Able to design a site plan which considers the existing building mass composition and function, site circulation and accessibility, greening areas, and site context
4. Able to develop a preliminary design that integrates with the building systems, including circulation system, structural system, utilities, and facade system
5. Able to present the design output in graphics according to the preliminary design standards

7.2.2.2. Student Performance Criteria (SPCs)

In the second project, there were Student Performance Criteria (SPCs) that must be achieved by each student, as follows:

2. Able to design a midrise building in an urban area with a building system approach
3. Able to develop architectural programs by collecting relevant data and reducing them into concepts
4. Able to design the site by considering the detailed urban guideline rules, building mass composition that responds to the urban design, and the open area in the outer building area.
5. Able to arrange spatial organization by considering the integrated building system
6. Able to apply the principles of health and safety in the building facilities, including lighting and persons with disabilities
7. Able to consider the aspects of human behavior

8. Able to apply aesthetic principles in the building design, especially building form and facades
9. Able to design a building structure system integrated with the spatial organization and building form
10. Able to complete construction details, including materials and connection techniques
11. Able to present the design outputs according to the preliminary design drawing standards

7.3. Part 1: VRDR Implementation in an On-going Design Studio

In an ongoing architectural design studio course, Part 1 implemented the VRDR system as an affordance-based design review tool. Our main objective was to determine if VRDR is effective for reviewing architectural design, specifically in the educational setting. We hypothesized that by using the affordance-based design review method using VRDR, student could improve his design work by discovering the perceived positive and negative affordances in the original design and making design decision in the revised design work. At the same time, supervisor could assist the student on improving his design by performing the same design review method using VRDR.

7.3.1. Methodology

This section explains workflow, participants involved, and procedures performed in Part 1.

7.3.1.1. Participants

For Part 1, we had a student and supervisor as participants. The supervisor we chose is a lecturer in the architecture program and a professional architectural design practitioner. His capability of understanding technical stuff such as operating the Oculus Quest, installing the required software, and simple troubleshooting, is also our consideration to pick him as one of the participants. The student who joined here is chosen by the supervisor and working under his supervision during the design studio course. Both student and supervisor equip Oculus Quest to access and review the design outputs in VR using VRDR.

7.3.1.2. Procedures

The procedures performed in the Part 1 study are described as follows:

a. Affordance identification and ASM mapping process

   Similar to Chapter 6, we must identify affordances using the Affordance Structure Matrix for design review. In this case, we defined and broke down the affordances from both projects' studio objectives and SPCs. Since design output from Chapter 6 and Chapter 7 was the output of the third-year architectural design studio from a different batch, we would use the same list of affordances from the previous Chapter and expand it more.

b. Model optimization and conversion to VRDR

   We used a BIM model of the design work made by the student. The student developed the model using Revit 2021. Once the student submitted the model, we used the Twinmotion exporter plugin to pre-optimize the model and convert it into FBX format. We did a further optimization using 3DSMax 2021. Once the model is optimized, we added it into the Unity project with VRDR components. The model, then, was linked to the CDE database for having the room properties shown inside the VE.

c. VRDR system improvement

   Based on the previous simulation in Chapter 6, we improved the VRDR system, especially UI/UX adjustments on the dashboard and tags. These adjustments could help users more aware of their position orientation inside the VE.

d. VRDR deployment to participants

   After adjusting the model, we deployed the VRDR app in the form of an APK format file which must be installed in the Quest. In the main study, we distributed the APK file directly to the student and supervisor. We also provide instructions to them on installing it in the Quest.

e. Implementation

We asked the student and the supervisor to perform an affordance-based design review process in the main study. They must review four design options: two design options from the First Project and two from the Second Project. They must review whether the affordances listed in the Affordance Structure Matrix can be perceived using VRDR in each design option.

7.3.1.3. Workflow

The workflow of Part 1 is briefly described in Figure 7-2. The grey and white boxes on the left side are procedures we performed. The flowchart on the right side is the workflow conducted by all parties – researcher, student, and supervisor – to complete the simulation. Each shape position represents which task is performed by which party during the process.

Before starting the simulation, we performed the "Affordance identification and ASM mapping process" procedure on each project. So, we had one ASM for each project used for the design review process. Then, once the design was finished, the student sent the BIM model of the finished design to us as the researchers. The model was optimized and converted into the VRDR system through "Model optimization and conversion to VRDR" and "VRDR system improvements" procedures. Once it was ready, researchers deployed VRDR as an APK file and sent it to the student and supervisor – the participants – for installation. Then, participants performed the design review process—all the results were submitted online. More detail on the design review process is explained in Section 7.3.3.

After they finished the design review process, we retrieved the ASM filled by the participants and performed the data analysis process, which is explained more extensively in Section 7.3.4. Once the analysis was concluded, the participants received the result as feedback. Then, the student and supervisor began revising the design based on the analysis result. When the revised design was completed, the workflow would restart from the beginning until they received the final analysis results.

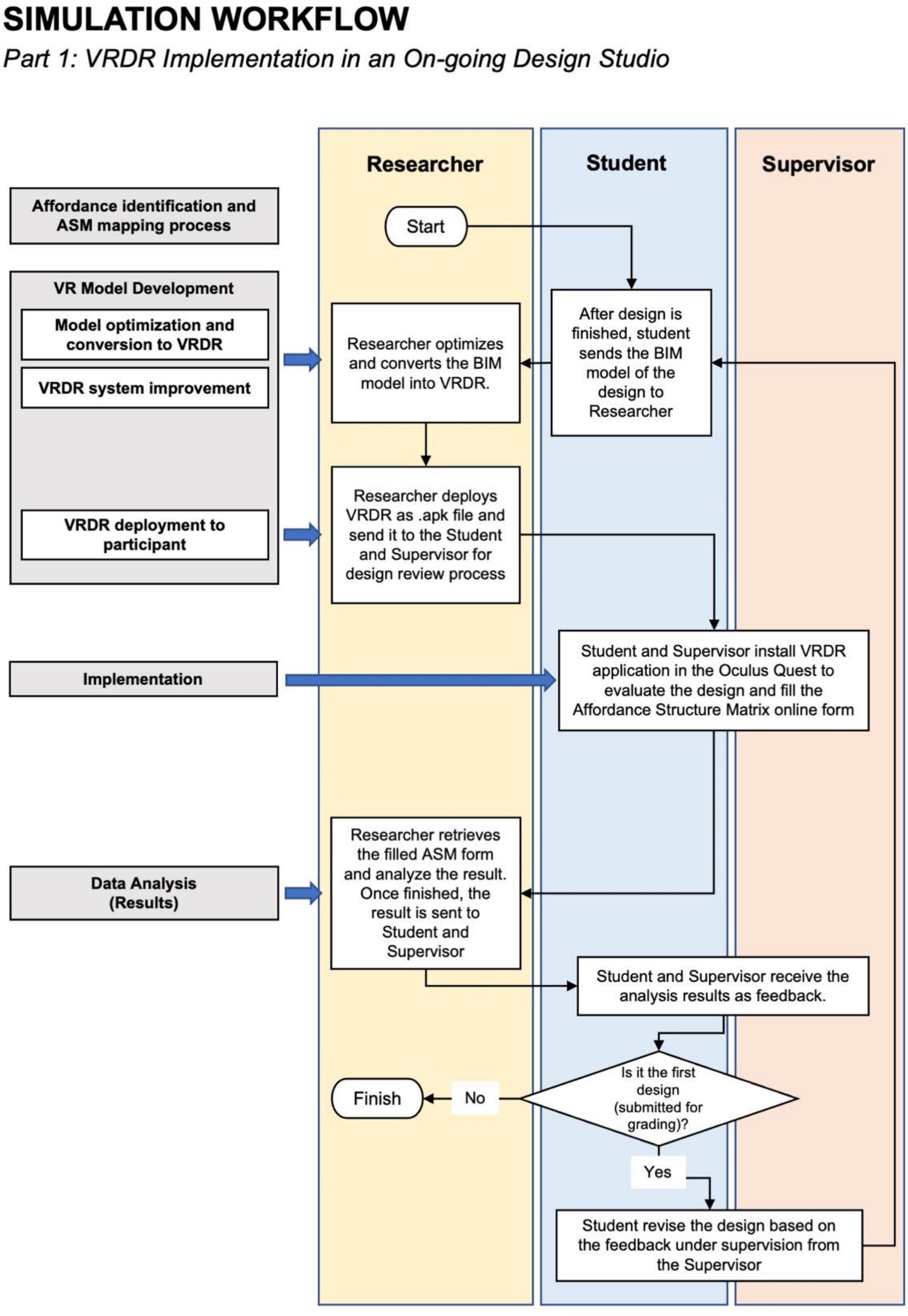


Figure 7-2. Simulation workflow for Part 1.

7.3.2. Affordance Identification and ASM Mapping Process

To execute the affordance-based design review process, we need to identify affordances targeted in the design as the indicators. These affordances were derived from studio objectives and the SPC of the design projects. As described in the previous section, the student must satisfy seven objectives and eight SPC to complete the LC project. Then, the student also must meet five studio objectives and ten SPC to complete the APT project. Same as Chapter 6, affordances were extracted from several objectives and SPCs only. ASM dismissed the remaining objectives and criteria related to the student's presentation techniques and working attitudes in this study. We defined the affordances from objectives and SPC into four groups (AUAP, AUAN, AAAP, and AAAN) using content analysis. Since the projects' objectives and SPCs were intertwined, we decided to map them into five objectives and five SPCs. Then, we defined the affordances as seen in Table 7-1 and Table 7-2. Then, these affordances are composed into Affordance Structure Matrix (ASM), which will be used for the design review process.

Table 7-1. Defined affordances with mapped studio objectives of LC and APT projects

ID	Objectives (LC)	Objective (APT)	AUAP	AUAN	AAAP	AAAN
OBJ1	Able to develop the architectural program, including site studies, user studies, and precedent studies, to formulate design goals and objectives, spatial programs, relationships between spaces, and initial ideas or concepts that can provide a picture of the success of the designed building.	Able to design an eight-floor midrise apartment with additional two floors of basement	• User activities suitability • Sufficient user capacity • Ease of adaptation	• Easily harm users	• Expansion-ability	• Ignite man-made disaster
OBJ2	Able to develop alternative spatial zoning on the site that guides the building design through the site analysis process, including building regulations, site context analysis, site access analysis, site topography analysis, and site potential analysis.	Able to design a site plan which considers the existing building mass composition and function, site circulation and accessibility, greening areas, and site context	• Reachability • Equal access and travel option • Independently accessible	• Unauthorized entry • Blocking user access	• Integrated with site context • Integrated with other building instance	• Site incompatibility

ID	Objectives (LC)	Objective (APT)	AUAP	AUAN	AAAP	AAAN
OBJ3	Able to develop schematic designs that show spatial organization and ideas in a 3D form.	Able to draft a schematic plan showing the layout of typical rooms, circulation area, shared spaces, and services area	• Explore-ability	• Lost in the building	• Sufficient capacity for essential furniture • Internal layout flexibility	• Space incompatibility
OBJ4	Able to develop the form or spatial composition of a building according to aesthetic principles by considering the site context and integration with the spatial organization prepared previously.	Able to draft conceptual and schematic design in the form of building mass studies that follow the detailed urban design guideline	• Give pleasant look • Provide local context • Give a sense of building purposes	• Provide a sense of tightness • Sense of boring • Stress trigger	• Right proportion • Right scaling • Geometrically defined space	• Visually unfit • Lack of lighting for visual

ID	Objectives (LC)	Objective (APT)	AUAP	AUAN	AAAP	AAAN
OBJ5	Able to develop preliminary designs of the building by considering constructability and function ability.	Able to develop a preliminary design that integrates with the building systems, including circulation system, structural system, utilities, and facade system	• Ease of hazard mitigation • Provide a sense of safety • Feel comfortable doing activities • Noise cancelation • Material compatibility with the design	• Encourage high usage of building energy • Tends to generate high-cost maintenance • Falling for height • Slipped or tripped • High physical effort	• Natural ventilation • Natural lighting • Weather protection • Recyclability • Supporting the load • Repairability • Material compatibility with instance purposes	• Getting we during rain • Excessive heat • Instability • Excessive glare • Indurability

Table 7-2. Defined affordances with mapped student performance criteria (SPC) of LC and APT projects

ID	SPC (LC)	SPC (APT)	AUAP	AUAN	AAAP	AAAN
SPC1	Able to formulate an architectural program that guides the functional design of the building.	Able to design a midrise building in an urban area with a building system approach	• User activities suitability • Ease of hazard mitigation • Provide Sense of safety • Sufficient user capacity • Ease of adaptation • Reachability • Explore-ability	• Easily harm users • Unauthorized entry • Lost in the building • Provide a sense of tightness	• Expansion-ability • Sufficient capacity for essential furniture • Internal layout flexibility	• Ignite man-made disaster • Space incompatibility • Getting wet during rain

ID	SPC (LC)	SPC (APT)	AUAP	AUAN	AAAP	AAAN
SPC2	Able to understand the principles of visual aesthetics and apply them in the form of two- and three-dimensional architectural design.	Able to apply aesthetic principles in the building design, especially building form and facades	• Give a sense of building purpose • Give pleasant look • Provide local context	• Sense of boring • Stress trigger	• Right proportion • Right scaling • Geometrically defined space	• Visually unfit • Lack of lighting for visual

ID	SPC (LC)	SPC (APT)	AUAP	AUAN	AAAP	AAAN
SPC3	Able to design architecture comprehensively based on environmental and sustainability aspects and utilize concepts generated from user analysis and environmental context.	Able to develop architectural programs by collecting relevant data and reducing them into concepts, able to design the site by considering the detailed urban guideline rules, building mass composition that responds to the urban design, and the open area in the outer building area, and able to consider the aspects of human behavior	• Feel comfortable doing activities • Noise cancellation	• Encourage high usage of building energy • Tends to generate high-cost of maintenance	• Natural lighting • Weather protection • Recyclability • Integrated with site context • Natural ventilation	• Site incompatibility • Excessive heat • Excessive glare

ID	SPC (LC)	SPC (APT)	AUAP	AUAN	AAAP	AAAN
SPC4	Able to pick building materials, components, and structural systems integrated with the design.	Able to design a building structure system integrated with the spatial organization and building form.	• Material compatibility with the design		• Supporting the load • Repairability • Material compatibility with instance purpose • Integrated with other building instance	• Indurability • Instability
SPC5	Able to design architecture with the principle of “barrier-free” design for the elderly and persons with disabilities.	Able to apply the principles of health and safety in the building facilities, including lighting and persons with disabilities	• Equal access and travel option • Independently accessible	• Falling for height • Slipped or tripped		

ID	SPC (LC)	SPC (APT)	AUAP	AUAN	AAAP	AAAN
				• High physical effort • Blocking user access		

7.3.3. Implementation

The implementation began when each student and supervisor had successfully installed the VRDR application in the provided Oculus Quest HMD using the deployment procedure. We provided remote support on the installation process and usage tutorial to ensure that they could do the design review process without hassle.

During Part 1, there were five design options reviewed by the participants. Two design options come from the lifestyle center project (LC), and three design options are from the apartment project (APT). For LC, the design options are taken from the submitted design for grading (LC1) and revised design after the first design review process (LC2). For APT, they are taken from the snapshot model while the design process is ongoing (APT1), the proposed design for grading (APT2), and the revised design after the proposed design review process (APT3). However, since in the field, the student could not catch up with the tight schedule of the design studio course, the APT1 design review was performed after the APT2 option was done. So, we decided to use only APT2 and APT3 options for the data analysis process. The model of all four design options can be seen in Figures 7-3 and 7-4.

LC1	LC2
	
	

Figure 7-3. Design options of LC projects (LC1 and LC2)

APT2	APT3
	
	

Figure 7-4. Design options of APT projects (APT2 and APT3)

To start the design review process, participants launched the VRDR app inside the Quest HMD. Like the previous simulation in Chapter 6, each participant must explore each design model in a virtual environment (VE) and review the design based on two design component groups: rooms and building components. Each room has its tag inside the VE that shows its parameters, such as room name, area, and volume. Once the participants find the room, they must review it and fill in the ASM by marking which affordances they perceive from it. The exact process must be applied to all available rooms and building components in the design model. After participants filled in the ASM, we started the data analysis process to determine the affordance-based design review result. The result was given back to the participants as the basis for the design revision process.

7.3.4. Design Changes

This section explains the design changes made by the student both in the LC and APT projects. We compared between the submitted and revised design using Revit to find out any changes made in the spatial entities or room and building components. To find changes made in the room components, we performed visual checking and extracted the quantity takeoff schedules from Revit from both design options. So, we can find any differences both visually (i.e. different room layout) and quantitatively (i.e. different room area and volume). For building components, mostly we only extracted the quantity takeoff schedules to find any differences quantitatively such as differences on numbers of places columns. Then, we compared them with the results from PDS process.

7.3.4.1. Changes in LC projects

In this section, we analyze the design changes in the LC project. For spatial entities or room, we are going to describe the design changes of following three rooms: Minibar, Prayer Room, and Minimarket. As seen in Table 7-3, Minibar is the room with the highest Δ area added with 5.48 m^2 and second highest Δ volume added after the restaurant with 19.19 m^3. Visually seen in Table 7-4, the student made a lot of changes to Minibar. She removed the separation wall on the eastern side of the room to make Minibar more spacious, moved the entrance door from the southwest side to the northern side of the room, and changed it into inversed corner wall with opening. With these treatments, calculated using PDS process, both student and supervisor assessed that Minimar has achieved the studio objectives with PI 0.62 & Imprv(+) 0.21 by student and PI 0.60 & Imprv(+) 0.37 by supervisor.

Next, Prayer Room is located in the 2nd floor of the LC project with small Δ area added with 0.34 m^2. Visually seen in Table 7-5, the student made fundamental changes here. Previously, she put two different wudhu area or purifying area inside. It was intended to separate between male and female users. But the purifying area placement could make some praying area used only for circulation from entrance to the purifying area. In the revised design, she moved the entrance door to the southwestern side and put only one purifying area with a wall separated the circulation and praying area. She also added a shoes compartment near the purifying area. With these changes, calculated using PDS process, both student and supervisor assessed that Prayer Room has achieved the studio objectives with PI 0.85 & Imprv(+) 0.40 by student and PI 0.69 & Imprv(+) 0.48 by supervisor. It is the highest PI and Imprv(+) points assessed by both student and supervisor.

Lastly, Minimarket is also located in the 2nd floor of the LC project with small Δ area decreased with -1.84 m^2. Visually seen in Table 7-6, the student made a few changes to the room. She changed the furniture setup with minor differences and the entrance door into a wider one. With these changes, calculated using PDS process, the student reviewed that Minimarket is neither achieved the studio objectives nor failed them with PI 0.50 and Imprv(-) 0.19. Meanwhile, the supervisor reviewed that Minimarket is not reached the studio objectives yet with NI 0.58 even though he scored the design improvement with Imprv(+) 0.25.

Then for building components, we are going to describe design changes of following components: façade, ceiling, and stairs. As seen in Table 7-7 and 7-8, there are some notes on design changes in the façade component. The student changed the windows with a lower height and put new lettering signages in various spots in the building. But, she didn’t make any changes to the hollow bricks arrangement in the southern side of the building. With these changes, calculated using PDS process, the student reviewed that façade component is reached the studio objectives with PI 0.73 & Imprv(+) 0.29. It is the highest Imprv(+) score for building component given by the student. But in contrary, the supervisor assessed that the façade component is not reached the objectives yet with NI 0.54 and Imprv(-) 0.27.

Next, the student added more ceiling components into the building. As detailed in Table 7-9, she added 71.77 m^2 of C1-type ceiling in the 1st floor. It seems like the ceiling was placed in some rooms to give a sense of proportional height to the user which quantitatively affected the room volume. With these changes, calculated using PDS process, the student reviewed that the ceiling component is slightly reached the studio objectives with PI 0.54 and Imprv(+) 0.10. It is the building component with the lowest PI scored by the student. Again in contrary, the supervisor reviewed that the component is not reached the studio objectives yet with NI 0.63 and Imprv(-) 0.35.

Lastly, the student added more stairs component into the building. As detailed in Table 7-10, the student added four stairs components with ground as the base level and F1 as the top level. These stairs helps user to access the building easier. No wonder, with these changes, the stairs components reached the highest PI score by the student with 0.75 and Imprv(+) 0.19. Meanwhile, the supervisor assessed that the stairs component is neither reached nor failed the studio objectives with PI 0.50. But, he thought the stairs have slightly improved with Imprv(+) 0.25.

Table 7-3. Room area and volume changes in LC project paired with PDS process results

Room Name	Level	Design changes description	Δ Area (m^2)	Δ Volume (m^3)	Student				Supervisor			
					PI	NI	Imprv(+)	Imprv(-)	PI	NI	Imprv(+)	Imprv(-)
MINIBAR	F1	Different spatial configuration and door entrance placement in Mini Bar room	5.48	19.19	0.62	0.38	0.21	0.04	0.60	0.40	0.37	0.19
TOILET	F1	There are missing washing basins.	0.82	2.87	0.62	0.38	0.23	0.15	0.54	0.46	0.27	0.10
PRAYER ROOM	F2	Different entrance with less washing area (wudhu) and different windows configuration on northern side	0.34	0.24	0.85	0.15	0.40	0.06	0.69	0.31	0.48	0.02
F2 RESTROOM	F2	There are additional washing basins.	0.27	0.72	0.67	0.33	0.31	0.10	0.62	0.38	0.35	0.04
OUTDOOR STAGE	F1	A new vegetation arrangement	0.00	0.00	0.60	0.40	0.23	0.13	0.60	0.40	0.37	0.10
ALFRESCO	F1	There's no difference.	0.00	-0.85	0.63	0.37	0.23	0.08	0.58	0.42	0.31	0.12
MINIMARKET	F2	Minor furniture setup differences and wider entrance	-1.85	-4.98	0.50	0.50	0.12	0.19	0.42	0.58	0.25	0.12
SME RETAIL	F1	Major differences in furniture setup, wider entrance, and additional opening	-2.51	-8.25	0.79	0.21	0.19	0.17	0.67	0.33	0.33	0.17
CAFE	F2	Major differences in furniture setup, wider entrance, and	-2.65	-9.21	0.69	0.31	0.21	0.04	0.60	0.40	0.37	0.02

Room Name	Level	Design changes description	Δ Area (m^2)	Δ Volume (m^3)	Student				Supervisor			
					PI	NI	Imprv(+)	Imprv(-)	PI	NI	Imprv(+)	Imprv(-)
		additional opening and entrance										
GF CAFE	F1	Different furniture setup, wider entrance and smaller dining area	-3.58	-12.52	0.60	0.40	0.15	0.12	0.58	0.42	0.38	0.23
RESTAURANT	F1	Smaller dining area, different kitchen and staff room arrangement, and different furniture setup.	-3.76	32.24	0.58	0.42	0.27	0.21	0.48	0.52	0.27	0.08
COSMETIC RETAIL	F1	Wider entrances and different furniture setup	-3.79	-52.37	0.60	0.40	0.25	0.23	0.54	0.46	0.37	0.13
FRANCHISE CAFÉ	F2	Smaller area with less curvy entrance wall and larger kitchen. Different furniture setup.	-6.99	-19.91	0.63	0.37	0.23	0.15	0.60	0.40	0.33	0.21
GYM	F2	Wider entrance, different opening setup and different room arrangement	-12.55	-33.88	0.60	0.40	0.23	0.12	0.46	0.54	0.37	0.06
AVERAGE					**0.64**	**0.36**	**0.23**	**0.13**	**0.57**	**0.43**	**0.34**	**0.11**

Table 7-4. Detailed description on design changes of Minibar in LC projects

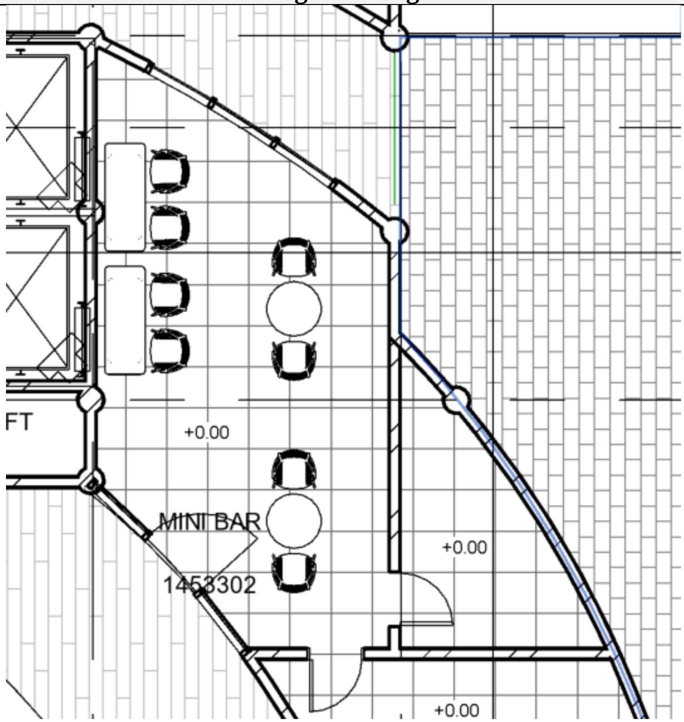
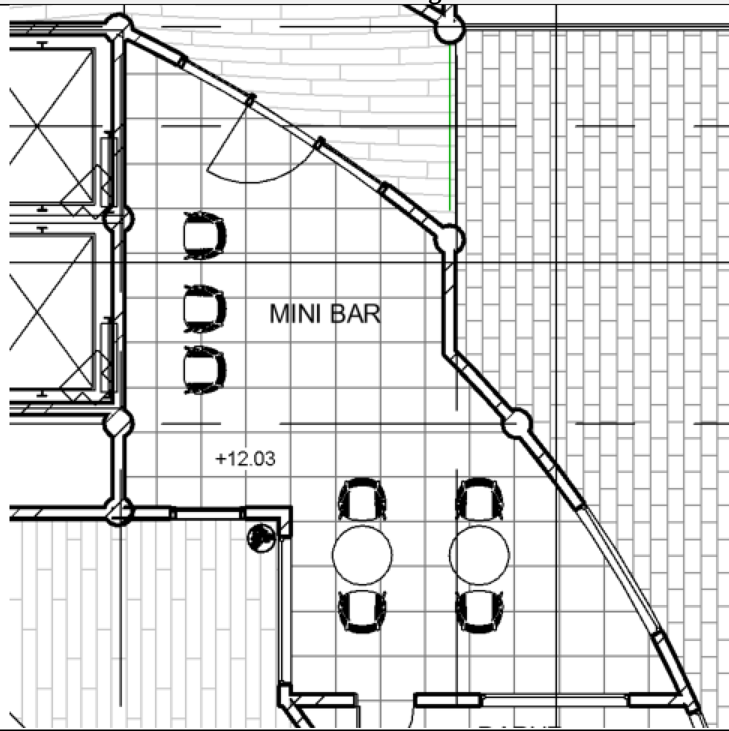
Room Name	MINIBAR	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
Level	F1	Student	0.62	0.38	0.21	0.04
Δ Area (m^2)	5.48	Supervisor	0.60	0.40	0.37	0.19
Δ Volume (m^3)	19.19	Description	Different spatial configuration and door entrance placement in Mini Bar room			
Original Design			**Revised Design**			
						

Table 7-5. Detailed description on design changes of Prayer Room in LC projects

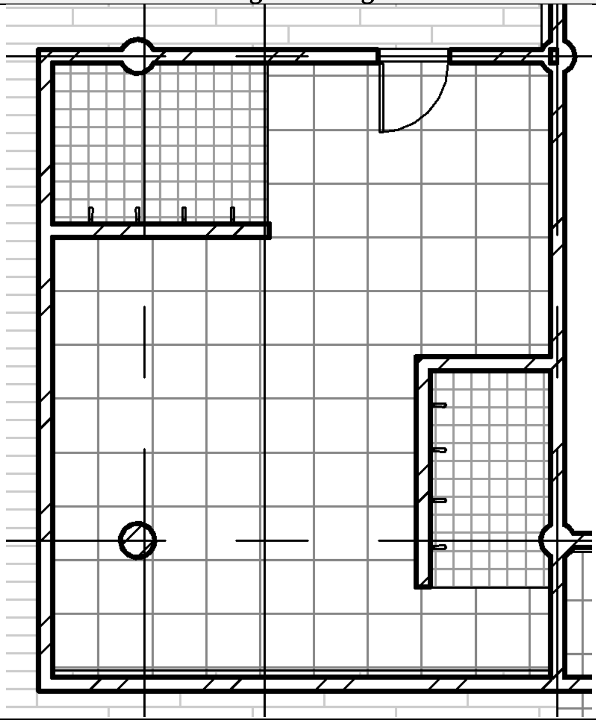
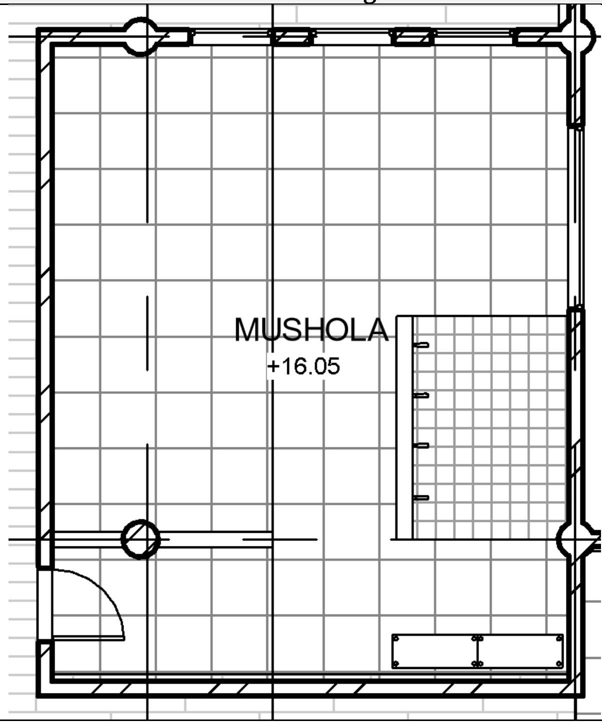
Room Name	PRAYER ROOM	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
Level	F1	Student	0.85	0.15	0.40	0.06
Δ Area (m^2)	0.34	Supervisor	0.69	0.31	0.48	0.02
Δ Volume (m^3)	0.24	Description	Different entrance with less purifying area (wudhu) and different windows configuration on northern side			
Original Design			**Revised Design**			
						

Table 7-6. Detailed description on design changes of Minimarket in LC projects

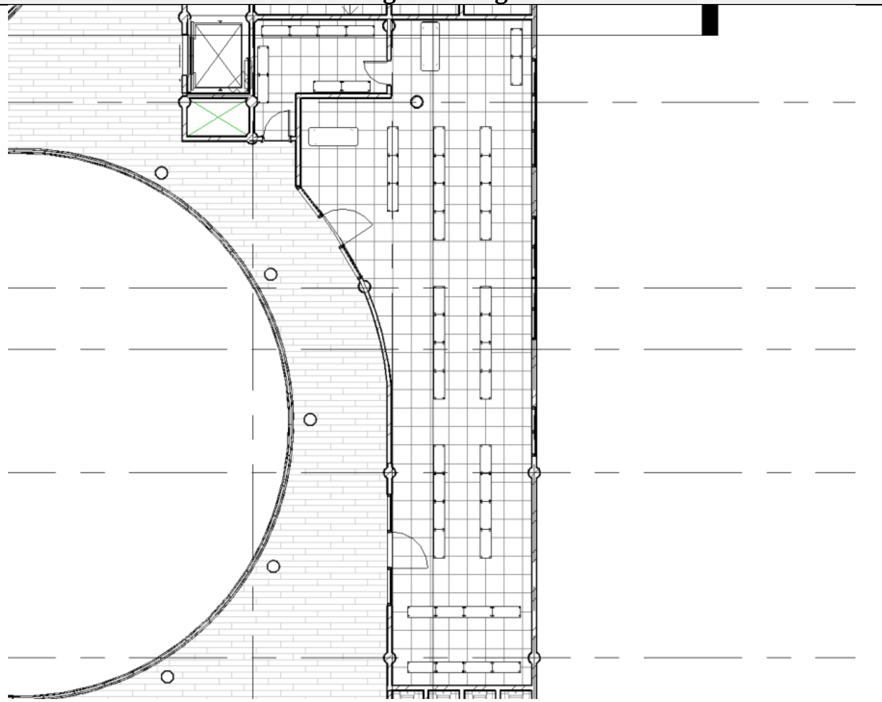
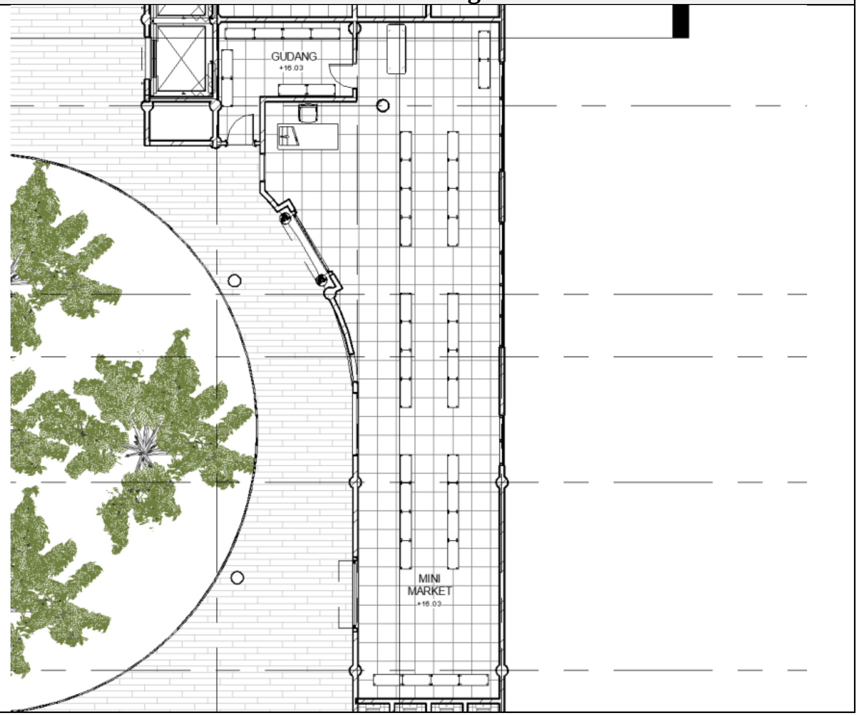
Room Name	MINIMARKET	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
Level	F2	Student	0.50	0.50	0.12	0.19
Δ Area (m^2)	-1.85	Supervisor	0.42	0.58	0.25	0.12
Δ Volume (m^3)	-4.98	Description	Minor furniture setup differences and wider entrance			
Original Design			**Revised Design**			
						

Table 7-7. Building component design changes in LC project paired with PDS process results

Building Component	Student				Supervisor				Notes on Design Changes
	PI	NI	Imprv(+)	Imprv(-)	PI	NI	Imprv(+)	Imprv(-)	
Facade	0.73	0.27	0.29	0.04	0.46	0.54	0.25	0.27	No changes on the hollow bricks, windows with lower height, new lettering signage
Railing	0.73	0.27	0.25	0.00	0.44	0.56	0.21	0.27	Additional 900mm Pipe railings in F1 and F2
Stairs	0.75	0.25	0.19	0.00	0.50	0.50	0.25	0.21	New short stairs from ground level to F1
Glass Walls	0.67	0.33	0.17	0.00	0.54	0.46	0.29	0.19	Majority of curtain walls are changed into specific opening components
Ramp	0.71	0.29	0.17	0.00	0.33	0.67	0.19	0.27	There's no changes
Solid Walls	0.58	0.42	0.12	0.06	0.65	0.35	0.29	0.10	More brick walls are added
Columns	0.58	0.42	0.12	0.02	0.46	0.54	0.17	0.15	Less columns placed.
Beams	0.56	0.44	0.10	0.00	0.48	0.52	0.27	0.29	New timber beams added for the greenery
Ceiling	0.54	0.46	0.10	0.02	0.37	0.63	0.19	0.35	Wider C1-type ceiling is added
Floor	0.58	0.42	0.06	0.08	0.40	0.60	0.23	0.29	Wider area of FL3 Roof Deck
AVERAGE	0.64	0.36	0.16	0.02	0.46	0.54	0.23	0.24	

Table 7-8. Detail design changes description of Facade component in LC projects

Building Component	FACADE	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
		Student	0.73	0.27	0.29	0.04
		Supervisor	0.46	0.54	0.25	0.27
		Description	No changes on the hollow bricks, windows with lower height, new lettering signage			
Original Design			**Revised Design**			
						

Table 7-9. Quantity takeoff of Ceilings component in the LC projects

LC1	**Type Mark**	**Level**	**Type**	**Area (m^2)**		**LC2**	**Type Mark**	**Level**	**Type**	**Area (m^2)**		**Δ Area (m^2)**
	C1	F1	Plain	905.23			C1	F1	Plain	977		71.77
	C1	F2	Plain	375.82			C1	F2	Plain	375.82		0

Table 7-10. Quantity takeoff of Stairs component in the LC projects

	Type Mark	Type	Base Level	Top Level	Actual Riser Height (mm)	Actual Number of Risers		Type Mark	Type	Base Level	Top Level	Actual Riser Height (mm)	Actual Number of Risers
	ST2	Precast Stair	GROUND	F1	-	-		ST2	Precast Stair	GROUND	F1	167	3
	ST2	Precast Stair	GROUND	F1	-	-		ST2	Precast Stair	GROUND	F1	167	3
	ST2	Precast Stair	GROUND	F1	-	-		ST2	Precast Stair	GROUND	F1	167	3
	ST2	Precast Stair	GROUND	F1	-	-		ST2	Precast Stair	GROUND	F1	167	3
LC1	ST2	Precast Stair	ROAD	VERANDAH	125	2	**LC2**	ST2	Precast Stair	ROAD	VERANDAH	125	2
	ST3	Wood Stair- Steel Stringer	F1	F2	200	20		ST3	Wood Stair- Steel Stringer	F1	F2	200	20
	ST3	Wood Stair- Steel Stringer	F1	F2	200	18		ST3	Wood Stair- Steel Stringer	F1	F2	200	18
	ST3	Wood Stair- Steel Stringer	F2	ROOFTOP	158	19		ST3	Wood Stair- Steel Stringer	F2	ROOFTOP	158	19

7.3.4.2. Changes in APT projects

In this section, we analyze the design changes in the APT project. For spatial entities or room, we are going to describe the design changes of following rooms which all are apartment units: T.Dago unit, T. Sukabungah unit, T. Sukawarna unit, and T. Braga unit.

As seen in Table 7-11, T. Dago unit (2BR) is the room with the highest Δ area added with 12.49 m^2 and also the highest Δ volume added with 37.48 m^3. Visually seen in Table 7-12, the student made a totally different room configuration and moved the entrance room to the lower side of the room. As a result, the new room configuration gives a more spacious living room compared to the original design. With those changes, calculated with PDS process, T. Dago unit has reached the studio objectives with PI 0.77 & Imprv(+) 0.25 reviewed by the student and PI 0.69 & Imprv(+) 0.35 reviewed by the supervisor.

In contrast with T. Dago unit, T. Sukabungah unit is the room with the highest Δ area decreased with -2.50 m^2 and also the highest Δ volume decreased with -7.50 m^3. Visually seen in Table 7-13, the student made a different room configuration where she switched the placement of kitchen and bedding and also moved the structural column grid position. With these changes, calculated with PDS process, the student reviewed that T. Sukabungah unit is reached the studio objectives with PI 0.73 and Imprv(+) 0.19. But, the supervisor thought in opposite where the unit is not reached the objectives yet with NI 0.63 and Imprv(+) 0.00 which means there is no improvement yet.

Next. T. Sukawarna unit is the room with the highest PI reviewed by the student with 0.77 and Imprv(+) 0.21. Visually seen in Table 7-14, the student has made the unit is wider through the horizontal axis, increased from 6.9 m to 7.5 m wide. A small furniture setup changes were also made by her. With these changes, it didn’t satisfy the supervisor yet since he reviewed the unit with PI 0.50 and Imprv (+) 0.29.

Lastly, T. Braga unit is the room with the highest PI reviewed by the supervisor with 0.75 and Imprv(+) 0.33. Compared to the previous design, the unit is slightly smaller with 0.30 m^2 less in area. Visually seen in Table 7-15, the student made a different wall partition setup, bathroom door placement, and switched between the kitchen placement and bedroom placement. With these changes, the student is also agree with the supervisor that the unit is reached the studio objectives with PI 0.75 and Imprv(+) 0.27.

Then for building components, we are going to describe design changes of following components: façade, column, stairs, and railing.

As seen in Table 7-16, the student reviewed that all building components in the APT project are not reached the studio objectives yet with the NI value is higher than PI value. Meanwhile, the supervisor gave mixed results. As seen in Table 7-17, the student made some design changes to the façade component by adding lower-height windows with new shading set. With these changes, the student assessed it with PI 0.25 & Imprv(-) 0.37 and the supervisor reviewed it with PI 0.65 & Imprv(+) 0.29.

Next, column is the building component with the highest PI reviewed by student with PI 0.40 & Imprv(-) 0.21 and also by supervisor with PI 0.75 & Imprv(+) 0.27. As detailed in Table 7-18, only a few changes related to structural columns placement made by the student where she only removed two small columns from the APT project. But the fundamental change made to the column placement is the structural grid position. This finding was found when we inspected T. Sukabungah unit.

Then, stairs component is the building component with the highest NI reviewed by the student with NI 0.79 & Imprv(-) 0.37. The supervisor reviewed that the stairs component is neither reached nor failed the studio objectives with PI 0.50 & Imprv(+) 0.31. As detailed in Table 7-19, there's no addition or changes to the stairs by the student. Lastly, railing component is the building component with the highest NI reviewed by the supervisor with NI 0.63 & Imprv(-) 0.42. The student reviewed it with NI 0.77 & Imprv(-) 0.42. As detailed in Table 7-20, there are some addition and reduction of glass panel railing placed across all building levels.

Table 7-11. Room area and volume changes in APT project paired with PDS process results (Sorted by Δ Area)

Room Name	Level	Design changes description	Δ Area (m^2)	Δ Volume (m^3)	Student				Supervisor			
					PI	NI	Imprv(+)	Imprv(-)	PI	NI	Imprv(+)	Imprv(-)
T. DAGO (2BR)	F2	Different room configuration and entrance, with roomy living room	12.49	37.48	0.77	0.23	0.25	0.00	0.69	0.31	0.35	0.06
T. SUKAMULYA (S)	FT	Wider room.	6.45	19.35	0.69	0.31	0.19	0.02	0.67	0.33	0.33	0.13
T. SUKAWARNA (S)	FT	Wider room	1.46	4.38	0.77	0.23	0.21	0.00	0.50	0.50	0.29	0.25
T. CAMPAKA (1BR)	FT	Different room arrangements (narrower bathroom and wider bedroom)	0.30	0.92	0.69	0.31	0.21	0.08	0.52	0.48	0.21	0.38
MANAGEMENT ROOM	F1	Different entrance door placement	0.00	0.21	0.75	0.25	0.13	0.04	0.67	0.33	0.37	0.13
COMMON ROOM	F1	There's no difference.	0.00	0.35	0.73	0.27	0.12	0.00	0.52	0.48	0.21	0.19
SECURITY ROOM	F1	Different entrance door placement	0.00	0.21	0.77	0.23	0.13	0.00	0.54	0.46	0.06	0.02
MINIMARKET	F1	Less door placed in the Storage Room (Gudang)	0.00	0.36	0.67	0.33	0.13	0.02	0.71	0.29	0.19	0.02
CAFE	F1	Different entrance door setup	0.00	0.37	0.63	0.37	0.21	0.06	0.50	0.50	0.12	0.15
READING ROOM	F1	Different entrance door and toilet placement	0.00	0.42	0.71	0.29	0.10	0.00	0.65	0.35	0.29	0.06

Room Name	Level	Design changes description	Δ Area (m²)	Δ Volume (m³)	Student				Supervisor			
					PI	NI	Imprv(+)	Imprv(-)	PI	NI	Imprv(+)	Imprv(-)
DAYCARE	F1	There's no difference	0.00	0.28	0.75	0.25	0.12	0.02	0.44	0.56	0.00	0.00
GARDEN	F2	There's no difference	0.00	1.02	0.71	0.29	0.29	0.04	0.44	0.56	0.00	0.00
T. SUKARAJA (S)	FT	Slightly different kitchen setup	0.00	0.00	0.71	0.29	0.08	0.02	0.58	0.42	0.00	0.00
T. ISOLA (2BR)	FT	Different column placement in the bathroom and different wall & door placement	0.00	0.00	0.73	0.27	0.13	0.00	0.71	0.29	0.38	0.10
ROOFTOP	RT	There's no difference	0.00	0.00	0.62	0.38	0.19	0.10	0.65	0.35	0.31	0.19
GYM	F2	Different door placements, wider storage room.	0.00	0.00	0.71	0.29	0.19	0.08	0.54	0.46	0.00	0.00
T. BRAGA (2BR)	F2	Different wall partition setup, bathroom door placement, and kitchen placement	-0.30	-0.90	0.75	0.25	0.27	0.00	0.75	0.25	0.33	0.10
T. SUKAPURA (S)	FT	Different wall partition setup, entrance door, and furniture placement	-0.35	-1.04	0.77	0.23	0.08	0.02	0.60	0.40	0.00	0.00
T. SUKABUNGAH (S)	F2	Different column grid position and kitchen positioning	-2.50	-7.50	0.73	0.27	0.19	0.04	0.37	0.63	0.00	0.00
AVERAGE					**0.72**	**0.28**	**0.17**	**0.03**	**0.58**	**0.42**	**0.18**	**0.09**

Table 7-12. Detail design changes description of T. Dago (2BR) apartment unit in APT projects

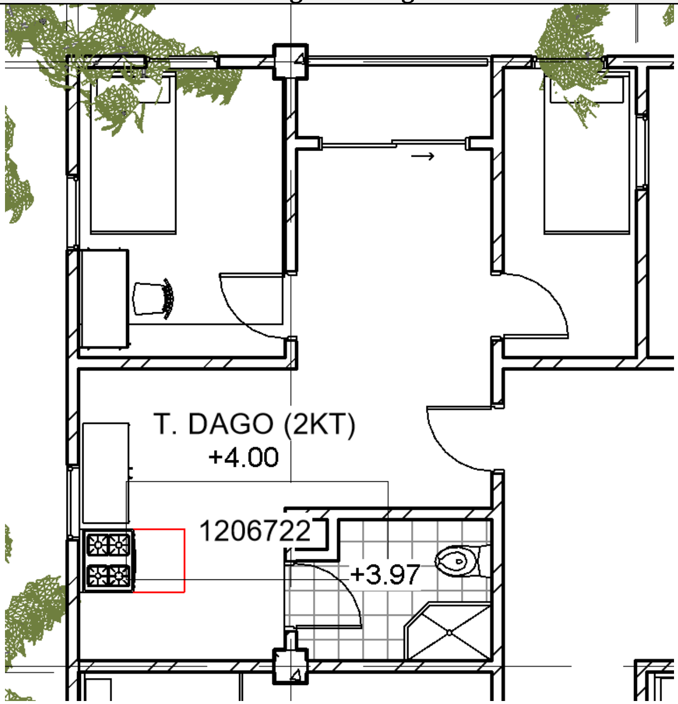
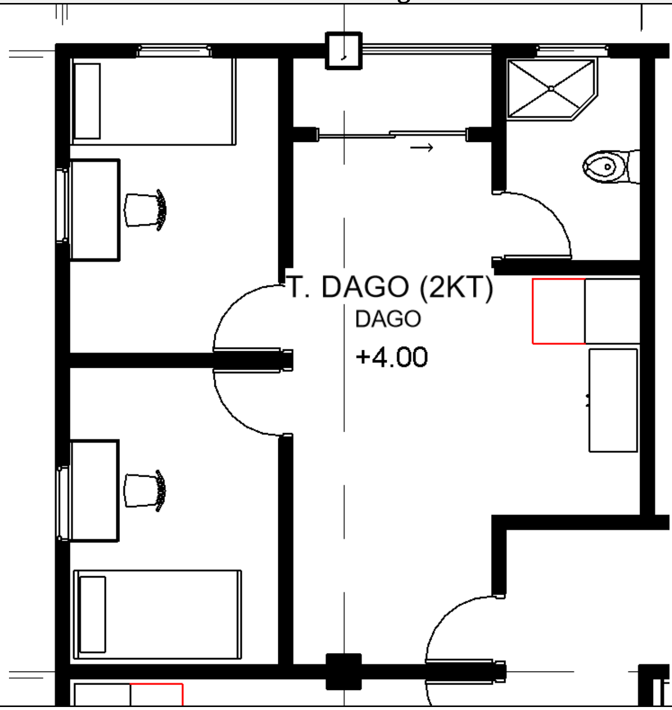
Room Name	T. DAGO (2BR)	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
Level	F2	Student	0.77	0.23	0.25	0.00
Δ Area (m²)	12.49	Supervisor	0.69	0.31	0.35	0.06
Δ Volume (m³)	37.48	Description	Different room configuration and entrance, with roomy living room			
Original Design			**Revised Design**			
						

Table 7-13. Detail design changes description of T. Sukabungah (S) apartment unit in APT projects

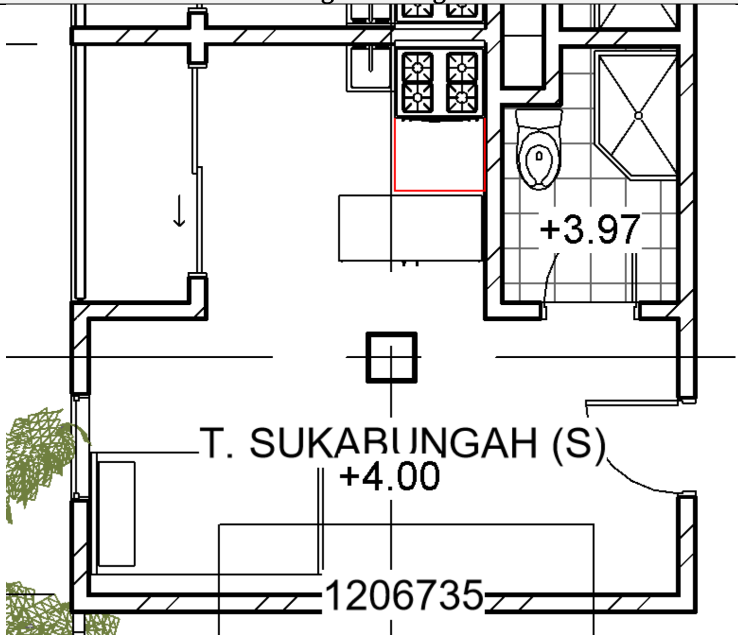
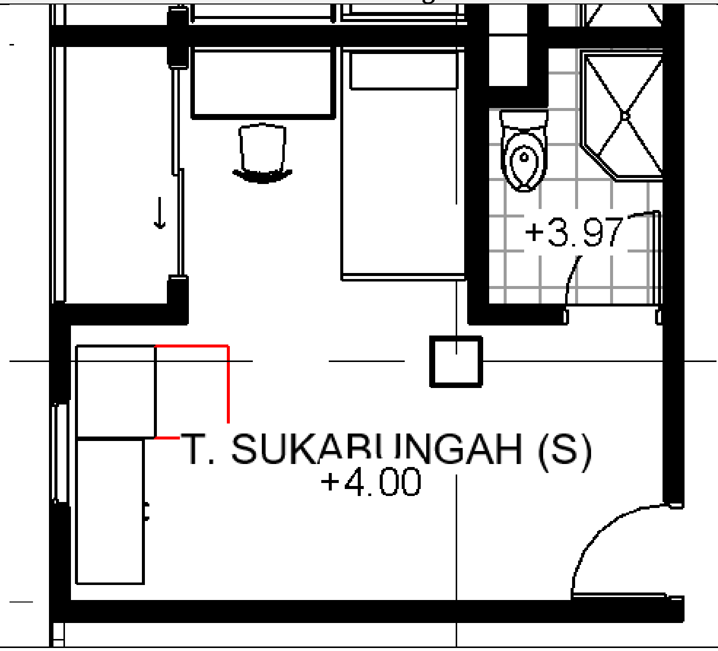
Room Name	T. SUKABUNGAH (S)	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
Level	F2	Student	0.73	0.27	0.19	0.04
Δ Area (m^2)	-2.50	Supervisor	0.37	0.63	0.00	0.00
Δ Volume (m^3)	-7.50	Description	Different column grid position and kitchen positioning			
Original Design			**Revised Design**			
						

Table 7-14. Detail design changes description of T. Sukawarna (S) apartment unit in APT projects

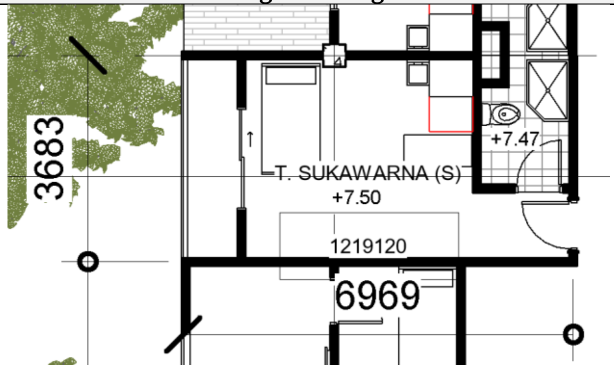
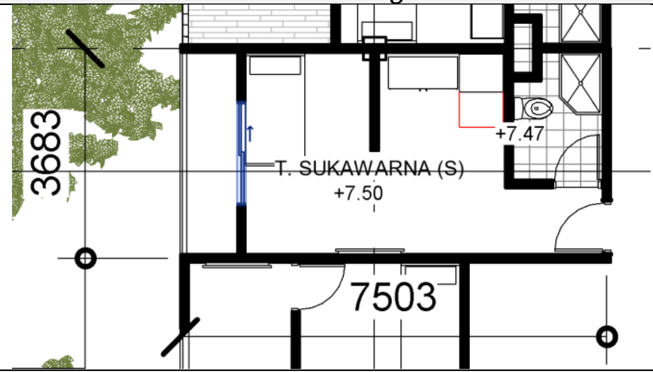
<table>
<tr><td>Room Name</td><td>T. SUKAWARNA (S)</td><td>PDS Result</td><td>PI</td><td>NI</td><td>Imprv(+)</td><td>Imprv(-)</td></tr>
<tr><td>Level</td><td>FT</td><td>Student</td><td>0.77</td><td>0.23</td><td>0.21</td><td>0.00</td></tr>
<tr><td>Δ Area (m^2)</td><td>1.46</td><td>Supervisor</td><td>0.50</td><td>0.50</td><td>0.29</td><td>0.25</td></tr>
<tr><td>Δ Volume (m^3)</td><td>4.38</td><td>Description</td><td colspan="4">Wider room</td></tr>
<tr><td colspan="3">Original Design</td><td colspan="4">Revised Design</td></tr>
<tr><td colspan="3">
</td><td colspan="4">
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Table 7-15. Detail design changes description of T. Braga (2BR) apartment unit in APT projects

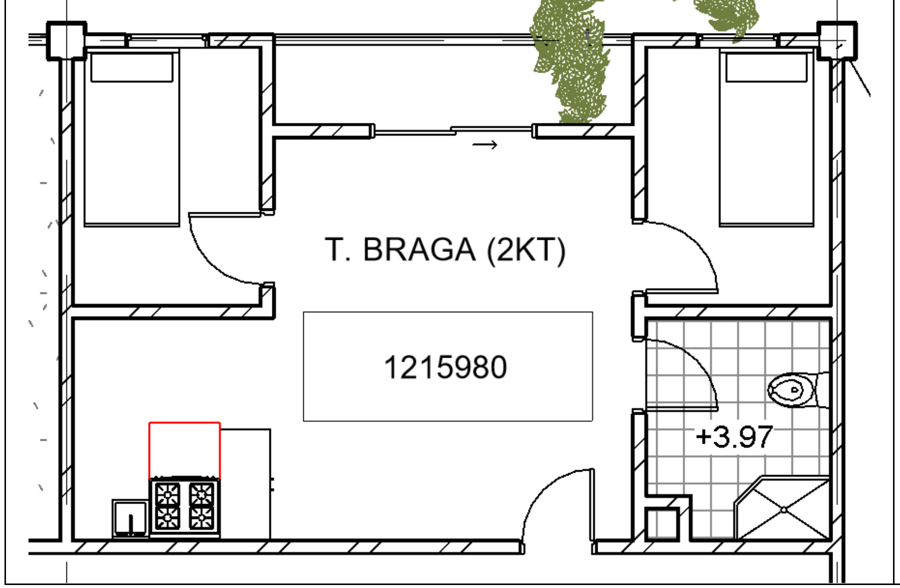
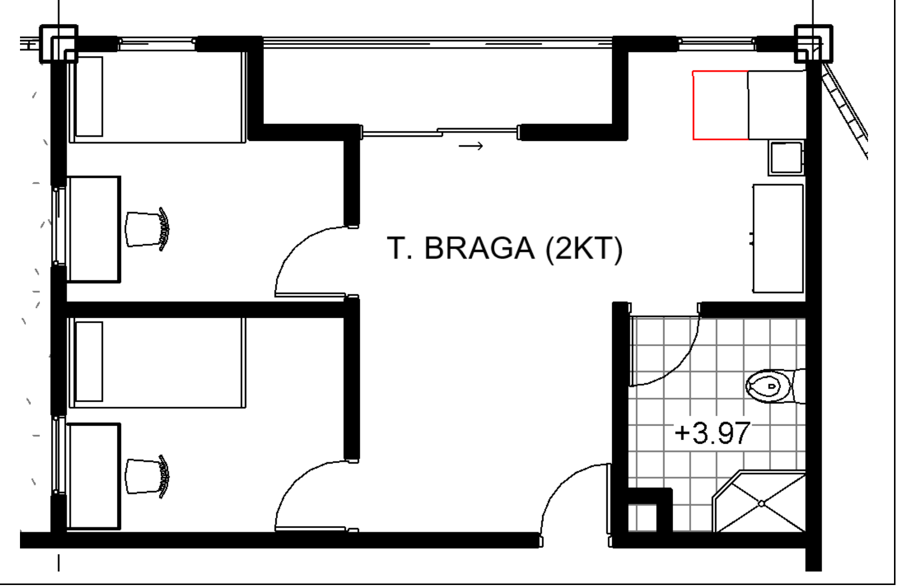
Room Name	T. BRAGA (2BR)	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
Level	F2	Student	0.75	0.25	0.27	0.00
Δ Area (m^2)	-0.30	Supervisor	0.75	0.25	0.33	0.10
Δ Volume (m^3)	-0.90	Description	Different wall partition setup, bathroom door placement, and kitchen placement			
Original Design			**Revised Design**			
						

Table 7-16. Building component design changes in APT project paired with PDS process results

Building Component	Student				Supervisor				Notes on Design Changes
	PI	NI	Imprv(+)	Imprv(-)	PI	NI	Imprv(+)	Imprv(-)	
Glass Walls	0.25	0.75	0.12	0.27	0.69	0.31	0.40	0.12	Less storefront-type of curtain wall placed; new set of window and shading
Stairs	0.21	0.79	0.12	0.37	0.50	0.50	0.31	0.31	No change on stairs
Ramp	0.27	0.73	0.10	0.31	0.37	0.63	0.13	0.35	There’s no changes.
Ceiling	0.37	0.63	0.08	0.19	0.44	0.56	0.10	0.40	Ceiling area addition on F1, F3, and F7
Columns	0.40	0.60	0.04	0.21	0.75	0.25	0.27	0.13	Less small column are placed
Facade	0.25	0.75	0.04	0.37	0.65	0.35	0.29	0.23	Lower-height windows with new shading set
Floor	0.23	0.77	0.04	0.35	0.44	0.56	0.15	0.38	Area reduction on specific flooring
Solid Walls	0.27	0.73	0.02	0.21	0.44	0.56	0.17	0.40	More brick walls are added
Railing	0.23	0.77	0.02	0.35	0.37	0.63	0.19	0.42	Addition and reduction on glass railing across all levels
Beams	0.33	0.67	0.00	0.13	0.69	0.31	0.33	0.19	Less concrete beams are placed
Average	**0.28**	**0.72**	**0.06**	**0.28**	**0.53**	**0.47**	**0.23**	**0.29**	

Table 7-17. Detail design changes description of facade component in APT projects

Building Component	FACADE	**PDS Result**	PI	NI	Imprv(+)	Imprv(-)
		Student	0.25	0.75	0.04	0.37
		Supervisor	0.65	0.35	0.29	0.23
		Description	Lower-height windows with new shading set			
Original Design			**Revised Design**			
						

Table 7-18. Quantity takeoff of Columns component in the APT projects

	Type Mark	**Type**	**Volume (m^3)**	**Count**			**Type Mark**	**Type**	**Volume (m^3)**	**Count**	**Δ Count**
APT2	CR3	Column	154.68	34		**APT3**	CR3	Column	166.18	34	0
	CR4	Small Column	8.98	8			CR4	Small Column	6.75	6	-2

Table 7-19. Quantity takeoff of Stairs component in the APT projects

	Type Mark	Type	Base Level	Top Level	Actual Number of Risers	Count			Type Mark	Type	Base Level	Top Level	Actual Number of Risers	Count
APT2	ST1	Monolithic Stair	BASEMENT 3	BASEMENT 2	16	1		APT3	ST1	Monolithic Stair	BASEMENT 3	BASEMENT 2	16	1
	ST1	Monolithic Stair	BASEMENT 2	BASEMENT 1	16	1			ST1	Monolithic Stair	BASEMENT 2	BASEMENT 1	16	1
	ST1	Monolithic Stair	BASEMENT 1	LANTAI 1	16	1			ST1	Monolithic Stair	BASEMENT 1	LANTAI 1	16	1
	ST1	Monolithic Stair	LANTAI 1	LANTAI 2	20	2			ST1	Monolithic Stair	LANTAI 1	LANTAI 2	20	2
	ST1	Monolithic Stair	LANTAI 2	LANTAI 3	20	2			ST1	Monolithic Stair	LANTAI 2	LANTAI 3	20	2
	ST1	Monolithic Stair	LANTAI 3	LANTAI 4	20	2			ST1	Monolithic Stair	LANTAI 3	LANTAI 4	20	2
	ST1	Monolithic Stair	LANTAI 4	LANTAI 5	20	2			ST1	Monolithic Stair	LANTAI 4	LANTAI 5	20	2
	ST1	Monolithic Stair	LANTAI 5	LANTAI 6	20	2			ST1	Monolithic Stair	LANTAI 5	LANTAI 6	20	2
	ST1	Monolithic Stair	LANTAI 6	LANTAI 7	20	2			ST1	Monolithic Stair	LANTAI 6	LANTAI 7	20	2
	ST1	Monolithic Stair	LANTAI 7	LANTAI 8	20	2			ST1	Monolithic Stair	LANTAI 7	LANTAI 8	20	2
	ST1	Monolithic Stair	LANTAI 8	LANTAI 9	20	2			ST1	Monolithic Stair	LANTAI 8	LANTAI 9	20	2

Table 7-20. Quantity takeoff of Railings component in the APT projects

APT2	Type	Base Level	Length (m)		APT3	Type	Base Level	Length (m)	Δ Length (m)

	Glass Panel - Bottom Fill		366203			Glass Panel - Bottom Fill		366203	0
	Glass Panel - Bottom Fill	LEVEL 1	2200			Glass Panel - Bottom Fill	LEVEL 1	0	-2200
	Glass Panel - Bottom Fill	LEVEL 2	33456			Glass Panel - Bottom Fill	LEVEL 2	24304	-9152
	Glass Panel - Bottom Fill	LEVEL 3	61244			Glass Panel - Bottom Fill	LEVEL 3	61244	0
	Glass Panel - Bottom Fill	LEVEL 4	35561			Glass Panel - Bottom Fill	LEVEL 4	41198	5637
	Glass Panel - Bottom Fill	LEVEL 5	30152			Glass Panel - Bottom Fill	LEVEL 5	30787	635
	Glass Panel - Bottom Fill	LEVEL 6	36551			Glass Panel - Bottom Fill	LEVEL 6	29537	-7014
	Glass Panel - Bottom Fill	LEVEL 7	26624			Glass Panel - Bottom Fill	LEVEL 7	32261	5637
	Glass Panel - Bottom Fill	ROOFTOP	32179			Glass Panel - Bottom Fill	ROOFTOP	37783	5604

7.3.5. Data Analysis Results

This section explains data analysis results from the VRDR implementation in Part 1. We used the ASMs filled by the participants as the data sources. We performed two data analysis processes here: the PDS process and comparing affordances between design components. We performed the PDS process to find out if the student achieves the studio objectives and SPCs by checking positive and negative indexes on each project and studying the effectivity of the VRDR system for the design revision process by checking the improvement index on each project. Then, we compared present affordances from the design components using distribution analysis to see the distribution of affordances presence for each component in each design option. We also compared the data analysis results between the student and supervisor to determine any differences between their perspectives when reviewing the design options.

7.3.5.1. PDS Process

From the ASM filled by the participants, we obtained the Positive Index (PI) and Negative Index for the LC project and APT project. First, we look at the result of the LC project in Table 7-21. We can see that the value of PI is higher than NI across all categories on the student side. The student perceived more positive affordances than negative affordances, indicating that the revised design has achieved most of the studio objectives and SPCs. It is reflected in the rooms (RM-OBJ and RM-SPC) and the design's building components (BC-OBJ and BC-SPC) group. Meanwhile, on the supervisor side, the value of PI is higher than NI only in RM-OBJ and RM-SPC, while the value of NI is higher than PI in BC-OBJ and BC-SPC. This result indicates the supervisor argued that the spatial or Rooms components in the revised design had achieved both studio objectives and SPCs but not with the building components group.

Next, we check out the result of the APT project in Table 7-22. It shows an intriguing outcome because both student and supervisor have the same conclusion. They reviewed that the building components in the revised design of APT have not attained the majority of objectives and SPCs with NI(Student) = 0.55, NI(Supervisor) = 0.52, and PI(Student) = 0.45, and PI(Supervisor) = 0.48. They argue that the revised design has achieved most studio objectives and SPCs across all categories except the BC-OBJ category.

Table 7-21. Positive Index (PI) and Negative Index (NI) for LC Project (Part 1)

LC Average	Student		Supervisor	
	PI	**NI**	**PI**	**NI**
RM-OBJ	0.67	0.33	0.59	0.41
RM-SPC	0.61	0.39	0.58	0.42
BC-OBJ	0.60	0.40	0.45	0.55
BC-SPC	0.64	0.36	0.43	0.57

Table 7-22. Positive and Negative Index for APT Project (Part 1)

APT Average	Student		Supervisor	
	PI	**NI**	**PI**	**NI**
RM-OBJ	0.72	0.28	0.59	0.41
RM-SPC	0.52	0.48	0.58	0.42
BC-OBJ	0.45	0.55	0.48	0.52
BC-SPC	0.67	0.33	0.55	0.45

We also obtained the Improvement index for both LC and APT projects. First, we inspect the result of LC in Table 7-23. Both student and supervisor found improvement on the latest design of LC compared to the original design option across all categories. Meanwhile, in Table 7-24, the student found improvement in most categories in the APT project result, except in the BC-OBJ category. On the other hand, the supervisor found negative improvement in the building components of the revised design of APT. The supervisor perceived more negative affordances in the revised design of the APT project compared to the original design.

Table 7-23. Improvement Index for LC Project (Part 1)

LC Average	Student		Supervisor	
	Imprv(+)	**Imprv(–)**	**Imprv(+)**	**Imprv(–)**
RM-OBJ	0.24	0.17	0.34	0.16
RM-SPC	0.21	0.20	0.34	0.17
BC-OBJ	0.13	0.02	0.26	0.17
BC-SPC	0.15	0.04	0.27	0.20

Table 7-24. Improvement Index for APT Project (Part 1)

APT Average	Student		Supervisor	
	Imprv(+)	**Imprv(–)**	**Imprv(+)**	**Imprv(–)**
RM-OBJ	0.17	0.03	0.17	0.09
RM-SPC	0.10	0.09	0.17	0.09
BC-OBJ	0.11	0.13	0.16	0.29
BC-SPC	0.18	0.03	0.23	0.28

7.3.5.2. Affordance presence in design components

We completed the distribution analysis from the ASM of Part 1 to determine how many affordances were present on each pair of design component groups and affordance category in every design option. The result sourced from the ASM completed by the student is in Table 7-25, and the supervisor is in Table 7-26. We can spot the perspective differences between the student and supervisor when reviewing architectural design options. We can identify which design option is better in terms of perceived affordances.

From the analysis, design review results from student and supervisor came out with the different situations. From the student's point of view, she perceived more positive affordances (AUAP and AAAP) than negative affordances (AUAN and

AAAP). The rate of perceived affordance pairs in the AUAP category is ranged from 20.67% (APT2-BC) to 75.93% (LC2-Room). In AAAP category, it is from 18.00% (LC1-BC) to 52.50% (LC2-Room). Meanwhile, perceived affordance pairs in the AUAN category range from 4.39% (APT3-Room) to 18.86% (APT2-Room) in the negative affordance categories. Then, it is from 2.63% (Room-APT3) to 24.21% (Room-APT2) in the AAAN category.

Meanwhile, from the supervisor's standpoint, the results are mixed. Not every positive affordance pair is perceived more than its counterpart negative affordance pair. For example, in the Room-LC1, its positive affordance pairs (AUAP and AAAP) are less present in percentage (22.92% and 14.17%) than its counterpart negative affordance pairs (AUAN with 25.00% and AAAN with 35.00%). On the other part, such as APT3-Room, its positive affordance pairs (AUAP and AAAP) are more present in percentage (67.37% and 37.54%) than its counterpart negative affordance pairs (AUAN with 40.35% and AAAN with 26.32%).

Table 7-25. Affordance presence for each design component in LC and APT projects reviewed by the student

Student	**LC1**		**LC2**		**APT2**		**APT3**	
	Room	**BC**	**Room**	**BC**	**Room**	**BC**	**Room**	**BC**
AUAP	47.08%	22.00%	75.83%	45.33%	52.98%	20.67%	64.56%	46.00%
AUAN	8.85%	7.50%	9.90%	6.67%	18.86%	13.33%	4.39%	6.67%
AAAP	28.33%	18.00%	52.50%	38.00%	31.58%	23.33%	43.51%	38.67%
AAAN	11.25%	6.00%	5.63%	3.00%	24.21%	10.00%	2.63%	3.00%

Table 7-26. Affordance presence for each design component in LC and APT projects reviewed by the supervisor

Super visor	**LC1**		**LC2**		**APT2**		**APT3**	
	Room	**BC**	**Room**	**BC**	**Room**	**BC**	**Room**	**BC**
AUAP	22.92%	26.67%	63.75%	49.33%	49.82%	56.67%	67.37%	59.33%
AUAN	25.00%	12.50%	44.79%	44.17%	50.00%	39.17%	40.35%	36.67%

Supervisor	LC1		LC2		APT2		APT3	
	Room	BC	Room	BC	Room	BC	Room	BC
AAAP	14.17%	16.00%	51.25%	58.67%	43.86%	58.00%	37.54%	30.67%
AAAN	35.00%	26.00%	42.50%	40.00%	42.63%	36.00%	26.32%	33.00%

Next, we take a closer look at the result by calculating the percentage margin between design options of LC and APT projects in all design components and affordance categories. The calculation result is presented in Table 7-27 for the student and Table 7-28 for the supervisor. First, the student's result shows that all positive affordance pairs in LC and APT projects and positive affordance groups (AUAP and AAAP) show positive values. It means that the student perceived more positive affordances in the revised design of LC and APT projects. On the other hand, all negative affordance pairs, except LC-Room-AUAN, show negative values. These indicate that the student perceived less negative affordances in the revised design of LC and APT projects, except the affordances in the AUAN group were perceived 1.04% more in the Room component of LC2 than in LC1.

For the supervisor, the result is distinctive, as seen in Table 7-28. The table shows that the LC project's positive and negative affordance pairs show positive value for the Room and Building Component groups. As the revised design, the supervisor judged that LC2 is improved due to increased perceived positive affordances and more problems to fix seen by the rise of perceived negative affordances. At the same time, in the APT project, almost all positive and negative affordance pairs show the negative value, which signifies the decrease of perceived affordances in pairs. Only the margin percentage in the APT-AUAP pair show a positive value. This result implies that the revised APT design improved almost all affordance pairs. Nevertheless, the design got new problems simultaneously due to the disappearance of positive affordances from the AAAP group.

Table 7-27. The margin of affordance presence percentages for each design component in LC and APT project reviewed by the student

Student	Δ LC		Δ APT	
	Room	BC	Room	BC
AUAP	28.75%	23.33%	11.58%	25.33%
AUAN	1.04%	-0.83%	-14.47%	-6.67%
AAAP	24.17%	20.00%	11.93%	15.33%
AAAN	-5.63%	-3.00%	-21.58%	-7.00%

Table 7-28. The margin of affordance presence percentages for each design component in LC and APT project reviewed by the supervisor

Supervisor	Δ LC		Δ APT	
	Room	BC	Room	BC
AUAP	40.83%	22.67%	17.54%	2.67%
AUAN	19.79%	31.67%	-9.65%	-2.50%
AAAP	37.08%	42.67%	-6.32%	-27.33%
AAAN	7.50%	14.00%	-16.32%	-3.00%

7.4. Part 2: Confirmation Study

In this Part 2, we conducted a confirmation study to affirm the result in Part 1. We raised the same hypotheses as to Chapter 6 where we hypothesized that,

1. The media used for design review process might affect how each participant perceived affordances in each design and then led to the review result.
2. With its immersive spatial capability compared to NVR, we expected that VR is more effective on helping participants to perceive affordances from spatial entities.
3. In the mean time, we also expected that each of design components might or might not perceived equally on both media. If an affordance is confirmed on both media, it is highly chanced that the affordance is actually present. The architectural designer could take action to the design component paired with that affordance.
4. Lastly, by having an affordance confirmed to be perceived on specific media across all design works, we expected that the affordance is highly

compatible with the media. If a participant wants to review that particular affordance presence, it is suggested to use the compatible media for review.

The presence of revised design work in Part 2 study could help confirming the results obtained from Chapter 6. Therefore, we used two different mediums for the affordance-based design review process: NVR and VR. In the end, we compare the results both from Part 1 and 2 to determine whether VRDR is adequate to be utilized for the affordance-based design review process.

7.4.1. Methodology

This section explains the participants who joined the Part 2 study, the procedures that must be completed, details of pre-simulation and post-simulation questionnaires.

7.4.1.1. Participants

The participants in this simulation were third-year architectural design students. Similar to the study we performed in Chapter 6, we assumed that the students have sufficient spatial reading skills to review an architecture design by perceiving affordances inside a VE and being familiar with operating BIM-based design authoring tools. Fifty-eight students – ranging from 20-24 years old (33.9% are 22) – participated in the simulation. 72.9% had no prior experience using VR devices, 50.8% were myopic, and 47.5% were not suffering any visual impairments. We conducted the simulation during the COVID-19 pandemic. So, we required all students who wanted to participate must have been vaccinated at least one shot (83.1% had their second shot) and followed the mandatory health protocol. We also performed the simulation according to the Japanese Ethical Guidelines for Medical and Health Research Involving Human Subjects and the principles of the Declaration of Helsinki. We provided informed consent to each participant.

Unlike Chapter 6, we divided the participants into two groups based on the design projects they reviewed. Group A reviewed the LC project using NVR media and the APT project using VR media. Group B reviewed the APT project using NVR media and the LC project using VR media. So, each participant experienced different projects with different media, while in Chapter 6, the participants reviewed the same design projects using NVR media and then using VR media. The previous procedure might impact participants' perception of the design project, especially in the VR media phase, since they did not experience a pure VR-only step but a VR-after-NVR step with the same design project.

7.4.1.2. Procedures

The procedures we performed for the Part 2 study, visualized as a flowchart in Figure 7-5, are as follows:

1. <u>Booking the simulation date</u>

   We offered the third-year architecture design students to join as participants and book the simulation date. This procedure is mandatory to manage the number of participants that can be handled and avoid any potential crowd in the middle of the pandemic situation.

2. <u>Checking participant condition</u>

   Before starting the simulation, each participant must inform us about their vaccination status. Also, we required participants always to wear a mask and maintain physical distancing during the simulation. The venue we used for the simulation was a semi-outdoor cafe for better air circulation.

3. <u>First onboarding process</u>

   In the first onboarding process, we explained the study objectives and design projects – including the design brief, studio objectives, and SPCs, the concept of affordances, a list of affordances, and design components that participants would review. Then, we divided the participants into groups: Group A and B.

4. <u>Design review process using NVR media</u>

   In this step, we let participants access the BIM model of the first assigned design project using Revit, including the design options (original and revised design). Participants were requested to examine both options and then review the design based on the presence of affordances they perceived. They must mark each affordance pair in the ASM form if they sensed the affordance presence in its paired design component (room and building components).

5. Second onboarding process

   We introduced VRDR and its essential interaction with the participants in the second onboarding process, including navigating inside the VRDR environment. We also provided a short video to see what VRDR looks like and what they must do with it.

6. Design review process using VR media

   In this step, we asked participants to wear Quest HMD and run the VRDR application to explore the second assigned design project, as seen in Figure 7-6. We asked them to review the original and revised design options by exploring all rooms with tags inside the application. Then, they examined the room and building components of all design options. Same as Step 4, they must put a mark on each affordance pair in the ASM form if they sensed the affordance presence in its paired design component (room and building components).

7. Filling in the post-simulation questionnaire

   After reviewing the design project using VR media, we asked the participants to fill in the post-simulation questionnaire to get their feedback on the VRDR system itself. The questionnaire contains open-ended questions asking about their experiences and what should be improved from VRDR.

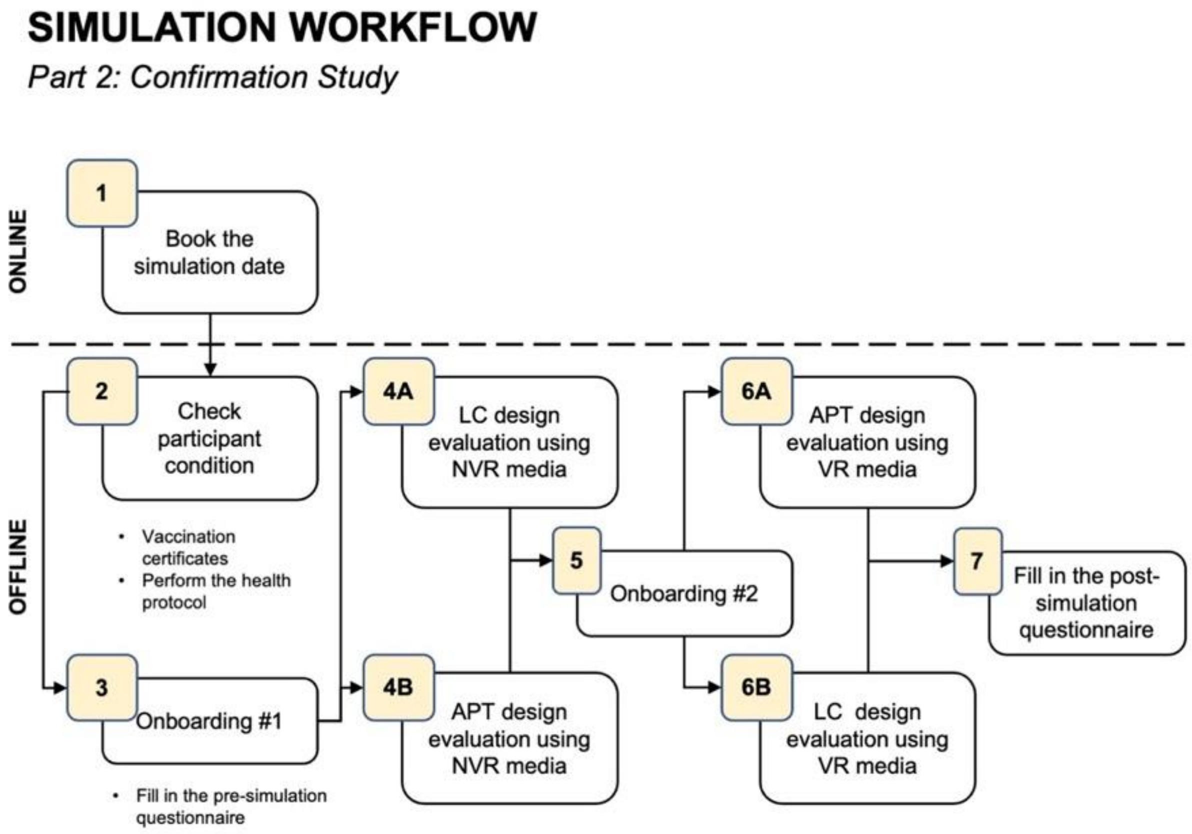


Figure 7-5. Simulation workflow for Part 2.

Figure 7-6. Part 2 simulation in progress. Photo credit: Author.

7.4.2. Results

This section explains data analysis results from the completed Part 2. We performed four data analysis processes here: PDS process, affordance vs. design components through correspondence and hierarchical clustering analysis method, affordance vs. medium comparison through correspondence and hierarchical clustering analysis method, medium comparison through paired statistical t-test method. We were using the ASMs filled by the participants as the data sources.

First, the objective of the PDS process in this part is to determine how far the student reached the studio objectives and SPCs based on the affordance presence in each design. Second, affordance vs. design component comparison aims to discover the relationship between affordances and design components in different mediums on each project.

Third, affordance vs. medium comparison objectives is to discover the relationship between affordances and medium used for the design review process in different design component groups and determine the medium compatibility to assist users perceiving affordance in each design project. Lastly, the objective of medium comparison is to compare medium effectivity on perceiving affordances between NVR and VR in each design.

7.4.2.1. PDS Process

Similar to what we did in section 7.3.5.1, we obtained the PI and NI for LC and APT projects from the ASM filled by the Part 2 participants. First, we look at the result for the LC project in Table 7-29. We see that in the Part 2 participants side, the values of PI are higher than NI across all categories. PI for Room components is at a higher rate compared to PI for Building Components. Second, we check out the result of the APT project in Table 7-30. We discover that in the Part 2 participants side, the values of PI are slightly higher than NI across all categories in the APT project. From the results, the students from Part 2 study argue that the designer has achieved most studio objectives and SPCs for the LC project, especially for Room components. It is because more positive affordances are perceived than negative affordances.

Table 7-29. Positive and Negative Index for LC Project (Part 2)

LC Average	Students (Part 2)	
	PI	NI
RM-OBJ	0.82	0.18

LC Average	Students (Part 2)	
	PI	**NI**
RM-SPC	0.78	0.22
BC-OBJ	0.57	0.43
BC-SPC	0.58	0.42

Table 7-30. Positive and Negative Index for APT Project (Part 2)

APT Average	Students (Part 2)	
	PI	**NI**
RM-OBJ	0.54	0.46
RM-SPC	0.54	0.46
BC-OBJ	0.56	0.44
BC-SPC	0.56	0.44

Next, we obtained the Improvement index for LC and APT projects from the Part 2 participants. First, we look at the result of LC in Table 7-31. Students from the Part 2 study found improvement in the LC2 design option than the LC1 as the original design across all categories, except the BC-OBJ category. It is shown that the value of Imprv(–) of BC-OBJ is higher than the value of Imprv(+) of its counterpart, while others have a higher value of Imprv(+).

Second, we check the result of APT in Table 7-32. It is indicated with higher values of Imprv(+) compared to values of Imprv(–) on RM-OBJ and RM-SPC groups and lower values of Imprv(+) compared to values of Imprv(–) on BC-OBJ and BC-SPC groups. Students of the Part 2 study found more improvement in the Room component groups (RM-OBJ and RM-SPC) and more deterioration in the Building Component groups (BC-OBJ and BC-SPC).

Table 7-31. Improvement Index for LC Project (Part 2)

LC Average	Students (Part 2)	
	Imprv(+)	Imprv(–)
RM-OBJ	0.70	0.10
RM-SPC	0.66	0.12
BC-OBJ	0.20	0.23
BC-SPC	0.24	0.19

Table 7-32. Improvement Index for APT Project (Part 2)

APT Average	Students (Part 2)	
	Imprv(+)	Imprv(–)
RM-OBJ	0.28	0.26
RM-SPC	0.27	0.24
BC-OBJ	0.14	0.29
BC-SPC	0.14	0.28

7.4.2.2. Affordances vs. Design Components

This section performed correspondence and hierarchical clustering analysis processes between affordances and design components in LC and APT projects using JMP software. The analysis output is presented in dendrograms, as seen in Figure 7-7, and we mapped the clusters based on the media used, seen in Table 7-33 as an example.

LC1

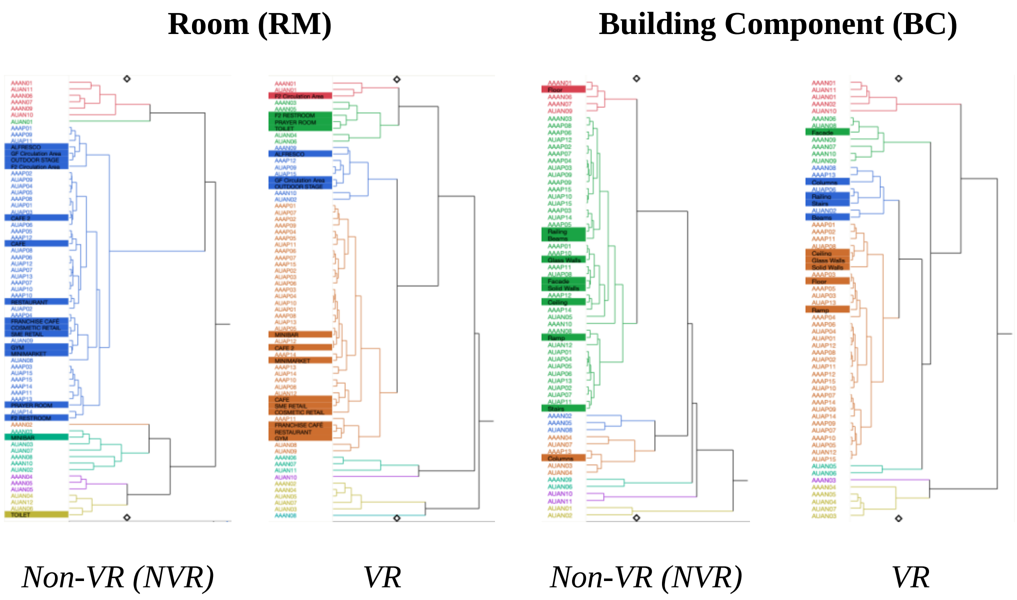


Figure 7-7. Dendrograms from hierarchical analysis method between affordances and design components in LC1

Table 7-33. Sample of mapped dendrogram values based on media used for perceiving the affordance pair

Affordance Code	LC1		
	Room		
	Toilet	Cafe	Minibar
AUAP01		D	S
AUAP02		D	S
AUAP03		S	

Then, we calculated the distribution of single media and double medium perceived pairs into four affordance categories: AUAP, AUAN, AAAP, and AAAN. Table 7-34 presents the results for pairs perceived by single media and Table 7-35 for pairs perceived by double medium from all projects. We look at Table 7-34. In each design component group (Room and BC), we found that there are four design component groups (LC1-Room, LC1-BC, LC2-Room, and APT2-Room) that have higher percentages of positive affordance groups (AUAP and AAAP) than the negative affordance groups (AUAN and AAAP). The other four design component groups (LC2-BC, APT2-BC, APT2-Room, and APT3-BC) have lower positive affordance groups than the negative affordance groups. Despite having the participants equally divided, it is still hard to conclude these results because these affordance pairs are confirmed to be perceived only by a single media. The pairs are perceivable using one media but then disappear with another media either NVR or VR. So, we decided also to check out affordance pairs perceived by the double medium.

Table 7-34. Affordance presence perceived at least by single media for each design component in LC and APT projects (Part 2)

Single (NVR/VR)	LC1		LC2		APT2		APT3	
	Room	BC	Room	BC	Room	BC	Room	BC
AUAP	50.83%	50.67%	40.42%	20.00%	45.61%	48.00%	45.61%	35.33%
AUAN	19.27%	19.17%	30.73%	49.17%	21.93%	53.33%	49.12%	59.17%
AAAP	51.25%	48.67%	40.00%	29.33%	60.00%	60.67%	45.96%	32.67%
AAAN	10.00%	28.00%	14.38%	61.00%	5.79%	37.00%	15.26%	20.00%

Next, we look at Table 7-35. Here, we found a more apparent pattern compare to the previous result. The percentages of positive affordance groups across all design components are higher than those of negative affordance groups. There are more perceived positive affordance pairs than perceived negative affordance pairs, confirmed by both NVR and VR medium.

Table 7-35. Affordance presence perceived by double media for each design component in LC and APT projects (Part 2)

Double (NVR & VR)	LC1		LC2		APT2		APT3	
	Room	BC	Room	BC	Room	BC	Room	BC
AUAP	39.17%	39.33%	47.08%	80.00%	24.17%	52.00%	45.61%	64.67%
AUAN	9.38%	3.33%	2.60%	9.17%	8.33%	12.50%	12.72%	24.17%
AAAP	41.25%	38.00%	46.67%	70.67%	12.92%	39.33%	42.46%	67.33%
AAAN	0.00%	4.00%	3.13%	2.00%	0.00%	10.00%	0.00%	17.00%

To see the affordance presence trend on each design component group, we visualize the result from Table 7-35 into bar charts at Figure 7-8 for LC projects and Figure 7-9 for APT projects. In the LC project, more positive affordance pairs in Room and BC groups are perceived in the revised design (LC2) than in the original design (LC1). For negative affordance pairs, the trends are mixed. In the AUAN group, there are more affordance pairs of BC group perceived in the LC2 compared within the LC1, but fewer affordance pairs of Room group perceived in the LC2 compared within the LC1. In the AAAN group, there are more affordance pairs of Room group perceived in the LC2 compared within the LC1, but fewer affordance pairs of BC group perceived in the LC2 compared within the LC1.

Meanwhile, Figure 7-9 shows that the affordance presence trend in all design component groups consistently increased in the APT project, except for the Room component in the AAAN group. The students perceived more positive and negative affordance pairs in the revised design (APT3) than the original design (APT2), which is perceived on both NVR and VR mediums.

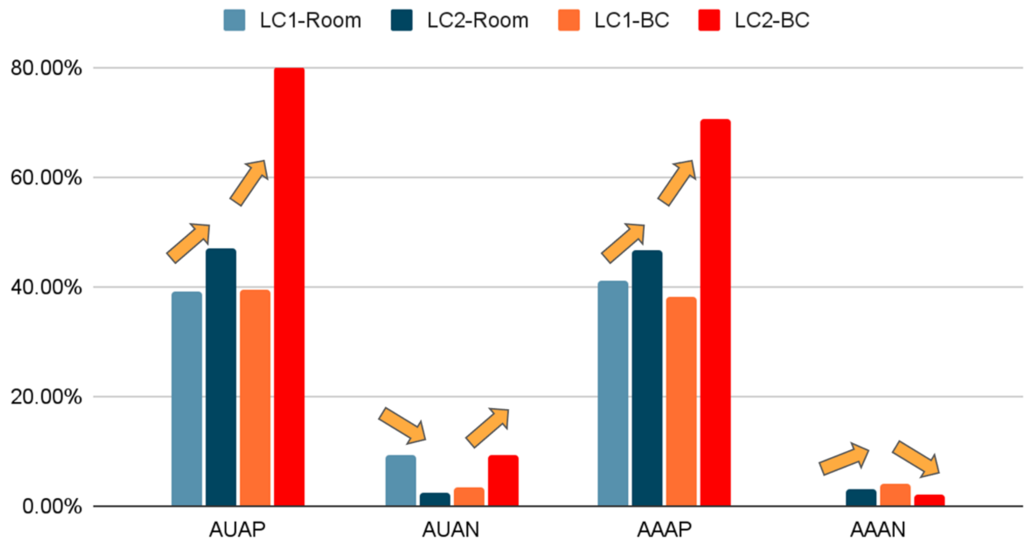


Figure 7-8. Affordance presence comparison chart on each affordance group and design component group between LC design options (perceived on both medium)

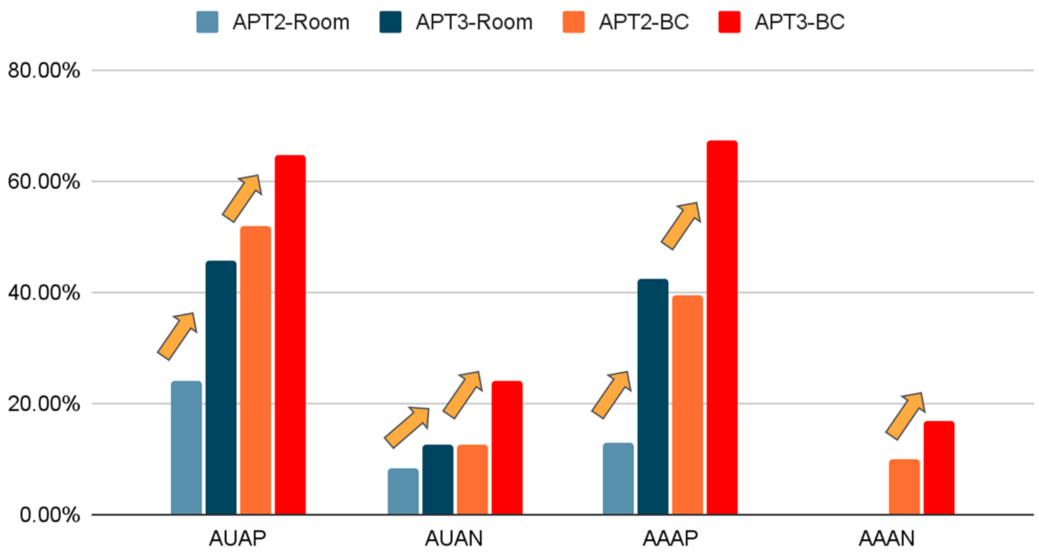


Figure 7-9. Affordance presence comparison chart on each affordance group and design component group between APT design options (perceived on both medium)

7.4.2.3. Affordances vs. Medium

This section explains the correspondence and hierarchical clustering analysis between affordances and medium used during the Part 2 study. The output is presented as a dendrogram seen in Figure 7-10. Then, we mapped the clusters in the dendrograms based on the media used within each design component group and calculated the distribution of perceived affordances on both design options in LC and APT projects. Table 7-36 presented the results.

LC1

Room | **Building Component**

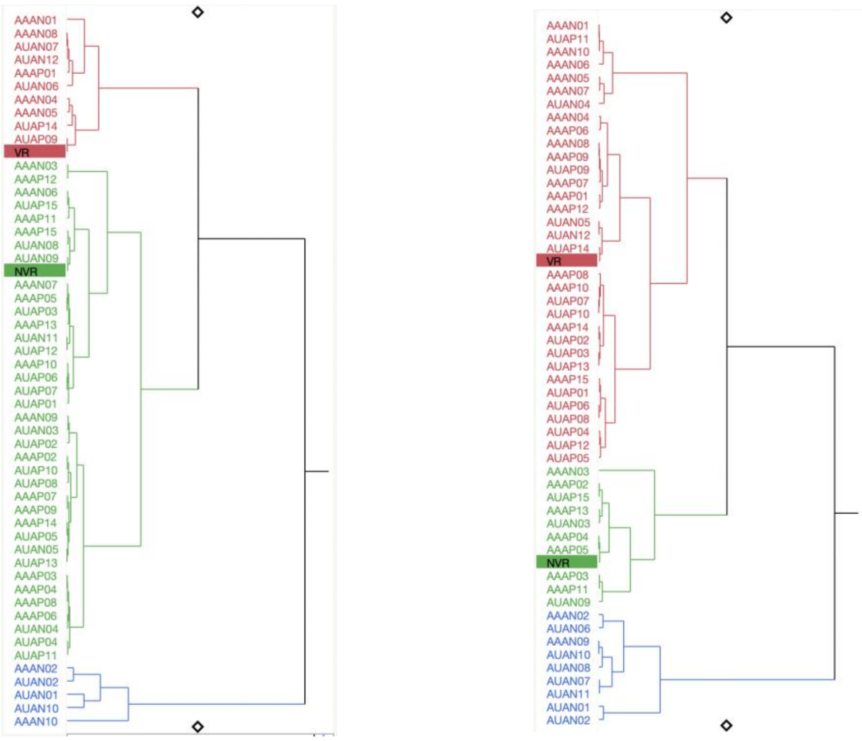


Figure 7-10. Dendrograms of hierarchical analysis method between affordances and medium in LC1

In Table 7-36, there are many affordances perceived on both LC and APT project's design options using specific media. These numbers show the number of affordances that have high compatibility to be perceived in a design project by using a specific media. Statistically, these affordances highly correlate with the media used for design review. For example, in the LC project, we found that six AAAP affordances are highly perceived using NVR media when a user reviews Building Components. Another example is in the APT project. 13 AUAP affordances have high compatibility to be perceived using VR media when a user reviews Room components in the APT projects.

Table 7-36. Number of affordances perceived on both design options in each LC and APT projects

Affordance Categories	LC				APT			
	Room		BC		Room		BC	
	NVR	VR	NVR	VR	NVR	VR	NVR	VR
AUAP	**3**	2	1	**2**	1	**13**	2	**6**
AUAN	**4**	2	2	**3**	0	**1**	1	**2**
AAAP	**3**	1	**6**	0	**6**	5	**10**	4
AAAN	**4**	2	1	**5**	0	**1**	0	0

We summarized the finding to narrow the result down to see how many affordances are perceived in both NVR and VR medium and LC and APT projects. Table 7-37 presents the summarized finding. These affordances considered have more compatibility to be perceived by certain media. In more detail, we identified each affordance and listed them in Table 7-38. The finding could help future users to pick which media is used for design to perceive specific affordances.

Table 7-37. Number of affordances perceived on both design options of LC and APT projects

Affordance Categories	LC + APT			
	Room		BC	
	NVR	VR	NVR	VR
AUAP	0	**1**	0	0
AUAN	0	**1**	**1**	**1**
AAAP	**1**	**1**	**3**	0
AAAN	0	0	0	0

Table 7-38. List of affordances perceived on both design options of LC and APT projects

Medium	**Design Components**	**Affordances**
NVR	Room	AAAP14: Repairability
	Building Components	AUAN03: Blocking user access AAAP04: Sufficient capacity for essential furniture AAAP05: Internal layout flexibility AAAP11: Weather protection

Medium	Design Components	Affordances
VR	Room	AUAP14: Noise cancellation AUAN06: Sense of boring AAAP01: Expansion-ability
	Building Components	AUAN05: Provide sense of tightness

7.4.2.4. Medium Effectivity Comparison

This section explains the results of paired t-tests comparing design review results using NVR and VR medium. The objective is to compare medium effectivity on helping user perceives affordances between NVR and VR medium in each design option. The results for the LC project are presented in Table 7-39. Meanwhile, for the APT project, the results are shown in Table 7-40.

For the LC project, Table 7-39 found that four categories have more pairs with a significant *p*-value in the Room group than the BC group (LC1-AUAP, LC1-AUAN, LC2-AUAP, and LC2 AAAP). Two categories have more pairs with a significant *p*-value in the BC group than the Room group (LC2-AUAN and LC2 AAAN). The rest of the two categories have the same number of affordance pairs with significant *p*-value both in Room and BC groups (LC1-AAAP and LC1-AAAN). On the other side, in Table 7-40 for the APT project, we found that all affordance categories have more pairs with a significant *p*-value in the Room group compared to the BC group. All results are discussed further in Section 7.5.

Table 7-39. Percentages of affordance pairs that have a significant p-value in the LC project

Projects (NVR vs. VR)	Paired t-test Results (p-value)	Room	BC
		Sig. Pairs (%)	Sig. Pairs (%)
LC1	AUAP	25.00%	12.50%
	AUAN	18.75%	6.25%
	AAAP	25.00%	25.00%
	AAAN	12.50%	12.50%
LC2	AUAP	62.50%	25.00%
	AUAN	0.00%	6.25%

Projects (NVR vs. VR)	Paired t-test Results (p-value)	Room	BC
		Sig. Pairs (%)	Sig. Pairs (%)
	AAAP	43.75%	25.00%
	AAAN	6.25%	12.50%

Table 7-40. Percentages of affordance pairs that have a significant p-value in the APT project

Projects (NVR vs. VR)	Paired t-test Results (p-value)	Room	BC
		Sig. Pairs (%)	Sig. Pairs (%)
APT2	AUAP	57.89%	37.50%
	AUAN	100.00%	50.00%
	AAAP	89.47%	62.50%
	AAAN	89.47%	62.50%
APT3	AUAP	57.89%	56.25%
	AUAN	84.21%	50.00%
	AAAP	100.00%	62.50%
	AAAN	63.16%	50.00%

7.5. Discussion

This section discusses the result from Part 1, where VRDR implementation in an ongoing design studio process was carried on, and from Part 2, the confirmation study of the findings from Part 1. We also compare the data analysis results between Part 1 and Part 2.

7.5.1. Design improvement with the proposed PDS process

Chapter 3.4.4 proposed a data analysis process for affordance-based design review process named the PDS process. This process aims to discover whether the latest design iteration is improved than the previous iteration based on the perceived positive and negative affordances and exercises if the tool or media we used in the study is effective for the design review process. This section discusses the result from Part 1 and Part 2 studies and finds out whether LC and APT projects' revised design improves and how effective the VRDR system is for the design review process.

First, we see Table 7-41, showing the LC project PI and NI from Part 1 and Part 2 studies. In Part 1, we have a student and her supervisor as the participants. While in Part 2, we have a group of third-year students as the participants. Compared to the Part 1 study, the students in the Part 2 trend result align with the student in Part 1. All PI values from Part 2's students and Part 1's student is higher than their NI counterparts. Both agree that the LC project's revised design has achieved the objectives and SPCs. However, it is different from the result from the supervisor, where the NI values are slightly higher than PI values in the BC-OBJ and BC-SPC categories. This result implies that the supervisor is considered that the room components in the revised design of the LC project have achieved the objectives and SPCs but not for the building components.

Table 7-41. Positive and Negative Index for LC Project (Part 1 and 2)

LC Average	Student (Part 1)		Students (Part 2)		Supervisor (Part 1)	
	PI	NI	PI	NI	PI	NI
RM-OBJ	0.67	0.33	0.82	0.18	0.59	0.41
RM-SPC	0.61	0.39	0.78	0.22	0.58	0.42
BC-OBJ	0.60	0.40	0.57	0.43	0.45	0.55
BC-SPC	0.64	0.36	0.58	0.42	0.43	0.57

Second, we look at Table 7-42, showing the PI and NI of the APT project from Part 1 and Part 2 studies. Students in Part 2 show that PI values from all categories are slightly higher than the NI values. It means that they argue that the revised design of APT has achieved the objectives and SPCs with a slight margin. It contrasts with the result from the Part 1 study where both student and supervisor have the same perception of the affordances they perceived when reviewing APT design options. It is shown that both of their NI values for BC-OBJ categories are slightly higher compared to PI values. This result indicates that they think that building components in the revised design of APT slightly has not yet achieved the objectives but achieved the SPCs.

Table 7-42. Positive and Negative Index for APT Project (Part 1 and 2)

APT Average	Student (Part 1)		Students (Part 2)		Supervisor (Part 1)	
	PI	**NI**	**PI**	**NI**	**PI**	**NI**
RM-OBJ	0.72	0.28	0.54	0.46	0.59	0.41
RM-SPC	0.52	0.48	0.54	0.46	0.58	0.42
BC-OBJ	0.45	0.55	0.56	0.44	0.48	0.52
BC-SPC	0.67	0.33	0.56	0.44	0.55	0.45

Since the results were obtained with VR as the media used for design review process, they confirm the second hypothesis where VR is more effective on helping students to perceive affordances from spatial entities. Furthermore, VR media helps the student to improve the spatial elements more compared to the building components. In addition, we suspect that the building typology might affect the trend pattern seen in the LC and APT projects. The student was asked to focus more on the LC project's spatial elements (rooms). While in the APT design, the student was focused more on the building systems (building components/BC). So, the student might be less aware of the BC in the LC than the APT. At the same time, the supervisor is supposed to review both spatial elements and building systems -consistently– regardless of the building typology that student-designed.

Next, we check the improvement index to determine how effectively the VRDR system is used for the design review based on affordance presence changes. Table 7-43 shows the improvement index for the LC project taken from Part 1 and Part 2 studies. As reviewed in Part 1, the results show that revised LC projects' Imprv(+) values are higher than their counterparts Imprv(–) across all categories. The margin between Imprv(+) and Imprv(–) ranges between 0.01 and 0.11, which is narrow. This result tells us that the student and supervisor of Part 1 argue that the improvement in the revised LC tends in the positive direction.

The students argue that the improvement for room components in the revised LC has a significant tendency towards the positive direction, but not for the building components on trying to achieve the studio objectives. As seen in Part 2, only the Imprv(+) value in the BC-OBJ is lower than its Imprv(–) value, with a margin of 0.03. It also has the highest margin between Imprv(+) and Imprv(–) in the RM-OBJ with 0.60 and RM-SPC with 0.54.

Table 7-43. Improvement Index for LC Project (Part 1 and 2)

LC Average	Student (Part 1)		Students (Part 2)		Supervisor (Part 1)	
	Imprv(+)	**Imprv(–)**	**Imprv(+)**	**Imprv(–)**	**Imprv(+)**	**Imprv(–)**
RM-OBJ	0.24	0.17	0.70	0.10	0.34	0.16
RM-SPC	0.21	0.20	0.66	0.12	0.34	0.17
BC-OBJ	0.13	0.02	0.20	0.23	0.26	0.17
BC-SPC	0.15	0.04	0.24	0.19	0.27	0.20

Lastly, Table 7-44 shows the improvement index for the APT project taken from Part 1 and Part 2 studies. We see that for the room component (RM-OBJ and RM-SPC) in Part 1 and 2, the Imprv(+) values are higher than the Imprv(-–) values. On the other hand, for the building components (BC-OBJ and BC-SPC), Imprv(+) values are lower than Imprv(–) values as reviewed by the supervisor and the Part

2's students. Results from the student from Part 1 show that the Imprv(+) values for building components grouped based on objectives are lower than Imprv(–) values. These results show that all participants agree that the improvement of room components in the revised APT design towards positive directions – but not for the building components.

Table 7-44. Improvement Index for APT Project (Part 1 and Part 2)

APT Average	Student (Part 1)		Students (Part 2)		Supervisor (Part 1)	
	Imprv(+)	Imprv(–)	Imprv(+)	Imprv(–)	Imprv(+)	Imprv(–)
RM-OBJ	0.17	0.03	0.28	0.26	0.17	0.09
RM-SPC	0.10	0.09	0.27	0.24	0.17	0.09
BC-OBJ	0.11	0.13	0.14	0.29	0.16	0.29
BC-SPC	0.18	0.03	0.14	0.28	0.23	0.28

We found improvements in the Room components across all projects from the Improvement Index results above that tend towards the positive direction which once again, it is confirming the second hypothesis. We also found mixed results in the building components across the projects on the other side. The improvements in the building components of the revised LC project are mainly towards the positive direction. While in the APT project, it towards a negative direction. So, in terms of improvements – the condition where we have more positive affordance and less negative affordances perceived, the VRDR system is considered more effective in improving spatial elements in the design but less effective for improving building systems (building components).

7.5.2. Relationship between affordances and design components

This section discusses the relationship between affordances and design components in the NVR and VR media between all design options of LC and APT projects. By analyzing the relationship between them, it is possible to determine which design components have achieved their purposes and which components must be improved.

This finding confirms the third hypothesis stated in the beginning. In the Part 1 study, the student found that positive affordances are more present than negative affordances. This result occurred in the design options of LC and APT projects. Meanwhile, the supervisor gave mixed results where positive affordances are not always present more than negative affordances. Then by calculating the percentage margin of affordance presence between design options of LC and APT projects, the result implies that students found more positive perceived affordances and mostly less perceived negative affordances in the revised design on all design components.

Meanwhile, the supervisor gave an exceptional result. The result tells LC design is improved and worse simultaneously due to the increase of positive and negative affordances presence on all design components. For the APT design, the supervisor reviewed that it is improved by having negative affordances presence decreased and worse in terms of AAAP affordances because the affordances in this category were disappeared.

Next, we compare between Part 1 result and Part 2 result. We found a similar pattern trend in the Part 1 result seen in Table 7-25 and Part 2 in Table 7-35. Both results show that more positive affordances are perceived than negative affordances. It is different from the results that came from the supervisor (see Table 7-26). This finding is also in-line with the Theory of Affordance itself, whereas Gibson (1979) said that "affordances are animal-relative properties of the environment." The student and supervisor can be considered "different kinds of animals" since both have different levels of understanding and experience when reviewing the architectural design.

7.5.3. Relationship between affordances and medium

This section discusses the result of the data analysis process finding the relationship between affordances and medium. In the previous section, the data analysis results indicate that there are five affordances associated more with the NVR media: affordance of blocking user access (AUAN03), the affordance of sufficient capacity for essential furniture (AAAP04), the affordance of internal layout flexibility (AAAP05), the affordance of weather protection (AAAP11) in building components, and affordance of repairability (AAAP14) in a room component. By logic, these affordances are more easily perceived by NVR media, where users can inspect the design in different views. While in VR, it is set up as a 1:1 scale first-person exploration.

Meanwhile, in the VR media, four affordances are more associated with

- the affordance of noise cancellation (AUAP14),
- the affordance of sense of boring (AUAN06),
- the affordance of expansion-ability (AAAP01) in a room, and
- the affordance of providing a sense of tightness (AUAN05) in building components.

Compared to what was happened in Chapter 6, the VR models in this study have sufficient information for users reviewing the design with minimal cognitive effort or direct perception – especially in reviewing room components. So, it finally confirms the second hypothesis without contrary which was happened in the Chapter 6. There are more associated affordances with room components in VR compared to NVR media. This result is logically acceptable since VR technology brings immersive spatial information to the user and the ability to explore the space. In addition, the summarized finding in the Table 7-37 and 7-38 confirms the last hypothesis regarding the relationship between media compatibility for review process and the perceived affordances.

7.5.4. Media effectivity comparison

This section compares media effectivity between NVR and VR media for the design review process. As described in section 7.4.2.4, the result shows that in the LC project, four affordance categories within the room group have more pairs with a significant p-value than those within the building component group. In the APT projects, all affordance categories within the room group have more pairs with significant *p*-value compared to the building component group. Having more significant pairs for rooms in the apartment project confirmed the finding that we had previously in Chapter 6 and also the first and third hypothesis stated earlier regarding the affection made by the media to the review results. Because in terms of functionality, apartment building typology has more defined and standardized physical properties than the lifecycle center typology, which has more various combinations of spatial programs. When an object has more defined physical properties, the affordance within the object can be more readily perceived by users who afford to perceive it.

7.6. Conclusion

This Chapter continues the experimental study of VRDR system utilization for the affordance-based design review process by implementing it in an ongoing architectural design studio course. The study consists of two parts. In Part 1, we had VRDR system implementation with a student and supervisor in a third-year architectural design studio course. Two design projects were tasked: a lifestyle center facility (LC) and an apartment (APT). They used VRDR to review the design outputs and then used the feedback to improve the design to achieve studio objectives and Student Performance Criteria (SPC). Then, they performed another design review process to check the improvement. In Part 2, we did a confirmation study with third-year architectural design bachelor students using non-VR (NVR) and VR media to confirm the design review result from Part 1 study and Chapter 6.

This Chapter focuses on discovering design improvement through the proposed PDS process, the relationship between affordances and design components, the relationship between affordances and medium, and the comparison of media effectivity. The first analysis result shows that the VRDR system is considered more effective in improving spatial elements but less effective for improving building systems in an architectural design. This result also signifies that the room components in the design projects achieved the objectives and SPC, but not yet for the building components. The second analysis determines which design components are more improved and less enhanced depending on the affordance presences and indicates how the student and supervisor perceive "different kinds of animal" on perceiving the affordances. The result is in-line with Gibson's Theory of Affordance The third analysis result reveals affordances that are more easily perceived using the NVR or VR media using direct perception. The fourth analysis confirms the importance of physical properties helping an object define its affordances and its ability to be perceived by users.

Furthermore, several findings tied to the effect of using the affordance-based design review method were found in this study. When a building typology can have better defined physical characteristics, it is much easier for users to perceive their affordances. In the PDS process, we suspect that the building typology might affect how a user perceives positive and negative affordances. Later in the paired *t*-test results in media effectivity comparison, the result shows an even more suspicious impact because of the building typology. Lastly, in comparing affordance and media, the results show that it is possible to pick a specific media for perceiving specific affordances to target.

This Chapter supports establishing the affordance-based design review method framework, which we explain in more detail in the next Chapter. The limitations of this study suggest the improvements for the future study and continuation of the affordance topic and the VR technology utilization in architectural design.

CHAPTER 8
OVERALL DISCUSSION

8.1. Practical Workflow of Affordance-based Design Review Method using Virtual Reality

Based on the lesson learned from the simulations performed in this study, we can conclude the practical workflow on how an architectural designer performs the affordance-based design review method using VR. This workflow, as shown in Figure 8-1, explains eight steps that must be taken by an architectural designer from start to finish. In addition, there is a conditional step (Step 8B) that may be per These steps can be categorized into three stages, as follows:

1. <u>Affordance Identification (Step 1-4)</u>

   In this stage, first of most, a designer must define the goals that he wants to achieve with his design. The goals can be decided based on his personal intention or guidance given by the project owner (Step 1). Once the goals are set, he defines the desired affordances that must be present and undesired affordances that must be avoided to be present in the design. The designer can perform a content analysis process inside a brainstorming session with his team (if there's any) or colleagues to have unbiased affordances. (Step 2). The designer also defines which design components that should be reviewed later (Step 3). This step can be taken after the spatial programme of the architectural design has been decided. Once those components are defined, designer can map them into the ASM (Step 4).

2. <u>VR Model Preparation (Step 5-6)</u>

   In this stage, the designer prepare the architectural design model as VR model in VRDR system. The preferred model is BIM model since it contains parameters that are easily extracted for the review process (Step 5). The designer can refer the data extraction process described in Section 5.2.3. After the VR model is prepared into VRDR system, the application can be deployed from Unity and installed in the VR HMD device (Step 6). Currently, VRDR is only compatible with Oculus Quest and Quest 2 HMD.

3. Design Review Process (Step 7-8B)

   In this last stage, the designer starts the design review process by exploring his architectural design as virtual environment inside VRDR (Step 7). He can check the design components throughly, both spatial elements and building components, one by one and sense whether the defined affordances can be perceived or not. Then, put a tick on the each cell/box in the ASM based on its respective design components and affordances. Once all design components are reviewed, the designer can calculate the amount of desired and undesired affordances that perceived. The objective of this review method is to have more desired affordance and less undesired affordance being perceived from the design. If there are several design options, additional PDS Process can be performed to check the improvement tendency of the design. The calculation method is referred to Section 3.4.4.

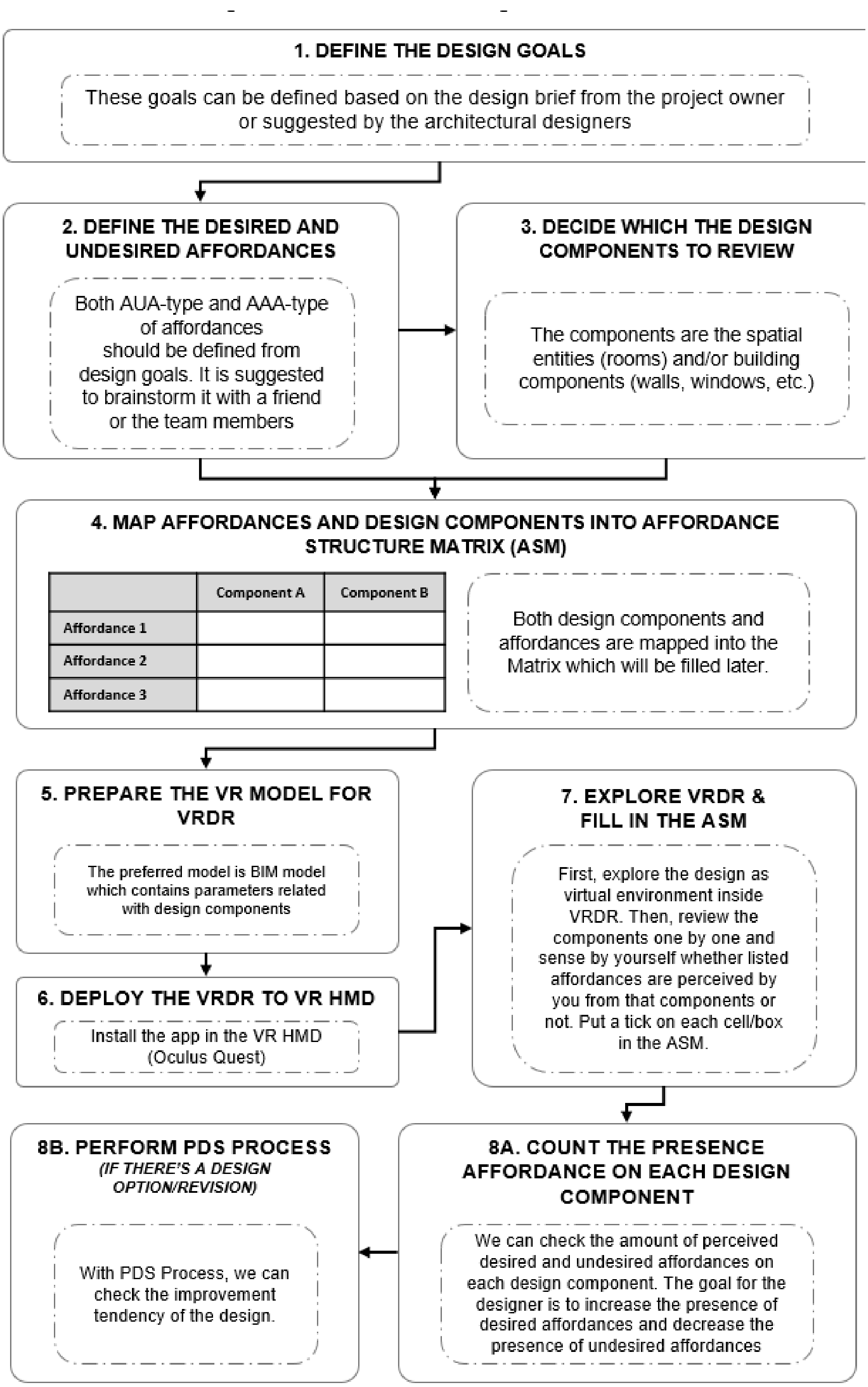


Figure 8-1. Practical Workflow of Affordance-based Design Review Method using Virtual Reality

8.2. Advancement of VRDR and Its Comparison with Existing Systems

This section discusses the the technical advancement of VRDR compared to the existing VR visualization systems available. We compare VRDR with three different systems: Unity Reflect (Review/Desktop), Twinmotion, and Enscape. The comprehensive comparison of all systems are presented in Table 8-1.

Table 8-1. Feature Comparison between VRDR and Similar Existing Systems

Comparison Factors	VRDR	Unity Reflect Review/Desktop(1)	Twinmotion(2)	Enscape(3)
VR Device Compatibility	Native mobile-based HMD (Oculus Quest & Quest 2)	Desktop-powered VR HMD (Oculus Rift and HTC Vive)	Desktop-powered VR HMD (Oculus Rift, Quest, HTC Vive, Windows MR)	Desktop-powered VR HMD (Oculus Rift, HTC Vive, Windows MR)
Advancement (VRDR vs. the rest)	• Equipped with affordance-based design approach • Untethered • Access to spatial entity/room information from cloud database	• Guiding on visual changes only • Tethered to PC • Access to BIM objects information • Cannot store user position • Cannot store/show additional	• Guiding on visual changes only • Tethered to PC • No BIM object parameters is shown to inform • Cannot store user position	• Guiding on visual changes only • Tethered to PC • No BIM object parameters is shown to inform • Cannot store user position

Comparison Factors	VRDR	Unity Reflect Review/Desktop(1)	Twinmotion(2)	Enscape(3)
	• Load/Save user position • Questionnaire viewer* • Text-based feedback input in VR mode	information (such as questionnaires)** • Text-based feedback input only in Desktop Mode	• Cannot store/show additional information (such as questionnaires) • Cannot provide text-based feedback	• Cannot store/show additional information (such as questionnaires)** • Cannot provide text-based feedback
Features to catch up by VRDR	• Single-player mode only • Material editor is not available. • Scene screen capture is not available • Object isolation and measuring tool are not available.	• Multiple users within a virtual environment • Object filtering and view isolation • Measuring tool	• Drag-and-drop material editor (for presenter only)	• Scene screen capture

Comparison Factors	VRDR	Unity Reflect Review/Desktop[(1)]	Twinmotion[(2)]	Enscape[(3)]
Other similar features (in VR mode)	• Dashboard-like UI • Point-and-click or free roam locomotion • Fullscreen mode • Sun study/position • Mini map for user orientation • Adjustable navigation settings	• Controller-pinned UI • Point-and-click locomotion • Fullscreen mode • Sun study/position • Allow for further development using Unity Pro IDE (Desktop only)	• Controller-pinned UI • Point-and-click locomotion • Fullscreen mode • Sun and weather study • Various graphical quality settings • Interior and street camera teleportation • Adjustable navigation settings	• Controller-pinned UI • Point-and-click or free roam locomotion • Windowed mode • Mini map for user orientation • Pre-setup camera teleportation
Rendering Engine	Unity	Unity	Unreal Engine	OpenGL & Vulkan-powered
Connection with Design Authoring Software	Manually exported from Revit or ArchiCAD to Unity and Google Sheets	Model changes are directly shown through Unity-provided plugin	Model changes are shown through Datasmith plugin (single-click synchronize process is needed)	Model changes are directly shown through Enscape-provided plugin
References:				

Comparison Factors	VRDR	Unity Reflect Review/Desktop[1]	Twinmotion[2]	Enscape[3]
(1) https://www.youtube.com/watch?v=7yAB0OK_spE (2) https://www.youtube.com/watch?v=NvCjWUgqCXk (3) https://www.youtube.com/watch?v=SdcIAT9rV9c **Further customization is needed using Unity Pro IDE				

8.3. Suggestion on Affordance Identification by Professional Architects

The research carried out in this study used educational settings in which the studio coordinator had conditioned many factors. The coordinator does this action to help students develop designs under learning outcomes that they must achieve. While in the professional world, internal (i.e., the architect's intentions or related to the internal situation) and external causes (stakeholders' influence, city regulations, and others) could influence the design direction, whether expected or unexpected.

During the affordances identification process, a professional architect can specify the affordances according to the designer's design style or personal intention. This preference applies to both desired and undesired affordances. The desired and undesired affordance terms are more suitable than positive and negative affordances. Occasionally, architects develop an architectural design that triggers the presence of negative affordances and avoids positive affordances by purpose. They did it to achieve specific design goals.

Technically, the VRDR features required by professional architects may differ from what is already available. So, there will be many adjustments and additional features according to the needs of each architect. In addition, the adaptability of each architect to the new tools and methods is different. Thus, an empathetic adjustment is needed to the user interface and experience of VRDR and the workflow of the offered design review method.

8.4. Comments on the Artifact-Artifact Affordances (AAA) Concept

The affordance theory, which Gibson first proposed in 1979, is the foundation of ecological psychology which prioritizes perception and motor control. This approach sees the two elements as a single unit that can be achieved under the right conditions without any cognitive effort performed by users. So, perception and motor control can be done directly. One of the advantages of using the theory of affordance by architects is that it helps them giving direction to the conditions for what information is available to users. So that, they can interact with artifacts and the built environment directly. Thus, users are free from excessive use of cognition and can carry out safe and effective interactions.

When expressing the concept of affordance-based design, Maier and Fadel put their concept on the Norman’s affordance theory, which is based on cognitive abilities and rejects the conception of direct perception developed in the ecological psychology approach. In his latest paper, Fadel has acknowledged his position (Masoudi, Fadel, et al., 2019). Fadel suggested that designers who use the affordance-based design approach to reposition their affordances according to Gibson's approach to ecological psychology.

When Maier and Fadel proposed the concepts of artifact-user affordances (AUA) and artifact-affordances (AAA) and the difference between the two, it was unclear how an artifact could interact with other artifacts. Norman's concept of affordance, which he embraced, requires the mental representation needed so that affordance can be perceived. Inanimate objects such as buildings or architectural designs do not have the cognitive abilities required by Norman’s affordance.

The difference between AUA and AAA is quite debated when viewed using Norman's affordance. When returned to Gibson's approach to affordance, the difference between movable and immovable objects becomes fluid. When an artifact is designed, it can be considered not as a separate object but as a unified system. Thus, affordance can be described by those involved in the same system, which explains the difference in affordance acceptance between non-VR and VR media. Affordance can be established as a relationship between artifacts and users (AUA) or as a relationship between artifacts and artifacts (AAA) perceived by users involved in the same system. This relationship can be established if it reaches the right conditions. With the affordance-based design approach, architects have a role in designing the right conditions for these affordances to be perceived directly by users.

CHAPTER 9
OVERALL CONCLUSION

9.1. Summary and Main Findings

This research aimed to develop an affordance-based design review method using virtual reality, specifically in educational settings. This method covered how to determine the affordances aimed to be perceived by users from an architectural design; the development of Virtual Reality Design Reviewer (VRDR) as the design review tool; recording the perceived affordances data using Affordance Structural Matrix (ASM); and data analysis methods that determined whether the design has achieved the objectives or criteria ruled by the design brief. In addition, this research also uncovered the tendency of how a party – student or supervisor – reviewed a design using an affordance-based approach. Both results became valuable inputs for a designer performing the decision-making process on his design. The case study was the second-semester of the third-year architectural design studio course in the Bachelor of Architecture Program of Institut Teknologi Bandung, Indonesia, mainly because the design problem taught in the course was fit with the research aim. Aside from introduction and conclusion, there were six body sections in this research, including literature review (architectural design review process using virtual reality and affordance-based design approach), virtual reality tool development including its early prototype, design review process simulation by comparing non-VR and VR media, the method implementation in an ongoing design studio course, and the final simulation as confirmation study.

Chapter 2 began the literature review process of this research. In the first part, the chapter explores the history of virtual reality technology and its trend in architectural design studies. In the early of its inception, VR technology had its ups and down moments since it did not meet most of the users' expectations. Not until 2012 immersive VR technology was re-emerged and afforded by the end-users. In architecture, virtual reality study trends include how VR technology is used in the design process and communicating with stakeholders in a design project. In addition, exploration of the use of VR technology also targets the cognitive side of searching for alternative designs, such as seeing user responses according to their spatial perception, defining spatial arrangements, and triggering users' emotions when faced with various design options. The capability of this VR technology certainly sparked the idea of using it in education. The search for adaptation of VR technology is carried out from technical implementation to the discourse on VR implementation in the education curriculum. Researchers also explored how VR technology can be utilized in the design studio course so that students can understand the relationship between spaces and places. At the end of the Chapter, we reviewed selecting a suitable VR system according to research needs. Each VR system has its advantages and disadvantages. We also must pay attention to how the chosen VR system can support the scenario and design of the virtual environment created by maximizing the capacity of the selected VR system and achieving optimum user experience and performance.

Then in the second part, the Chapter continued exploring the affordance-based design approach based on the Theory of Affordance cited by Gibson and its development within the ecological psychology studies – including the concept of affordance initiated by Norman, which accommodates the cognitive efforts instead of direct perceptions. The discussion continued reviewing the affordance concept adoption in the architectural design process and how architects explored the desired and undesired affordances to define how users should interact with their architectural designs. Architects must define the affordances thoroughly from spatial elements and building components of the design.

Chapter 3 reviewed the affordance-based design (ABD) framework and explored one of the propositions of affordances utilization in architecture as the design review method. With ABD, architects should define the affordances of their designs into two main groups: artifact-user affordances (AUA) and artifact-artifact affordances (AAA). The affordances, later, must be mapped into positive and negative affordances as an Affordance Structure Matrix to conduct affordance-based design review method. Then, we explained the data analysis processes performed in this research. We also proposed a novel data analysis process in the affordance-based design review method called PDS Process. PDS itself stood for Present, Disappear and Stagnant. This process measured the amount of present and disappeared perceived affordances in the latest iteration of a design based on the theory of affordance. Then, it was calculated into four indexes. Positive Index (PI) showed the tendency of a design iteration to be positively enhanced. Negative Index (NI) showed the tendency of a design iteration to be negatively revised. Improv(+) showed the design iteration improvement towards the positive direction. Lastly, Imprv(–) showed the design iteration improvement towards the negative direction. PI and NI helped designers if the design iteration had finally reached its objective or not based on the perceived affordances. At the same time, Imprv(+) and Imprv(–) signaled the designer if the tool or media used for the design review process was helpful or not.

In Chapter 4, the research conducted its pilot study as a proof of concept. It explored the user interaction inside a virtual environment (VE) with a Building Information Modeling (BIM) model as a digital entity of a building connected with its physical entity simulated with a cloud-based database. This particular concept was known as Digital Twin, as it combined digital and physical entities as unified entities. On top of that, we built a Connected Digital Twin (CDT) prototype. It was consisted of a BIM model inside a VE and connected to a real-time database that simulates IoT devices' presence, as illustrated in Figure 4-1. Inside it, we built a user interaction prototype developed using Unity game engine with C# programming scripts GameObjects for essential interactions. Then, it was deployed to Oculus Quest VR head-mounted device (HMD). With the prototype, the experiment scenario was prepared and performed. The research found that the prototype could present a BIM model in a VE with its building components' parameters linked to the geometry. So, users can inspect the building situated in an immersive situation without visiting the building. Even though it was primarily situated in the post-occupancy phase of a building, the basic interaction prototype could be utilized in the earlier phase of the architectural design process – in this case, for the design review process.

Chapter 5 brought the basic interaction prototype and extended it as the foundation of Virtual Reality Design Reviewer (VRDR) development. VRDR was designed to help students understand and review their designs in the nuance of the architectural design studio course. Simulation research is used as the research method in this

Chapter by reconstructing designs into a real-world setting to drive individual perceptions of any users inside it. The research also worked with previous design studio outputs retrieved from the faculty archive and authored as BIM models. The aim was to offer VRDR as a VR system for students to review design works using the affordance-based design approach. We developed VRDR in three system layers: BIM models, design review as the decision-making process, and user interface and experience layers. Those layers were transformed into a system framework that consists of the Common Data Environment (CDE) of the BIM model, the VR model itself, and a standalone VR HMD connected to the Internet. Figure 5-3 describes how these framework parts worked as a system within VRDR. Once developed using the Unity game engine, we deployed VRDR to Oculus Quest VR HMD and were ready to use.

After being developed in Chapter 5, Chapter 6 exercised a simulation by utilizing VRDR in performing an affordance-based design review method. For this simulation, this research used design outputs from the third-year architectural design studio course as the case study. Affordances measured for the simulation were identified from the design studio brief. Then, they were mapped into Affordance Structure Matrix (ASM) with the design component groups that would be reviewed: spatial components group represented with rooms, and building components group. For comparison, this research also performed the same design review process using non-VR (NVR) media such as printed CAD-based drawing and BIM authoring software. The simulation involved the third-year students of the architectural design bachelor program. They reviewed the provided design models using both NVR (CAD-based drawing and BIM model) and VR (VRDR) medium. They were done the simulation by checking whether the listed affordances were perceived or not and recorded the result in the ASM form.

Based on the simulation results, the research performed three sets of data analysis:

1) The relationship between affordances and the reviewed design components showed that the media selection affects the correlative association relationship between affordances and reviewed design components. The relationship analysis results in the NVR and VR media could help students

determine which design components have achieved the objectives and which components must be improved.

2) The relationship between affordances and the media used for the design review was observed. It was found that affordances could be perceived easier using direct perception if the media used for the design review process provided sufficient information. Once the amount of information was adequate, users could easily perceive the affordance.

3) The comparison of media effectivity for the design review process was performed. The result demonstrated that perceived affordance of the building components, especially positive affordance, are significantly greater using the VR media than the affordances of rooms. In line with the ecological psychology approach, components with apparent properties could help users perceive the affordances.

Chapter 7 extended the exercise of VRDR utilization by performing two parts of the study. Part 1 of the study was the VRDR implementation in an ongoing design studio course. In par with the previous Chapter, this research implemented VRDR in a third-year architecture design studio course to a student and supervisor. Both used VRDR to review the student's design work and use the review result as feedback for design revision. Once the design work was revised, they performed the same design review process using VRDR to determine whether the design was improved from the affordance-based design approach. Two design projects were reviewed in this Chapter: lifestyle center (LC) and apartment (APT). The affordances measured for the design review process were determined from the studio objectives and student performance criteria (SPC) as required in the design briefs. Since the objectives and SPC were intertwined, the defined affordances were categorized into five objectives and five SPCs. Later, the affordances were composed into the ASM and paired with the design component groups: rooms and building components. Once it was ready, the VRDR was deployed to the student and supervisor for the design review process. Figure 7-2 shows that the workflow would be repeated for the revised design.

From the Part 1 implementation, this research performed two sets of data analysis processes: the PDS process and affordances presence comparison between design components. First, the PDS process result showed that both student and supervisor argued that LC and APT projects' revised design was most improved after being reviewed using VRDR. In the LC project, the Positive Index (PI) of room components were measured higher by student and supervisor than the Negative Index (NI). The supervisor measured higher NI than PI for the building component groups, while the student argued the opposite. Nevertheless, both of them reviewed that the revised design of the LC project had a higher Improvement Index (Imprv+), showing that VRDR could help the student improve the LC project design. In the APT project, both student and supervisor reviewed that the revised design has achieved the objective and SPC except for the building components, which had higher NI in the objective pair group. The result was also in-line with the Improvement Index result where in the same pair group, Imprv(–) value was higher. Second, affordances presence comparison between design components demonstrated more direct result. Statistically, students perceived more positive affordances and less negative affordances on both revised designs of LC and APT projects. While in the same time, the supervisor reviewed that more positive and negative affordances were perceived in the LC projects less positive and negative affordances in the APT projects. These results should signal to the student that the revised design has solved several design problems and raised other design problems at the same time.

Second, Part 2 of the study was a confirmation study to affirm the result of Part 1. This research performed similar sets of simulation and data analysis processes with Chapter 6 with the addition of the PDS Process and improved workflow as presented in Figure 7-8. The simulation was participated by third-year architectural design students. The analysis focused on the design improvement through the proposed PDS process, the relationship between affordances and design components, the relationship between affordances and medium, and the comparison of media effectivity. The PDS process showed that the VRDR system was considered more effective in improving spatial elements than improving building components in a building design. It also showed that the spatial components achieved the objectives and SPC, but not fully yet for the building components. The relationship between affordances and design components determined which design components were more improved and less enhanced based on the affordances presence.

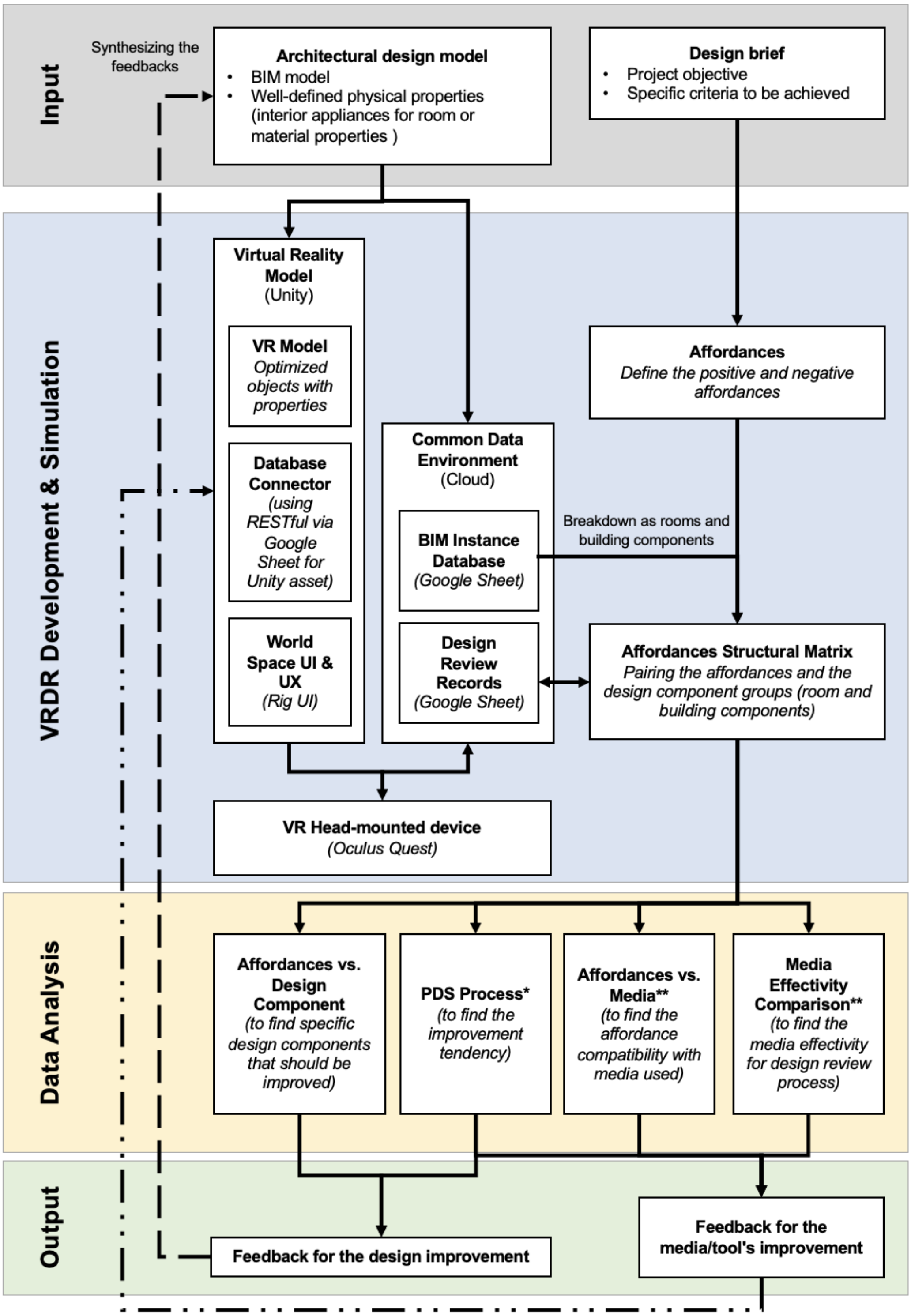
Interestingly, this analysis also revealed the differences between a student and supervisor on how they perceived the affordances. The relationship between affordances and medium revealed the list of affordances that could be perceived easily using either NVR or VR medium using direct perception. Lastly, the comparison of media effectivity confirmed the obligation of physical properties for perceiving affordances by users.

9.2. Framework of Affordance-based Design Review Method using Virtual Reality

To summarize the results of the research carried out, we developed an affordance-based design review method framework using virtual reality, as seen in Figure 8-1. This framework describes how the affordance-based design method is implemented in stages, from input preparation to handling the resulting output. This framework is generally divided into four major parts: input, VRDR development and simulation, data analysis process, and output.

In the Input section, we have to prepare an architectural design model and related design brief. We suggest that the design model be developed in the form of a BIM model to facilitate extracting the 3D geometry along with the parameters of the building components attached to it. In addition, the design model must have well-defined physical properties, including the presence of interior furnishings that can define the room and the use of appropriate materials for building components. A design brief related to the architectural design model needs to be prepared. Information related to project objectives and specific criteria that must be achieved must also be included in the design brief. Thus, affordance can be identified quickly based on project objectives and specific criteria. Then, both inputs are brought to the VRDR Development & Simulation section. In general, the framework in this section is the same as the VRDR system framework in Figure 5-3, with the addition of the flow of defining affordances and mapping affordances to the Affordance Structural Matrix (ASM).

The process continues to the Data Analysis section. Based on the results of data analysis and the findings obtained in Chapters 6 and 7, it was found that the four sets of data analysis processes carried out could produce different feedback results. The data analysis process of the relationship between affordances and design components was finding specific design components that must be improved. The resulting findings can be helpful as feedback for design improvement. Meanwhile, the findings from the analysis of the relationship between affordances and media and media effectivity comparison resulted in feedback for improving VRDR as a media or design review tool. Specifically for the PDS Process, the findings produced can provide feedback, both for improving the quality of architectural design (based on the Positive and Negative Index results) and also for improving VRDR as a design review tool (based on Imprv(+) and Imprv(–) values). Furthermore, the feedback obtained must be further synthesized by each architectural designer to improve the quality of the architectural design in order to achieve the project objectives and specific criteria agreed upon in the design brief.



*can be performed only if a design iteration/revised design is available
**can be performed if review process is performed using two or more media/tools

Figure 9-1. The framework of affordance-based design review method using virtual reality

9.3. Advantages and Disadvantages of VRDR

The Virtual Reality Design Reviewer (VRDR) was developed as part of the affordance-based design review method. Starting from the Connected Digital Twin prototype, VRDR development focuses on how users can be aware of the design components they are reviewing and easily navigate in the virtual environment at the same time. Some of the advantages of the VRDR system are:

a. There is a data relationship between the model and the database on the Internet. It opens the possibility to expand other data requirements to be visualized into VRDR in the future

b. User can save the last position when exploiting VE. So that when the user feels exhausted using the HMD, the user can save the last location point in the VE and then load it back to the last saved point

c. Optimized for mobile-based VR headset. VRDR was explicitly developed for the Oculus Quest running on an Android-based operating system and mobile processor from the start. So, we do not need a sophisticated, high-spec VR HMD device to run it, and

d. The interface is straightforward to access. Rig UI is installed in front of the avatar so that the features needed by the user can be accessed quickly. In addition, users can also hide the Rig UI by clicking the toggle on the lower left side.

There are also disadvantages to the VRDR system, such as:

a. Single user experience. Currently, VRDR is still being developed only to be used by single users. The multiplayer development in VRDR allows for more lively interactions and direct feedback quickly

b. It still takes time to import the building models into the system. Importing the model into VRDR takes a long process starting from model optimization, exporting model parameters to the cloud database, and putting them back together in the virtual environment.

c. The typing input system is still limited to the hand controller and keyboard. So, the user must click the keyboard letter keys one by one using the hand controller. It can be an opportunity in the future for developing typing-free feedback input, such as voice memo or voice recognition text.

9.4. Significances and Key Lessons of the Research

9.4.1. Contribution to Architectural Education Practice

This research opens new options for students, especially in reviewing the architectural designs they made in their early design stages. Thus, students can measure the quality of their designs in a quantitative method based on the affordances they perceive to be present in the design components in question, both rooms and other building components. Then, the assessment findings between the student and the supervisor can show the transparency of the assessment between the two. Supervisors can understand how their students understand design quality with a quantitative approach to affordances. Vice versa, students can find out the supervisor's point of view on the design of the building.

This affordance-based design review method also opens the possibility to be used as a method for demonstrating the quality of architectural design. By using the VRDR system and the affordance-based design review method, the supervisor demonstrates the quality of the design components targeted for their affordance to emerge. At the same time, students can also feel and understand it immersively in the virtual environment. ASM becomes a tool to mark the presence of affordance in building design. Of course, the ability of each student to perceive affordance will be different. However, supervisors can set benchmarks by matching the design examples visualized in the virtual environment with the presence of affordances marked on the ASM by the supervisor.

9.4.2. Addressing to Environmental Psychology studies in the scope of built environment

This research adopts the concept of affordance, which has developed for more than 40 years and became the basis of the study of Environmental Psychology. During its development, many hypotheses were developed from the Theory of Affordance, which Gibson first coined until it was adopted by several researchers in scientific studies of the built environment. This research framework also contributes to how the concept of affordance is used to review architectural designs in educational settings with the intermediary of virtual reality technology. Scientifically, this research has abled to:

a. develop studies related to affordance in the built environment with the intermediary of virtual reality technology
b. apply the concepts of direct perception and affordance as an architectural design review method approach, and
c. make a qualitative to quantitative architectural design review based on affordances.

9.4.3. Contribution to Virtual Reality studies in the field of architecture

This research utilizes immersive virtual reality technology as a medium for the affordance-based review design process. In particular, this research has:

a. developed virtual reality system that connects a virtual environment with a cloud-based database that can add information content needed for the design review process
b. explored the advantages and disadvantages of using virtual reality technology in the affordance-based design review process, which is helpful for the development of advanced virtual reality systems in the future
c. performed the implementation of virtual reality technology in an ongoing architectural design course studio

9.4.4. Contribution to the Architectural Design and Engineering in the future

Calling back to the introduction section, this study criticizes existing research of VR adaptation for design review process. During the review process, participants tended to refer to qualitative expressions such as beautiful, less sturdy, etc. Even some studies using a quantitative approach also utilized ratings on choosing between positive or negative expressions. This study proposes an affordance-based design as an approach for architectural design review process using VR. With three simulations performed, we can develop a framework of affordance-based design review method using VR and a practical workflow on how to perform the review method. With a lack of its adaptation in architectural design process, this study contributes to providing practical examples of how an affordance-based design approach can be used to review architectural designs. The examples given start with the scope of design studio education which can then be developed into the scope of professional architects. This study can also provide a unique perspective in reviewing architectural design, not just a technical approach to buildings and the environment. But also, presenting architectural designs that are responsive to the affordances between building designs as artifacts and end users.

With affordance-based design review method using VR, architects and architecture designers can review their designs by quantifiying the perceived affordances based on what they and their users experienced in the VR environment. People perceives affordances when exploring the the 1:1 scale of architectural design inside immersive VR environment. In the future, it is possible to perform a cross-approach review process between affordance-based approach and engineering analysis, such as lighting or thermal comfort analysis. But, additional tools might be needed to give adequate sensoric feedback to users.

9.5. Limitations of Study

There are several limitations in this study. First, this research was still limited to the scope of education only. The use of the affordance-based design review method in the scope of professional architects requires further adjustments and research. It is due to the need or achievement of real project targets that are more realistic. Of course, they have different benchmarks from the design studio assignments in the universities. When we expand the method trial to the scope of professional architects in the future, it should start with a small project such as housing and settlements. By using the affordance-based design review method, architects will get valuable input from the owner as the building end-user starting from the affordance identification process.

The presence of the COVID-19 pandemic limited communication and interaction between researchers and the team of data collectors in Indonesia. Researchers were trying hard to monitor the simulations and data collection process remotely. We did it to ensure that all steps were taken according to the workflow that had been previously planned. The pandemic situation also decreased the trust from potential simulation participants for joining the simulation trial. They were afraid of catching the COVID-19 during the simulation process. We followed the health protocol recommended by health authorities in Indonesia and Japan to ensure that there is not community transmission during the simulation. During the simulation, no one from the data collectors and participants was infected with the disease. In the future, we can use a similar remote monitoring procedure if we want to perform the design review process using VR remotely. Multi-player capability would be a terrific addition to the VRDR system.

This research was also still limited in the scope of Indonesian culture. Architectural design is a product that must suit the local site and user context. In this study, the case studies were lifestyle center and apartment which are heavily relied on local context and culture. These factors dramatically influence how one understands a building design. Thus, the statistical findings were local, but the pattern might be like that of participants from other regions. Nevertheless, in the future, the implemented method should be tested in other regions to find out the similarities and differences.

Next, there is still an integration gap between the VRDR system and the design review method itself. There is a discontinuity in the workflow between virtual environment exploration using VRDR and design review process. To review the design, at one point, users remove the VR HMD device and fill in the ASM form. Then, they use the device to continue the exploration and so on. Even though the questionnaire is possible to be shown inside the virtual environment, further adjustments in UI and UX are needed in the future to make users able to respond and give feedback easily inside the virtual environment.

Lastly, compared to the existing system, technically VRDR is still a prototype. For the future of VRDR, the goal is to have tighter integration between VRDR and the affordance-based design review method itself. Additional features should be carefully selected without making VRDR bloatware.

9.6. Suggestion For Future Studies and Implementation

The adaptation of the theory of affordance in the realm of the built environment, especially architecture, is still an area that can be explored further. The availability of virtual reality technology that is increasingly sophisticated and easy to reach can help further develop this research. The research that has been done was still focused on students as the subject of implementing the affordance-based design review process. The influence of lecturers as supervisors for students in this research was still light and only limited to verifying the results of design reviews conducted by students. It is the first opportunity to develop this research by conducting counterbalancing research in which supervisors are the main participants. Thus, we can get a more holistic picture regarding the performance of the VRDR application and the effectivity of the affordance-based design review method. The second opportunity is to conduct a study on applying the affordance-based design review method within the scope of a professional architect. So, we can also find out how effective the affordance-based design review method with VR is in helping professional architects produce targeted designs.

From a technical point of view, the development of a VRDR system can be done by adding various features such as multiplayer, instant data analysis process, to exploring the use of ML to estimate ASM results for users. In addition, the building model optimization process needs to be made more concise and streamlined to speed up the process of converting the building model into a VR model and improve the virtual environment performance in the HMD.

Based on those suggestions and limitations that should be overcome, we propose the future development of VRDR and the design review method as follows,

Table 9-1. Proposed Plan on Future Development of VRDR

	Affordane-based Design Review Method	**VRDR System**
Year 1-2	• Trial simulation in the scope of professional architects (small project scale such as housing) • Further simulation in the educational settings with more students involved (used as part of design studio)	• Tightening integration between the ASM and VRDR within the virtual environment • Initial development of multi-player mode • Improvement on the onboarding process for easier introduction to VRDR
Year 3-5	• Wider adoption in the educational settings (self and peer-evaluation during the design process) • Expanding the ABD approach beyond the design review process, begins from the project initiation. • Further trial simulation with professional architects (large project scale)	• Full integration between ASM and VRDR • MVP of multi-player mode • Initial development of cross-approach review process and

The proposed path for future development might changed depends on the availability of resources and scaling up capabilities. In the existing educational environment, for example, we can expect that there's inadequate understanding of the VR systems or even the affordances concept itself. A proper introduction and onboarding process should be prepared before the implementation begins. For starters, a trial in a small group of students with various levels of understanding on VR with a common level of interest for learning is sufficient. In the future, the system can be developed to be more agile to accommodate more users with diverse needs.

REFERENCES

Allam, Z., Siew, G., & Fokoua, F. (2020). *How COVID-19 Will Shape Architectural Education*. ArchDaily. https://www.archdaily.com/939423/how-covid-19-will-shape-architectural-education

Al-Qawasmi, J. (2006). Digital media in architectural design education: reflections on the e-studio pedagogy. *Art, Design & Communication in Higher Education*, *4*(3), 205–222. https://doi.org/10.1386/adch.4.3.205/1

Angulo, A. (2013). Immersive Simulation of Architectural Spatial Experiences. *11th EAEA Envisioning Architecture: Design, Evaluation, Communication Conference*. http://cumincad.scix.net/cgi-bin/works/Show?_id=sigradi2013_212&sort=DEFAULT&search=virtual reality&hits=2442

Angulo, A. (2015). Rediscovering Virtual Reality in the Education of Architectural Design: The immersive simulation of spatial experiences. *Ambiances*, *1*. https://doi.org/10.4000/ambiances.594

Aydin, S., & Aktaş, B. (2020). Developing an Integrated VR Infrastructure in Architectural Design Education. *Frontiers in Robotics and AI*, *7*, 495468. https://doi.org/10.3389/frobt.2020.495468

Bai, Rui-Yuan and Liu, Y.-T. (1998). Towards a Computerized Procedure for Visual Impact Analysis and Assessment - The Hsinchu Example. *CAADRIA '98 : Proceedings of The Third Conference on Computer Aided Architectural Design Research in Asia.*, 67–76.

Banaei, M., Ahmadi, A., Gramann, K., & Hatami, J. (2020). Emotional evaluation of architectural interior forms based on personality differences using virtual reality. *Frontiers of Architectural Research*, *9*(1), 138–147. https://doi.org/10.1016/j.foar.2019.07.005

Bartosh, A., & Anzalone, P. (2019). Experimental Applications of Virtual Reality in Design Education. *ACADIA 2019 - Ubiquity and Autonomy*, 458–467. http://papers.cumincad.org/cgi-bin/works/paper/acadia19_458

Bashabsheh, A. K., Alzoubi, H. H., & Ali, M. Z. (2019). The application of virtual reality technology in architectural pedagogy for building constructions. *Alexandria Engineering Journal*, *58*(2), 713–723. https://doi.org/10.1016/j.aej.2019.06.002

Bekele, M. K., & Champion, E. (2019). Redefining Mixed Reality: User-Reality-Virtuality and Virtual Heritage Perspectives. *Intelligent & Informed, Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2019, Volume 2*, 675–684. http://papers.cumincad.org/cgi-bin/works/paper/caadria2019_196

Biocca, F., & Delaney, B. (1995). Immersive Virtual Reality Technology. In F. Biocca & M. R. Levy (Eds.), *Communication in the Age of Virtual Reality* (pp. 57–124). Lawrence Erlbaum Associates, Inc.

Bitaraf, S., Kameli, M., & Sedgpoor, B. S. (2021). Teaching the design of residential architecture based on affordances. *Technology of Education Journal*. https://doi.org/http://dx.doi.org/10.22061/tej.2021.6613.2421

Boletsis, C., & Cedergren, J. E. (2019). VR Locomotion in the New Era of Virtual Reality: An Empirical Comparison of Prevalent Techniques. *Advances in Human-Computer Interaction, 2019*. https://doi.org/10.1155/2019/7420781

Borghi, A. M., & Riggio, L. (2015). Stable and variable affordances are both automatic and flexible. *Frontiers in Human Neuroscience*, *9*(JUNE), 1–16. https://doi.org/10.3389/fnhum.2015.00351

Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: How much immersion is enough? *Computer*, *40*(7), 36–43. https://doi.org/10.1109/MC.2007.257

Brown, D. C., & Blessing, L. (2005). The relationship between function and affordance. *Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference - DETC2005*, *5*, 155–160. https://doi.org/10.1115/detc2005-85017

Brown, D. C., Maier, J. R. A., Cormier, P., & Lewis, K. (2015). An affordance-based approach for generating user-specific design specifications. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM*, *29*(3), 281–295. https://doi.org/10.1017/S089006041500027X

Camacho, D., Dobbs, T., Fabbri, A., Gardner, N., Haeusler, M. H., & Zavoleas, Y. (2019). Hands On Design - Integrating haptic interaction and feedback in virtual environments for enhanced immersive experiences in design practice. *M. Haeusler, M. A. Schnabel, T. Fukuda (Eds.), Intelligent & Informed - Proceedings of the 24th CAADRIA Conference - Volume 1, Victoria University of Wellington, Wellington, New Zealand, 15-18 April 2019, Pp. 563-572*.

Carreiro, M. B. T., & Pinto, P. D. L. (2013). The evolution of representation in architecture. *Future Tradition - 1st ECAADe Regional International Workshop*, 27–38. https://doi.org/10.1162/NECO_a_00475

Castelo-Branco, R., Leitão, A., & Santos, G. (2019). Immersive Algorithmic Design. *Architecture in the Age of the 4th Industrial Revolution - Proceedings of the 37th ECAADe and 23rd SIGraDi Conference - Volume 2*, *2*(2003), 455–464.

Chamilothori, K., Chinazzo, G., Rodrigues, J., Dan-Glauser, E. S., Wienold, J., & Andersen, M. (2019). Subjective and physiological responses to façade and sunlight pattern geometry in virtual reality. *Building and Environment*, *150*, 144–155. https://doi.org/10.1016/j.buildenv.2019.01.009

Chemero, A. (2018). An outline of a theory of affordances. *How Shall Affordances Be Refined?: Four Perspectives: A Special Issue of Ecological Psychology*, *7413*(2003), 181–195. https://doi.org/10.4324/9780203726655-5

Chen, L.-H., Lee, C.-F., & Tsai, C.-M. (2007). Perceiving affordances through perceptual information. *International Association of Societies of Design Research*, 1–8.

Chen, M., Mata, I., & Fadel, G. (2020). Interpreting and tailoring affordance based design user-centered experiments. *International Journal of Design Creativity and Innovation*, *8*(1), 46–68. https://doi.org/10.1080/21650349.2019.1651675

Chen, Y. V., Qian, Z. C., & Lei, W. T. (2016). Designing a situational awareness information display: Adopting an affordance-based framework to amplify user experience in environmental interaction design. *Informatics*, *3*(2). https://doi.org/10.3390/informatics3020006

Chirico, A., Ferrise, F., Cordella, L., & Gaggioli, A. (2018). Designing awe in virtual reality: An experimental study. *Frontiers in Psychology*, *8*(JAN). https://doi.org/10.3389/fpsyg.2017.02351

Chung, J. K. H., Kumaraswamy, M. M., & Palaneeswaran, E. (2009). Improving megaproject briefing through enhanced collaboration with ICT. *Automation in Construction*, *18*(7), 966–974. https://doi.org/10.1016/j.autcon.2009.05.001

Coppens, A., Mens, T., & Gallas, M.-A. (2019). Parametric Modelling Within Immersive Environments – Building a Bridge Between Existing Tools and Virtual Reality Headsets. *VR, AR & VISUALISATION | Experiments - Volume 2 - ECAADe 36*, 711–716.

Coroado, L., Pedro, T., D'Alpuim, J., Eloy, S., & Dias, M. S. (2015). VIARMODES Visualization and Interaction in Immersive Virtual Reality for the Architectural Design Process. *ECAADe 33*, 125–134.

Dagit III, C. E. (1993). Establishing Virtual Design Environments in Architectural Practice. In U. Flemming & S. van Wyk (Eds.), *CAAD Futures '93* (pp. 513–522). Elsevier Science Publishers B.V. http://papers.cumincad.org/data/works/att/42ab.content.pdf

de Klerk, R., Duarte, A. M., Medeiros, D. P., Duarte, J. P., Jorge, J., & Lopes, D. S. (2019). Usability studies on building early stage architectural models in virtual reality. *Automation in Construction*, *103*, 104–116. https://doi.org/10.1016/j.autcon.2019.03.009

de Vasconcelos, G. N., Malard, M. L., van Stralen, M., Campomori, M., de Abreu, S. C., Lobosco, T., Gomes, I. F., & Lima, L. D. C. (2019). Do we still need CAVEs? *Sousa, JP, Xavier, JP and Castro Henriques, G (Eds.), Architecture in the Age of the 4th Industrial Revolution - Proceedings of the 37th ECAADe and 23rd SIGraDi Conference - Volume 3, University of Porto, Porto, Portugal, 11-13 September 2019, Pp. 133-142*.

Diemer, J., Alpers, G. W., Peperkorn, H. M., Shiban, Y., & Mühlberger, A. (2015). The impact of perception and presence on emotional reactions: A review of research in virtual reality. In *Frontiers in Psychology* (Vol. 6, Issue JAN). https://doi.org/10.3389/fpsyg.2015.00026

Dorta, T. (1996). Hybrid modeling. *Digital Design: The Quest for New Paradigms [23nd ECAADe Conference Proceedings]*, *19*(9), 819–827. https://doi.org/10.4018/978-1-4666-8111-8.ch019

Dorta, T., Safin, S., Boudhraâ, S., & Marchand, E. B. (2019). Co-designing in social VR. *Intelligent and Informed - Proceedings of the 24th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2019*, *2*, 141–150.

Dvorak, J., Hamata, V., Skacilik, J., & Benes, B. (2005). Boosting up Architectural Design Education with Virtual Reality. *Central European Multimedia and Virtual Reality Conference*.

Fabian Dembski, Wössner, U., & Letzgus, M. (2019). The Digital Twin: Tackling Urban Challenges with Models , Spatial Analysis and Numerical Simulations in Immersive Virtual Environments. In J. Sousa, J. Xavier, & G. Castro Henriques (Eds.), *Architecture in the Age of the 4th Industrial Revolution -*

Proceedings of the 37th eCAADe and 23rd SIGraDi Conference (Vol. 1, pp. 795–804).
Figueroa, P., Bischof, W. F., Boulanger, P., & Hoover, H. J. (2005). Efficient comparison of platform alternatives in interactive virtual reality applications. *International Journal of Human-Computer Studies*, *62*(1), 73–103. https://doi.org/10.1016/J.IJHCS.2004.08.004
Freitas, M. R. de, & Ruschel, R. C. (2013). What is happening to virtual and augmented reality applied to architecture? *Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2013)*, 407–416. http://cumincad.scix.net/cgi-bin/works/Show?_id=caadria2013_043&sort=DEFAULT&search=virtual reality %7Byear%7D gt %222000%22 &hits=1613
Fröst, P. (2002). *Interactive Tools for Collaborative Architectural Design*. http://cumincad.scix.net/cgi-bin/works/Show?_id=ddssar0211&sort=DEFAULT&search=game&hits=159
Gaitatzes, A., Christopoulos, D., & Roussou, M. (2001). Reviving the past. *Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage - VAST ’01*, *82*(1), 103. https://doi.org/10.1145/584993.585011
Gero, J. S., & Kannengiesser, U. (2012). Representational affordances in design, with examples from analogy making and optimization. *Research in Engineering Design*, *23*(3), 235–249. https://doi.org/10.1007/S00163-012-0128-Y/FIGURES/14
Ghani, I., Ahmad, R., Woods, P., & Salleh, A. G. (2012). Sense of place in virtual heritage environment: a review. *CAAD | INNOVATION | PRACTICE [6th International Conference Proceedings of the Arab Society for Computer Aided Architectural Design (ASCAAD 2012)]*, 181–189. http://cumincad.scix.net/cgi-bin/works/Show?_id=ascaad2012_018&sort=DEFAULT&search=virtual reality %7Byear%7D gt %222000%22 &hits=1613
Gibson, J. J. (1976). The theory of affordances and the design of the environment Symposium on Perception in Architecture, American Society for Esthetics, Toronto, October 1976. In E. Reed & R. Jones (Eds.), *Reasons for realism: selected essays of James J. Gibson (1982)*. Lawrence Erlbaum Associates.
Gibson, J. J. (1979). The theory of affordances. In J. J. Gieseking, W. Mangold, C. Katz, S. Low, & S. Saegert (Eds.), *The People, Place, and Space Reader* (pp. 56–60). Routledge. https://doi.org/10.4324/9781315816852
Globa, A., Wang, R., & Beza, B. B. (2019). Sensory Urbanism and Placemaking - Exploring Virtual Reality and the Creation of Place. *Intelligent & Informed, Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2019*, 737–746. http://papers.cumincad.org/cgi-bin/works/paper/caadria2019_211
Groat, L. N., & Wang, D. (2013). *Architectural Research Methods* (Second Edi). John Wiley & Sons, Inc.
Gupta, D., & Uma Maheswari, J. (2019). Affordance-based Design Method: A Case Study of University Campus. *IOP Conference Series: Earth and*

Environmental Science, *323*(1). https://doi.org/10.1088/1755-1315/323/1/012158

Gutiérrez A., M. A., Vexo, F., & Thalmann, D. (2008). Stepping into virtual reality. In *Stepping into Virtual Reality*. https://doi.org/10.1007/978-1-84800-117-6

Hamida, S. ben, Jankovic, M., Curatella, F., Sasse, S., Baltay, S., Callot, M., Huet, A., & Centralesupélec, J.-C. B. (2016). *VALUE PROPOSITION DESIGN FOR SYSTEMS AND SERVICES BY ADAPTING AFFORDANCE-BASED DESIGN*. http://proceedings.asmedigitalcollection.asme.org/pdfaccess.ashx?url=/data/conferences/asmep/90700/

Heft, H. (2003). Affordances, Dynamic Experience, and the Challenge of Reification. *Ecological Psychology*, *15*(2), 149–180. https://doi.org/10.1207/S15326969ECO1502_4

Heydarian, A., Carneiro, J. P., Gerber, D., Becerik-Gerber, B., Hayes, T., & Wood, W. (2014a). Immersive Virtual Environments: Experiments on Impacting Design and Human Building Interaction. *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2014)*, 729–738.

Heydarian, A., Carneiro, J. P., Gerber, D., Becerik-Gerber, B., Hayes, T., & Wood, W. (2014b). Immersive Virtual Environments: Experiments on Impacting Design and Human Building Interaction. *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2014)*, 729–738.

Higuera-Trujillo, J. L., López-Tarruella Maldonado, J., & Llinares Millán, C. (2017). Psychological and physiological human responses to simulated and real environments: A comparison between Photographs, 360° Panoramas, and Virtual Reality. *Applied Ergonomics*, *65*, 398–409. https://doi.org/10.1016/j.apergo.2017.05.006

Horne, M., & Thompson, E. M. (2008). The Role of Virtual Reality in Built Environment Education. *Journal for Education in the Built Environment*, *3*(1), 5–24. https://doi.org/10.11120/jebe.2008.03010005

Horvat, N., Škec, S., Martinec, T., Lukacevic, F., & Perišic, M. M. (2019). Comparing virtual reality and desktop interface for reviewing 3D CAD models. *Proceedings of the International Conference on Engineering Design, ICED*, *2019-Augus*(AUGUST), 1923–1932. https://doi.org/10.1017/dsi.2019.198

Hosokawa, M., Fukuda, T., Yabuki, N., Michikawa, T., & Motamedi, A. (2016). Integrating CFD and VR for indoor thermal environment design feedback. In S. Chien, S. Choo, M. A. Schnabel, W. Nakapan, M. J. Kim, & S. Roudavski (Eds.), *Living Systems and Micro-Utopias: Towards Continuous Designing, Proceedings of the 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2016* (pp. 663–672). CUMINCAD. http://papers.cumincad.org/cgi-bin/works/Show?caadria2016_663

Huang, H. M., Liaw, S. S., & Lai, C. M. (2016). Exploring learner acceptance of the use of virtual reality in medical education: a case study of desktop and projection-based display systems. *Interactive Learning Environments*, *24*(1), 3–19. https://doi.org/10.1080/10494820.2013.817436

Isdale, J. (1998). *What is Virtual Reality? - A Web-based Introduction*. http://vr.isdale.com/WhatIsVR.html

Isdale, J. (2003). Introduction to Virtual Environment Technology. In *IEEE VR2003*. http://vr.isdale.com/IntroVETutorial.2003.color.pdf

Jeannerod, M. (1981). Specialized channels for cognitive responses. *Cognition*, *10*(1–3), 135–137. https://doi.org/10.1016/0010-0277(81)90036-6

Johansson, M., Roupe, M., & Tallgren, M. V. (2014). From BIM to VR - Integrating immersive visualizations in the current design process. *Proceedings of the 32nd ECAADe Conference - Volume 2 (ECAADe 2014)*, 1–9.

Kalantari, S., Contreras-Vidal, J. L., Smith, J. S., Cruz-Garza, J., & Banner, P. (2018). Evaluating educational settings through biometric data and virtual response testing. *Recalibration on Imprecision and Infidelity - Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2018*, 118–125.

Kalarat, K. (2014). Relief Mapping on facade of Sino Portuguese Architecture in Virtual Reality. *2014 4th International Conference on Digital Information and Communication Technology and Its Applications, DICTAP 2014*, 333–336. https://doi.org/10.1109/DICTAP.2014.6821706

Kamath, R. S., Dongale, T. D., & Kamat, R. K. (2013). Development of Virtual Reality Tool for Creative Learning in Architectural Education. *International Journal of Quality Assurance in Engineering and Technology Education*, *2*(4), 16–24. https://doi.org/10.4018/ijqaete.2012100102

Kasireddy, V., Zou, Z., Akinci, B., & Rosenberry, J. (2016). Evaluation and Comparison of Different Virtual Reality Environments towards Supporting Tasks Done on a Virtual Construction Site. *Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan - Proceedings of the 2016 Construction Research Congress, CRC 2016*, 2371–2381. https://doi.org/10.1061/9780784479827.236

Kieferle, J., & Woessner, U. (2015). BIM Interactive - About Combining BIM and Virtual Reality. *Real Time: Proceedings of the 33rd ECAADe Conference, Vienna, Austria.*, *1*, 69–75.

Kieferle, J., & Woessner, U. (2020). Virtual Reality in Early Phases of Architectural Studies Experiments with first year students in immersive rear projection based virtual environments. *ECAADe 37 / SIGraDi 23*, *3*, 99–106. https://doi.org/10.5151/proceedings-ecaadesigradi2019_399

Kim, K., Rosenthal, M. Z., Zielinski, D., & Brady, R. (2012). Comparison of Desktop , Head Mounted Display , and Six Wall Fully Immersive Systems using a Stressful Task. *IEEE Virtual Reality 2012*, 143–144.

Kim, M. K. (2020). Affordance-based interior design with occupants' behavioural data. *Indoor and Built Environment*, *0*(0), 1–17. https://doi.org/10.1177/1420326X20948015

Korea Architectural Accrediting Board. (2018). *KAAB Conditions & Procedures For Professional Degree Programs in Architecture 2018 Edition*. Korea

Architectural Accrediting Board. http://eng.kaab.or.kr/files/KAAB_2018_C_and_P.pdf
Koutamanis, A. (2006). BUILDINGS AND AFFORDANCES. *Design Computing and Cognition '06*, *June*, 345–364. https://doi.org/10.1007/978-1-4020-5131-9
Kuliga, S. F., Thrash, T., Dalton, R. C., & Hölscher, C. (2015). Virtual reality as an empirical research tool — Exploring user experience in a real building and a corresponding virtual model. *Computers, Environment and Urban Systems*, *54*, 363–375. https://doi.org/10.1016/j.compenvurbsys.2015.09.006
Kun Yuan, Dong Yang, & Yumei Cui. (2012). Application of virtual reality technology in the space teaching of Landscape Architecture. *2012 International Symposium on Information Technologies in Medicine and Education*, *1*, 375–378. https://doi.org/10.1109/ITiME.2012.6291321
Leigh, J., Johnson, A., Renambot, L., Peterka, T., Jeong, B., Sandin, D. J., Talandis, J., Jagodic, R., Nam, S., Hur, H., & Sun, Y. (2013). Scalable resolution display walls. *Proceedings of the IEEE*, *101*(1), 115–129. https://doi.org/10.1109/JPROC.2012.2191609
Lin, C., Lo, T., & Hu, X. (2021). Exploring the Possibilities of a Virtual Reality Aided Architectural Design System. In V. Stojakovic & B. Tepavcevic (Eds.), *Towards a new, configurable architecture - Proceedings of the 39th eCAADe Conference - Volume 2, University of Novi Sad, 8-10 September 2021* (pp. 555–564).
Lindström, J. (2008). Real Time Database Systems. In *Wiley Encyclopedia of Computer Science and Engineering*. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470050118.ecse575
Loyola, M., Rossi, B., Montiel, C., & Daiber, M. (2020). *Use of Virtual Reality in Participatory Design*. *December 2019*, 449–454. https://doi.org/10.5151/proceedings-ecaadesigradi2019_156
Lucaites, K., Fletcher, B., & Pyle, A. (2017). Measuring the Impact of Affordance-Based Clickability Cues. *Proceedings of ACM Conference*, *2657*. https://doi.org/10.1145/nnnnnnn.nnnnnnn
Lymer, G., Ivarsson, J., & Lindwall, O. (2009). Contrasting the use of tools for presentation and critique: Some cases from architectural education. *International Journal of Computer-Supported Collaborative Learning*, *4*(4), 423–444. https://doi.org/10.1007/s11412-009-9073-9
Maheswari, J. U., Charlesraj, V. P. C., & Battacharya, S. (2017). User-inspired design methodology using Affordance Structure Matrix (ASM) for construction projects. *MATEC Web of Conferences*, *120*, 1–15. https://doi.org/10.1051/matecconf/201712008011
Maier, J. R. A. (2005). *FOUNDATIONS OF AFFORDANCE BASED DESIGN A Dissertation*.
Maier, J. R. A., Ezhilan, T., & Fadel, G. M. (2008). The affordance structure matrix - A concept exploration and attention directing tool for affordance based design. *2007 Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC2007*, *3 PART A*, 277–287. https://doi.org/10.1115/DETC2007-34526

Maier, J. R. A., & Fadel, G. M. (2007). Identifying affordances. *Proceedings of ICED 2007, the 16th International Conference on Engineering Design*, *DS 42*(August), 25–27.

Maier, J. R. A., & Fadel, G. M. (2009a). Affordance based design: a relational theory for design. *Research in Engineering Design*, *20*, 13–27. https://doi.org/10.1007/s00163-008-0060-3

Maier, J. R. A., & Fadel, G. M. (2009b). Affordance-based design methods for innovative design, redesign and reverse engineering. *Research in Engineering Design*, *20*(4), 225–239. https://doi.org/10.1007/s00163-009-0064-7

Maier, J. R. A., Fadel, G. M., & Battisto, D. G. (2009). An affordance-based approach to architectural theory, design, and practice. *Design Studies*, *30*(4), 393–414. https://doi.org/10.1016/j.destud.2009.01.002

Masoudi, N., Fadel, G. M., Pagano, C. C., & Elena, M. V. (2019a). A review of affordances and affordance-based design to address usability. *Proceedings of the International Conference on Engineering Design, ICED, 2019-Augus*(AUGUST), 1353–1362. https://doi.org/10.1017/dsi.2019.141

Masoudi, N., Fadel, G. M., Pagano, C. C., & Elena, M. V. (2019b). A review of affordances and affordance-based design to address usability. *Proceedings of the International Conference on Engineering Design, ICED*, *2019-Augus*(1), 1353–1362. https://doi.org/10.1017/dsi.2019.141

McGrenere, J., & Ho, W. (2000a). Affordances : Clarifying and Evolving a Concept. *Graphics Interface*, *May*, 1–8.

McGrenere, J., & Ho, W. (2000b). Affordances : Clarifying and Evolving a Concept. *Graphics Interface*, *May*, 1–8.

Mizell, D. W., Jones, S. P., Slater, M., & Spanlang, B. (2002). Comparing immersive virtual reality with other display modes for visualizing complex 3D geometry. *University College London, …*, *November*, 1–7. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.99.5391&rep=rep1&type=pdf

Morse, C., & Soulos, F. (2019). Interactive Facade Detail Design Reviews with the VR Scope Box. *ACADIA 19:UBIQUITY AND AUTONOMY [Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)]*, 422–429.

Moural, A., Eloy, S., Dias, M. S., & Pedro, T. (2013). How Space Experimentation Can Inform Design: Immersive Virtual Reality as a Design Tool. *SIGraDi 2013*, 182–185.

Nadavar, A., Petzold, F., Nassif, J., & Schubert, G. (2018). *Interactive Virtual Reality Tool for BIM Based on IFC - Development of OpenBIM and Game Engine Based Layout Planning Tool - A Novel Concept to Integrate BIM and VR with Bi-Directional Data Exchange*. http://papers.cumincad.org/cgi-bin/works/Show?caadria2018_057

Nagy, D., Stoddart, J., Villaggi, L., Burger, S., & Benjamin, D. (2018). Digital dérive: Reconstructing urban environments based on human experience. *Recalibration on Imprecision and Infidelity - Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2018*, 72–81.

Nandavar, A., Petzold, F., Schubert, G., & Youssef, E. (2019). Opening BIM in a new dimension. *Intelligent and Informed - Proceedings of the 24th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2019*, *1*, 595–604.

Naz, A., Kopper, R., McMahan, R. P., & Nadin, M. (2017). Emotional qualities of VR space. *Proceedings - IEEE Virtual Reality*, 3–11. https://doi.org/10.1109/VR.2017.7892225

Nguyen, D., Moleta, T. J., & Schnabel, M. A. (2019). Mindful Manifestation - A method for designing architectural forms using brain activities. *Intelligent & Informed, Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2019*, 485–494. http://papers.cumincad.org/cgi-bin/works/paper/caadria2019_142

Norman, D. A. (1988). *The psychology of everyday things*. Basic Books.

Norman, D. A. (1999). Affordance, conventions, and design. *Interactions*, *6*(3), 38–43. https://doi.org/10.1145/301153.301168

Norman, D. A. (2013). The Design of Everyday Things. In *Basic Books* (Revised an). Basic Books. https://doi.org/10.15358/9783800648108

Oprean, D., Verniz, D., Zhao, J., Wallgrun, J. O., Duarte, J. P., & Klippel, A. (2018). Remote Studio Site Experiences: Investigating the Potential to Develop the Immersive Site Visit. *Learning, Adapting and Prototyping, Proceedings of the 23rd International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2018*, 421–430. http://papers.cumincad.org/cgi-bin/works/paper/caadria2018_309

Osiurak, F., Rossetti, Y., & Badets, A. (2017). What is an affordance? 40 years later. *Neuroscience and Biobehavioral Reviews*, *77*(August 2016), 403–417. https://doi.org/10.1016/j.neubiorev.2017.04.014

Paes, D., Arantes, E., & Irizarry, J. (2017). Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. *Automation in Construction*, *84*, 292–303. https://doi.org/10.1016/j.autcon.2017.09.016

Pagano, C. C., Day, B., & Hartman, L. S. (2021). An Argument Framework for Ecological Psychology and Architecture Design. *Https://Doi.Org/10.1080/24751448.2021.1863665*, *5*(1), 31–36. https://doi.org/10.1080/24751448.2021.1863665

Paranandi, M., & Sarawgi, T. (2002). Virtual Reality in Possibilities. *Proceedings of the 7th International Conference on Computer Aided Architectural Design Research in Asia*, 309–316. http://papers.cumincad.org/cgi-bin/works/paper/3439

Pausch, R., Proffitt, D., & Williams, G. (1997). Quantifying immersion in virtual reality. *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 1997*, 13–18. https://doi.org/10.1145/258734.258744

Plechatá, A., Sahula, V., Fayette, D., & Fajnerová, I. (2019). Age-related differences with immersive and non-immersive virtual reality in memory assessment. *Frontiers in Psychology*, *10*(JUN), 1–12. https://doi.org/10.3389/fpsyg.2019.01330

Regia-Corte, T., Marchal, M., Cirio, G., & Lécuyer, A. (2013). Perceiving affordances in virtual reality: Influence of person and environmental properties in perception of standing on virtual grounds. *Virtual Reality*, *17*(1), 17–28. https://doi.org/10.1007/s10055-012-0216-3

Ries, B. T. (2011). *Facilitating effective virtual reality for architectural design*. 170. http://search.proquest.com/dissertations/docview/865877852/abstract/BF2FAD132CD74C68PQ/3

Rodriguez, C., Hudson, R., & Niblock, C. (2018). Collaborative learning in architectural education: Benefits of combining conventional studio, virtual design studio and live projects. *British Journal of Educational Technology*, *49*(3), 337–353. https://doi.org/10.1111/bjet.12535

Rogers, J., & Schnabel, M. A. (2018). Digital Design Ecology - An Analysis for an Intricate Framework of Architectural Design. *Collaborative & Participative Desgin - ECAADe 36*, *1*(Kvan 2004), 459–468.

Rogers, J., Schnabel, M. A., & Moleta, T. J. (2019). *Reimagining relativity*. *2*, 727–736.

Rua, H., & Alvito, P. (2011). Living the past: 3D models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage - the case-study of the Roman villa of Casal de Freiria. *Journal of Archaeological Science*, *38*(12), 3296–3308. https://doi.org/10.1016/j.jas.2011.07.015

Ruddle, R. A., Payne, S. J., & Jones, D. M. (1999). Navigating large-scale virtual environments: What differences occur between helmet-mounted and desk-top displays? *Presence: Teleoperators and Virtual Environments*, *8*(2), 157–168. https://doi.org/10.1162/105474699566143

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers, Third Edition*. John Wiley & Sons, Inc. https://doi.org/10.1002/9781119287568

Sampaio, A. Z. (2018). IMPROVING BIM WITH VR IN CONSTRUCTION. *16th International Conference E-Society 2018*, 155–162.

Schubert, G., Bratoev, I., Strelchenko, V., & Petzold, F. (2019). I Hear, What You Are Doing! - Workspace Awareness in Collaborative Virtual Environments. *Intelligent & Informed, Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2019*, 583–592. http://papers.cumincad.org/cgi-bin/works/paper/caadria2019_344

Scorpio, M., Laffi, R., Teimoorzadeh, A., & Sibilio, S. (2021). Immersive virtual reality as a tool for lighting design: Applications and opportunities. *Journal of Physics: Conference Series*, *2042*(1). https://doi.org/10.1088/1742-6596/2042/1/012125

Serpa, F., & Eloy, S. (2020). How non-designers understand the architecture design project : a comparative study using immersive virtual. *Interaction Design and Architecture(s) Journal*, *45*, 287–301.

Sherman, W. R., & Craig, A. B. (2003). Understanding Virtual Reality: Interface, Application, and Design. In *Understanding Virtual Reality: Interface, Application, and Design*. https://doi.org/10.1162/105474603322391668

Shu, Y., Huang, Y.-Z., Chang, S.-H., & Chen, M.-Y. (2018). Do virtual reality head-mounted displays make a difference? A comparison of presence and self-efficacy between head-mounted displays and desktop computer-facilitated virtual environments. *Virtual Reality 2018 23:4*, *23*(4), 437–446. https://doi.org/10.1007/S10055-018-0376-X

Single Responsibility Principle. (2000). https://web.archive.org/web/20150202200348/http://www.objectmentor.com/resources/articles/srp.pdf

Slater, M. (2003). A note on presence. *Presence Connect*, *3*(January 2003), 1–5. www.cs.ucl.ac.uk/staff/m.slater

Sousa Santos, B., Dias, P., Pimentel, A., Baggerman, J. W., Ferreira, C., Silva, S., & Madeira, J. (2009). Head-mounted display versus desktop for 3D navigation in virtual reality: A user study. *Multimedia Tools and Applications*, *41*(1), 161–181. https://doi.org/10.1007/s11042-008-0223-2

Souza, T. L. de. (2020). *A 360° history of the city: the digital reconstruction of the Rio de Janeiro Panorama by Victor Meirelles and Henri Langerock from the end of the 19th century*. 563–568. https://doi.org/10.5151/sigradi2020-78

Srivastava, J., & Shu, L. H. (2012). AFFORDANCES AND ENVIRONMENTALLY SIGNIFICANT BEHAVIOR. *Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, 1–9.

Sutherland, I. (1965). “The Ultimate Display” by Ivan Sutherland, 1965. *Multimedia: From Wagner to Virtual Reality*, 4–5.

Sutherland, I. E. (1963). Sketchpad a man-machine graphical communication system. *AFIPS Conference Proceedings - 1963 Spring Joint Computer Conference, AFIPS 1963*, 329–346. https://doi.org/10.1145/1461551.1461591

Symes, E., Ellis, R., & Tucker, M. (2007). Visual object affordances: Object orientation. *Acta Psychologica*, *124*(2), 238–255. https://doi.org/10.1016/j.actpsy.2006.03.005

Tang, M. (2018). Virtual Reality And Augmented Reality In Education. *The 34th National Conference on the Beginning Design Student, (NCBDS)*, 1–12. https://www.usma.edu/cfe/Literature/Boyles_17.pdf

Thompson, B. (2021). Work-in-Progress–LIVE: Model for Learning in Interactive and Immersive Virtual Environments. *2021 7th International Conference of the Immersive Learning Research Network (ILRN)*, 1–3. https://doi.org/10.23919/iLRN52045.2021.9459362

Triberti, S., Repetto, C., & Riva, G. (2014). Psychological factors influencing the effectivity of virtual reality-based analgesia: A systematic review. *Cyberpsychology, Behavior, and Social Networking*, *17*(6), 335–345. https://doi.org/10.1089/cyber.2014.0054

Tsering Wangyal, A., Hong Poh Source, L., Yi Wei, C., Kah Mun, C., Alphonso, A., & Wangyal Liang Hong Poh, T. (2019). *Title An affordance based design framework for technology-enabled learning spaces An affordance based design framework for technology-enabled learning spaces* (Vol. 36). ASCILITE.

Tsou, C. H., Tsai, M. H., Wang, Y. S., Hsu, T. W., Hsu, P. H., Lin, W. C., Lin, C. H., Lin, I. C., & Chuang, J. H. (2017). Immersive VR Environment for

Architectural Design Education. *SIGGRAPH Asia 2017 Posters, SA 2017*. https://doi.org/10.1145/3145690.3145726
Tucker, M., & Ellis, R. (1998). On the Relations between Seen Objects and Components of Potential Actions. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 830–846. https://doi.org/10.1037/0096-1523.24.3.830
Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, *8*(6), 769–800. https://doi.org/10.1080/13506280042000144
Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, *116*(2), 185–203. https://doi.org/10.1016/j.actpsy.2004.01.004
Tweed, C. (2001). Highlighting the affordances of designs. *Computer Aided Architectural Design Futures 2001*, 681–696. https://doi.org/10.1007/978-94-010-0868-6_51
Vital, R. (2006). *Incorporation of cultural elements into architectural historical reconstructions through virtual reality*. http://search.proquest.com/dissertations/docview/305345736/abstract/BF2FAD132CD74C68PQ/2
Wang, B., Moleta, T. J., & Schnabel, M. A. (2019). The new mirror. *Intelligent and Informed - Proceedings of the 24th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2019*, *1*, 535–544.
Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(5), 683–703. https://doi.org/10.1037/0096-1523.10.5.683
Warren, W. H. (1995). Constructing an Econiche. *Global Perspectives on the Ecology of Human-Machine Systems*, 210–237. https://doi.org/10.1201/9780203753095-8
Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(3), 371–383. https://doi.org/10.1037/0096-1523.13.3.371
Whyte, J., & Nikolic, D. (2018). *Virtual Reality and the Built Environment* (Second Edi). Routledge.
Wickens, C. D. (1992). Virtual reality and education. *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, *1992-Janua*, 842–847. https://doi.org/10.1109/ICSMC.1992.271688
Wineman, J. D., & Peponis, J. (2010). Constructing Spatial Meaning. *Environment and Behavior*, *42*(1), 86–109. https://doi.org/10.1177/0013916509335534
Wu, C. F., Wong, Y. K., Hsu, H. H., & Huang, C. Y. (2022). Applying Affordance Factor Analysis for Smart Home Speakers in Different Age Groups: A Case Study Approach. *Sustainability (Switzerland)*, *14*(4). https://doi.org/10.3390/su14042156

APPENDICIES

Appendix A Design Brief for First Simulation (Chapter 6)

AR3290 Studio Perancangan Arsitektur IV, Semester II – 2019/2020
Program Studi Arsitektur
Sekolah Arsitektur, Perencanaan dan Pengembangan Kebijakan
Institut Teknologi Bandung

Tugas 1
Lifestyle Center

Koordinator:
Dr.Eng. Arif Sarwo Wibowo, ST., MT.

Dosen Pembimbing:
1. Dr. Ir. Woerjantari Kartidjo, MT.
2. Dr. Agus Suharjono Ekomadyo, ST., MT.
3. Ir. Baskoro Tedjo, MSEB., Ph.D.
4. Ir. Budi Faisal, MAUD., MLA., Ph.D.
5. Ir. Tri Yuwono, MT.
6. Dr.-Ing. Ir. Boedi Darma Sidi, MSA.
7. Widiyani, ST., MT., Ph.D.
8. Dewi Larasati, ST., MT., Ph.D.
9. Dr. Ir. Endang Triningsih, MSP., MLA.
10. Ir. Wiwik Dwi Pratiwi, MES., Ph.D.
11. Dr. Mochamad Prasetiyo Effendi Yasin, M.Arch., MAUD.
12. Dr. Firmansyah, ST., MT.

Asisten Dosen dan Asisten Akademik:
1. Hafshah Salamah, ST., MT.
2. Romi Bramantyo Margono, ST., M.Sc.
3. Anthony Derry, ST.

Penjelasan Tugas 1:
Selasa, 14 Januari 2020

Pengumpulan Tugas 1 (Bagian A):
Selasa, 28 Januari 2020
Pukul: 07.00-08.00

Pengumpulan Tugas 1 (Bagian B):
Selasa, 28 Januari 2020
Pukul: 11.00-12.00

Pengumpulan Tugas 1 (Bagian C):
Selasa, 03 Maret 2020
Pukul: 07.00-08.00

Pin-up Tugas 1:
Selasa, 03 Maret 2020
Pukul: 08.00-15.00

PENDAHULUAN

Tugas 1 AR3290 ini menitikberatkan tema "penciptaan tempat" *(place-making*). Dalam perancangan arsitektur, konsep *place* (tempat) secara sederhana digunakan untuk membedakan dengan *space* (ruang): *place* (tempat) adalah *space* (ruang) yang mempunyai makna. Dalam tata bentuk, ruang bisa dibentuk mengkomposisi elemen horisontal, vertikal, dan gabungan keduanya (Ching, 2007:96-160). Place tercipta karena karena komposisi bentuk pada ruang tersebut (*form*), aktivitas pengguna (*activities*), dan citra dari penggunaan ruang tersebut (*images*) (Montgomery, 1998:98). Desain arsitektur bertema place-making secara sederhana adalah menggubah bentuk/ruang dengan membayangkan bagaimana tempat tersebut akan hidup oleh aktivitas dan memberikan citra yang baik bagi pengggunanya. Kasus proyek yang dipilih adalah fasilitas *Lifestyle Center* di kota Bandung. Dengan demikian "place-making" yang dimaksudkan dalam tugas ini adalah menciptakan tempat yang aman, nyaman yang dapat menjadi wadah aktualisasi diri bagi seluruh masyarakat Kota Bandung.

Dengan tugas ini diharapkan mahasiswa mampu mengembangkan kemampuan untuk merancang bangunan dengan mengeksplorasi gubahan bentuk/ruang dengan mengintegrasikannya dengan konteks tapak, aspek fungsi dan aspek keterbangunan. Beberapa matakuliah yang terkait seperti AR2250 Gubahan Bentuk Arsitektur dan AR3110 Perancangan Tapak menjadi relevan untuk dilihat kembali perannya pada studio ini. Melalui tugas ini pula mahasiswa dengan sadar mengimplementasikan konsep "place" dalam rancangan bangunan, untuk menjadikan arsitektur lebih mempunyai makna bagi penggunanya.

AR3290 Studio Perancangan Arsitektur IV, Semester II – 2019/2020
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TUJUAN

1. Menyusun program arsitektur meliputi kajian prakarsa (inisiatif) proyek, kajian pengguna, dan studi presedens, untuk merumuskan misi, isu, dan tujuan perancangan, program ruang, hubungan antar ruang, dan gagasan atau konsep awal yang mampu memberikan bayangan tentang keberhasilan bayangan yang akan dirancang.
2. Menyusun berbagai alternatif zonasi ruang pada tapak yang memandu perancangan bangunan melalui proses analisis tapak meliputi: kajian peraturan bangunan, analisis konteks sekitar tapak, analisis pencapaian lahan, analisis kemiringan lahan, dan analisis potensi tapak
3. Membuat rancangan skematik berupa denah skematik yang menunjukkan organisasi ruang dan sketsa gagasan arsitektural untuk membayangkan wujud 3 dimensional bangunan
4. Mengembangkan gubahan bentuk/ruang bangunan sesuai dengan kaidah-kaidah estetika dengan mempertimbangkan konteks tapak dan intergrasi dengan organisasi ruang yang telah disusun sebelumnya
5. Mengembangkan prarancangan (*preliminary design*) bangunan dengan mempertimbangkan aspek keterbangunan, fungsi, dan keindahan bangunan.
6. Menyajikan hasil rancangan secara grafis sesuai standar gambar prarancangan.
7. Mengembangan sikap belajar yang positif selama proses mengerjakan tugas.

KRITERIA KINERJA

Kriteria kinerja mahasiswa (*Students Performance Criteria*/ SPC) merupakan indicator kompetensi yang harus dicapai oleh mahasiswa setelah mengerjakan tugas, meliputi:

1. Mampu merumuskan program arsitektur yang memandu rancangan fungsional bangunan (SPC KAAB 16).
2. Mahasiswa mampu memahami prinsip-prinsip estetika visual dan menerapkannya dalam perancangan arsitektur secara dua dan tiga dimensional (SPC KAAB 15)
3. Mampu merancang arsitektur secara komprehensif berbasis pertimbangan aspek lingkungan dan keberlanjutan (SPC KAAB 17) dan memanfaatkan konsep yang dihasilkan terhadap dari analisis pengguna dan konteks lingkungan (SPC KAAB 18)
4. Mampu memilih material, komponen, dan sistem struktur bangunan yang terintegrasi dalam rancangan bangunan (SPC KAAB 20)
5. Mahasiswa mampu merancang arsitektural dengan prinsip “barrier free” bagi penyandang disabilitas dan lansia (SPC KAAB 19)
6. Mampu menyajikan gagasan arsitektural secara grafis (SPC KAAB 04) dengan memanfaatkan aneka media dan teknologi informasi untuk menunjukkan proses desain yang dilakukan (SPC KAAB 05 dan 06).
7. Mahasiswa mampu menyajikan gambar arsitektural seuai dengan standar gambar prarancangan (SPC KAAB 02)
8. Mahasiswa menyadari pentingnya sikap positif dan bekerja secara kolektif untuk mencapai hasil yang terbaik (SPC KAAB 03)

TINJAUAN TUGAS

Pemerintah Kota Bandung berencana untuk membangun dua buah Lifestyle Center yang berdampingan dengan apartemen kelas menengah-atas di daerah Cikapundung (Lokasi Pasar Elektronik Cikapundung) dan di daerah Jalan Laswi pada laham milik PT KAI. Luas lahan keseluruhan kurang lebih sekitar 10.000 m2 (5.000m2 untuk Lifestyle Center dan 5.000m2 untuk apartemen)

Peserta harus memilih salah satu lokasi tersebut di atas dan diminta untuk merancang sebuah bangunan Lifestyle Center pada lokasi yang telah ditunjukkan di peta. Peserta harus mempertimbangkan kondisi lingkungan sekitar dan adanya rencana pembangunan apartemen pada lokasi di sebelahnya. Kajian potensi dan kendala perancangan pada lahan harus dilakukan oleh masing-masing peserta dengan melihat kondisi lahan dan daerah di sekitarnya. Peserta diminta untuk memenuhi kebutuhan ruang yang tertera di bawah ini.

Peraturan bangunan yang diberlakukan pada kedua lahan tersebut adalah:
KDB: 50% ; KLB: 3,0 ; KDH: minimal 30% ; GSB dan GSS tertera pada gambar.

Program Ruang *Lifestyle Center*

FASILITAS UTAMA									
1	**Kantor Pengelola**								
	Kantor Admin	6	orang	5	m2/orang	30	m2		
	Kantor Marketing	4	orang	5	m2/orang	20	m2		
								50	**m2**
2	**Bioskop**								
	Theater	2	unit	250	m2/unit	500	m2		
	Ticketing	4	orang	1,5	m2/orang	6	m2		
	Lounge	1	unit	200	m2/unit	200	m2		
	Ruang Proyektor	2	unit	21,5	m2/unit	43	m2		
	R. Penyimpanan	1	unit	25	m2/unit	25	m2		
								774	**m2**
3	***Leisure Facility***								
	Game Center	1	unit	50	m2/unit	50	m2		
	Karaoke	1	unit	180	m2/unit	180	m2		
	Gym	1	unit	240	m2/unit	240	m2		
								470	**m2**
4	***Coworking Space***								
	Ruang Kerja	120	orang	2,5	m2/orang	300	m2		
	Ruang Pengelola	3	orang	5	m2/orang	15	m2		
								315	**m2**
5	**Minimarket**								
	R. Penjualan	1	unit	80	m2/unit	80	m2		
	Kasir	1	unit	5	m2/unit	5	m2		
	Gudang	1	unit	20	m2/unit	20	m2		
	Sirkulasi internal minimarket			20	%	21	m2		
								126	**m2**
6	***ATM Center***								
	ATM Booth	8	unit	2	m2/unit	16	m2		
								16	**m2**
7	**Retail (isi fleksibel)**								
	Unit Sewa Tipe A	10	unit	100	m2/unit	1000	m2		
	Unit Sewa Tipe B	20	unit	50	m2/unit	1000	m2		
								2000	**m2**
8	**Restoran/Café (4 unit)**								
	Area Makan	120	orang	1,5	m2/orang	180	m2		
	Counter/Kasir	4	unit	10	m2/unit	40	m2		
	Dapur	12	orang	2	m2/orang	24	m2		
	Gudang	4	unit	10	m2/unit	40	m2		
								284	**m2**
9	***Food Court*** **(jumlah unit gerai disesuaikan)**								
	Area Makan	200	orang	1,4	m2/unit	280	m2		
	Dapur + Gudang	20	orang	2	m2/orang	40	m2		
	Kasir	1	unit	10	m2/unit	10	m2		
								330	**m2**
10	***Toilet***								
	Toilet Pria								
	WC Cubicle	9	unit	1,8	m2/unit	16,2	m2		
	Urinal	6	unit	0,9	m2/unit	5,4	m2		
	Wastafel	6	unit	0,75	m2/unit	4,5	m2		
	Sirkulasi di area toilet	15	orang	0,3	m2/orang	4,5	m2		
	Toilet Wanita								
	WC Cubicle	15	unit	1,8	m2/unit	27	m2		
	Wastafel	6	unit	0,75	m2/unit	4,5	m2		
	Sirkulasi di area toilet	21	orang	0,3	m2/orang	6,3	m2		
	Toilet Difabel	3	unit	4,9	m2/unit	14,7	m2		
	Janitor	3	unit	1,5	m2/unit	4,5	m2		
								87,6	**m2**
11	**Mushola (tidak boleh di basement)**								
	Area Sholat	100	orang	1,2	m2/unit	120	m2		
	Area Wudhu	20	orang	1	m2/orang	20	m2		
								140	**m2**
12	**Utilitas (luas minimum)**								
	AHU	1	unit	50	m2/unit	50	m2		
	Plumbing, Panel Elektrikal dll.	1	unit	20	m2/unit	20	m2		
								70	**m2**
							Total	**4662,6**	**m2**
11	**Sirkulasi**			30%		1398,78	m2		
								1398,78	**m2**
	Total Luas Fasilitas Utama							**6061,38**	**m2**

FASILITAS PARKIR KENDARAAN & TAXI									
1	**Area Tunggu Transportasi Online**								
	Ojek Online	10	motor	2	m2/motor	20	m2		
	Taxi Online	3	mobil	25	m2/mobil	75	m2		
								95	
2	**Car Care (Salon Mobil)**								
	Mobil	6	mobil	25	m2/mobil	150	m2		
	Kantor	4	orang	3	m2/orang	12	m2		
	Gudang	1	unit	5	m2/unit	5	m2		
								167	
3	**Parkir Kendaraan (semi basement)**								
	Sepeda Motor	120	motor	2	m2/motor	240	m2		
	Mobil	60	mobil	25	m2/mobil	1500	m2		
								1740	
								0	
	Total Luas Fasilitas Parkir Kendaraan & Taxi							**2002**	**m2**

LUARAN TUGAS

Bagian A: Rancangan Skematik dan Maket Studi

Jadwal:

Selasa, 28 Januari 2020; pukul: 07.00-08.00, di Studio Lantai 5 atau Galeri AR Lantai 1

Luaran:

1. Rencana Tapak *(Site Plan)* skala 1:200
2. Denah Lantai 1 *(Ground Plan)* skala 1:200
3. Denah Lantai 2 *(2nd Floor Plan)* skala 1:200
4. Denah Lantai 3 *(3rd Floor Plan)* skala 1:200
5. Maket Studi skala 1:500

Ketentuan:

- Seluruh berkas pengumpulan dikumpulkan dalam format kertas gambar atau kertas roti ukuran standar internasional A2 (420mm x 594mm) dengan orientasi *landscape*.
- Maket studi menggunakan bahan berwarna *monochrome*: putih atau abu-abu atau coklat atau krem.
- Seluruh gambar dikerjakan dengan menggunakan teknik manual.
- Berkas yang telat dan tidak sesuai ketentuan akan ditolak.

Bagian B: Gambar Prarancangan

Jadwal:

Rabu, 26 Februari 2020; pukul: 11.00-12.00, di Studio Lantai 5 atau Galeri AR Lantai 1

Luaran:

1. Rencana Induk *(Master Plan)* skala 1:1000
2. Rencana Tapak *(Site Plan)* skala 1:200
3. Denah Lantai 1 *(Ground Plan)* skala 1:200
4. Denah Lantai 2 *(2nd Floor Plan)* skala 1:200
5. Denah Lantai 3 *(3rd Floor Plan)* skala 1:200
6. Tampak 1 *(Elevation 1)* skala 1:200
7. Tampak 2 *(Elevation 2)* skala 1:200
8. Tampak 3 *(Elevation 3)* skala 1:200
9. Tampak 4 *(Elevation 4)* skala 1:200
10. Potongan 1 *(Section 1)* skala 1:200
11. Potongan 2 *(Section 2)* skala 1:200
12. Potongan Prinsip 1 *(Detailed Section 1)* skala 1:50
13. Potongan Prinsip 2 *(Detailed Section 2)* skala 1:50
14. *Exploded Axonometric* atau Gambar lain yang memberikan informasi penting (skala disesuaikan)

Ketentuan:

- Seluruh berkas pengumpulan dikumpulkan dalam format kertas gambar ukuran standar internasional A2 (420mm x 594mm) dengan orientasi *landscape*.
- Diperkenankan untuk menggunakan teknik gambar manual maupun digital.
- Berkas yang telat dan tidak sesuai ketentuan akan ditolak.

<u>Bagian C: Maket Akhir dan Poster Rancangan</u>

<u>Jadwal:</u>

Selasa, 3 Maret 2020; pukul: 07.00-08.00, di Studio Lantai 5 atau Galeri AR Lantai 1

<u>Luaran:</u>

1. Maket Akhir skala 1:500
2. Poster Rancangan, memperlihatkan:
    a. Konsep dan berbagai kajian utama dalam perancangan.
    b. Perspektif Suasana, minimal 4 gambar yang memperlihatkan konsep perilaku pada rancangan.
    c. Perspektif Mata Burung, minimal 1 gambar.
3. Berkas Digital Final, meliputi berkas pengumpulan Bagian A, Bagian B dan Bagian C, dengan foto maket sebanyak minimal 4 foto dari sudut pandang yang berbeda.

<u>Ketentuan:</u>

- Maket akhir menggunakan bahan berwarna *monochrome*: putih atau abu-abu atau coklat atau krem.
- Poster dikumpulkan dalam format kertas gambar ukuran standar internasional A2 (420mm x 594mm) dengan orientasi *portrait*, berjumlah maksimum 2 lembar.
- Diperkenankan untuk menggunakan teknik gambar manual maupun digital.
- Berkas digital final dikumpulkan melalui proses unggah ke alamat web yang akan ditentukan kemudian.
- Berkas yang telat dan tidak sesuai ketentuan yang diminta akan ditolak dan tidak dapat diikutsertakan dalam Pin-up Tugas 1.

KETENTUAN KEHADIRAN

Peserta wajib mengikuti seluruh perkuliahan dan kegiatan studio yang diadakan.

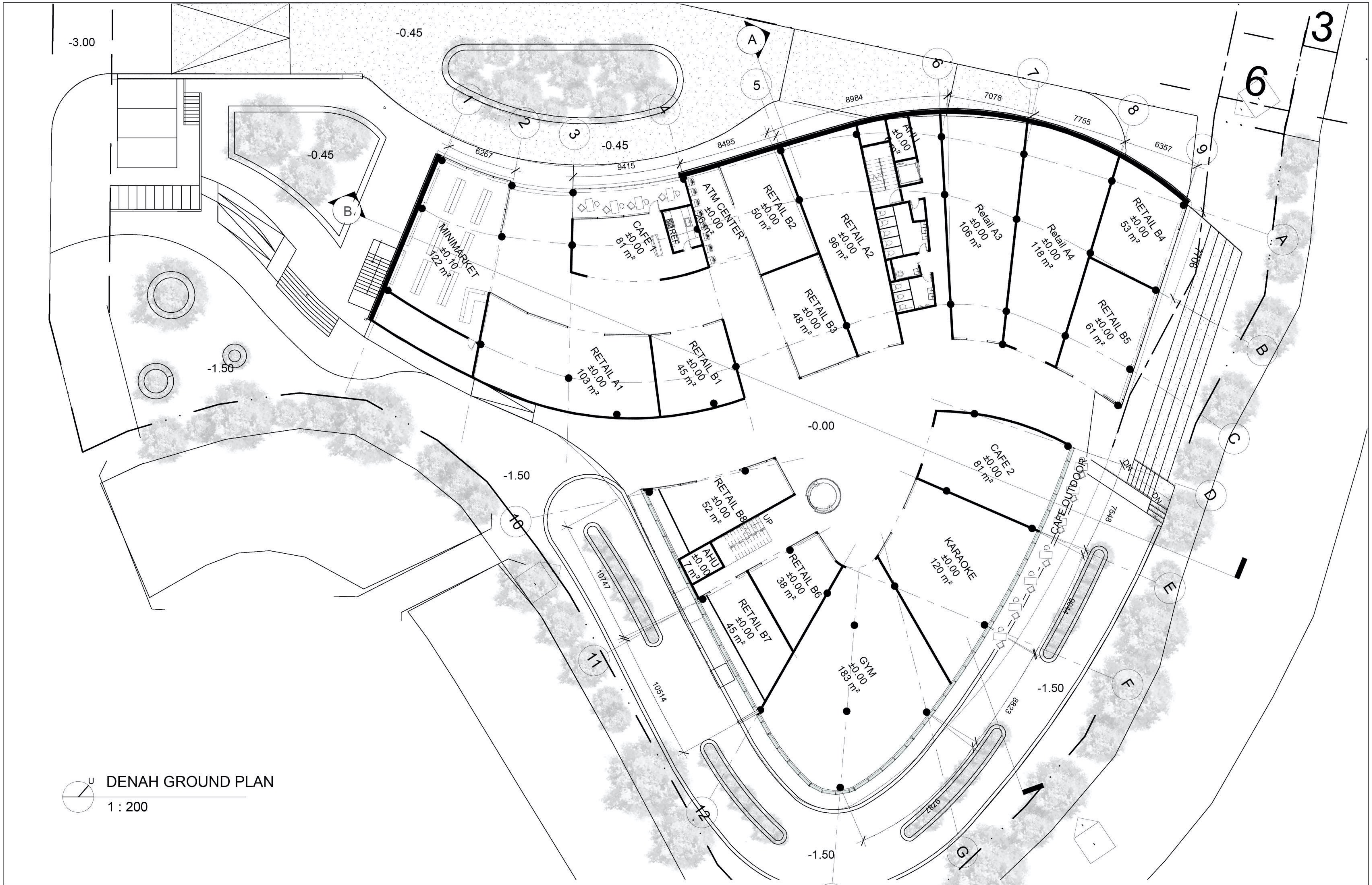
1. Kehadiran kuliah minimal sebanyak 6 kali dari 7 kali perkuliahan selama Tugas 1
2. Kehadiran studio minimal 80% selama Tugas 1 (7 pekan+)
3. Asistensi minimal 1 kali dalam 1 pekan (dibuktikan dengan kartu asistensi)

Peserta yang tidak memenuhi ketentuan di atas, akan dikenakan sanksi, mulai dari pengurangan nilai, tidak diperkankan mengikuti UAS hingga ganjaran nilai E.

TATA LAKSANA KULIAH DAN STUDIO

- Kuliah dimulai pukul 7.15. Pengisian/pemeriksaan kehadiran ditutup pukul 7.30.
- Peserta yang datang setelah 7.30 diperkenankan mengikuti perkuliahan, namun tidak diperkenankan untuk mengisi daftar hadir, dan dalam perhitungan kehadiran dianggap tidak hadir.
- Prosedur permohonan ijin ketidakhadiran maupun tidak hadir karena sakit, mengikuti ketentuan ITB.
- Tata tertib dan tata laksana studio mengacu pada prosedur studio yang telah diterbitkan oleh Prodi AR ITB.

Appendix B Drawing of Project X (Chapter 6)



DENAH GROUND PLAN

1 : 200

Appendix C Drawing of Project Y (Chapter 6)

KONSEP

" Rekoneksi antara ***urban village*** dan alam melalui pengalaman ruang yang mengalir (***flowing experience***)."

Berlokasi di daerah Ciikapundung, the flo' dirancang di pertengahan kampung kota dengan tujuan menciptakan urban sensation Bandung sebagai kota desa dengan mengimplementasikan unsur-unsur alam.

PENDEKATAN METAFORA

THE VALLEY
Secara geografis Kota Bandung dapat dikatakan seperti lembah, karena dikelilingi oleh pegunungan. Void yang dirancang pada lantai 1 dan 2 dengan unsur tanaman dan air pada lantai dasarnya merupakan implementasi dari metafora lembah.

WALKWAYS
Pada lantai dasar terdapat inner court yang diapit oleh sirkulasi yang mengarah ke plaza.

IMPLEMENTASI LEMBAH DALAM RANCANGAN

DESAIN FASADE DAN MATERIAL

Material yang digunakan untuk fasade sebagian besar merupakan elemen alam yaitu bambu dan tanaman. Material bambu merupakan ekspresi dari sifat mudah beradaptasi dan fleksibel. Material bambu sebagai wadah refleksi bagi pengunjung the flo' lifestyle center. Material bambu diiapit oleh lapisan plester berwarna putih cenderung keruh dan bertekstur kasar. Menunjukkan kesan bersih juga sebagai refleksi bahwa tidak ada yang sempurna melalui teksturnya yang kasar.

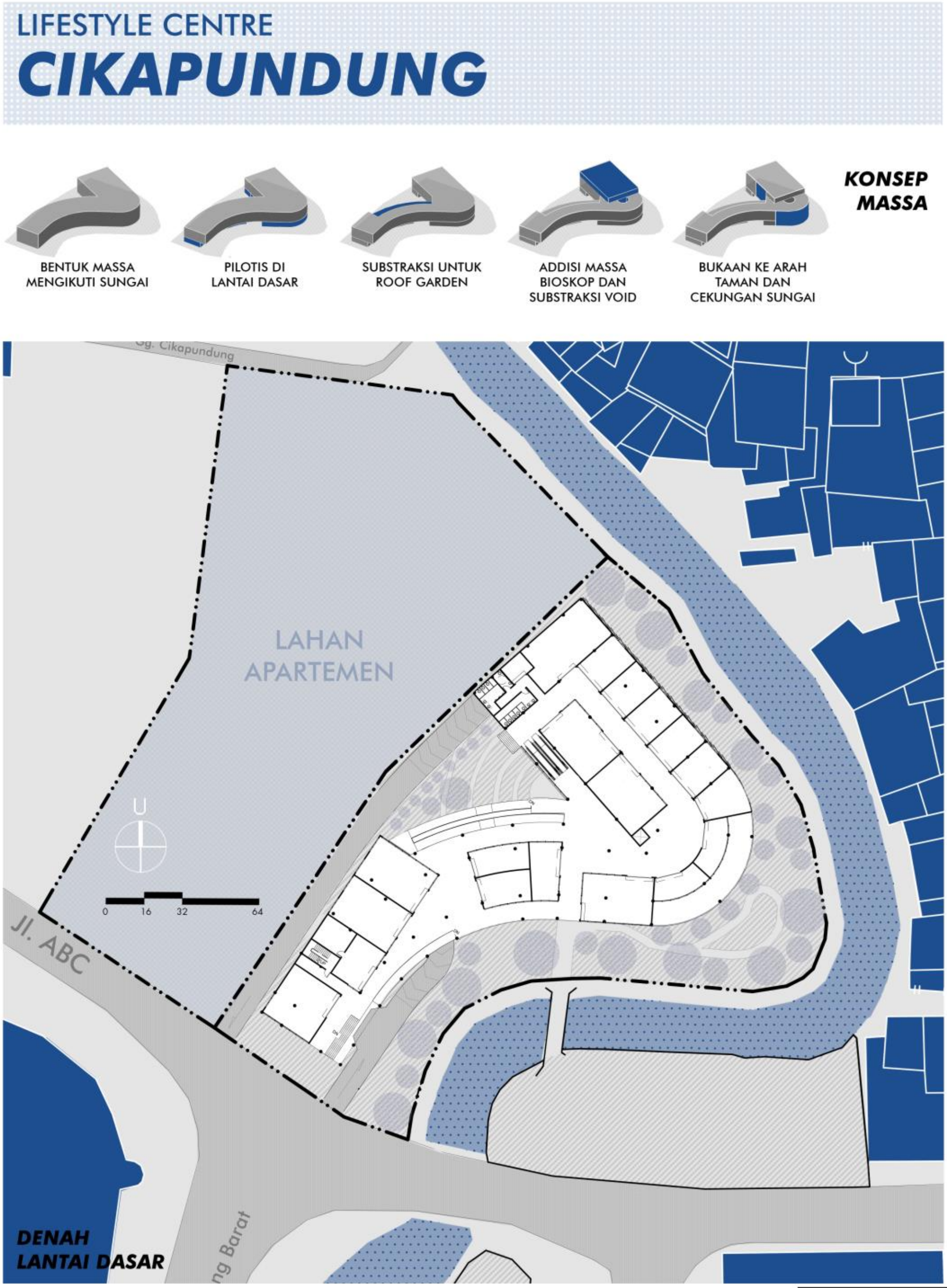
[redacted]

[redacted]

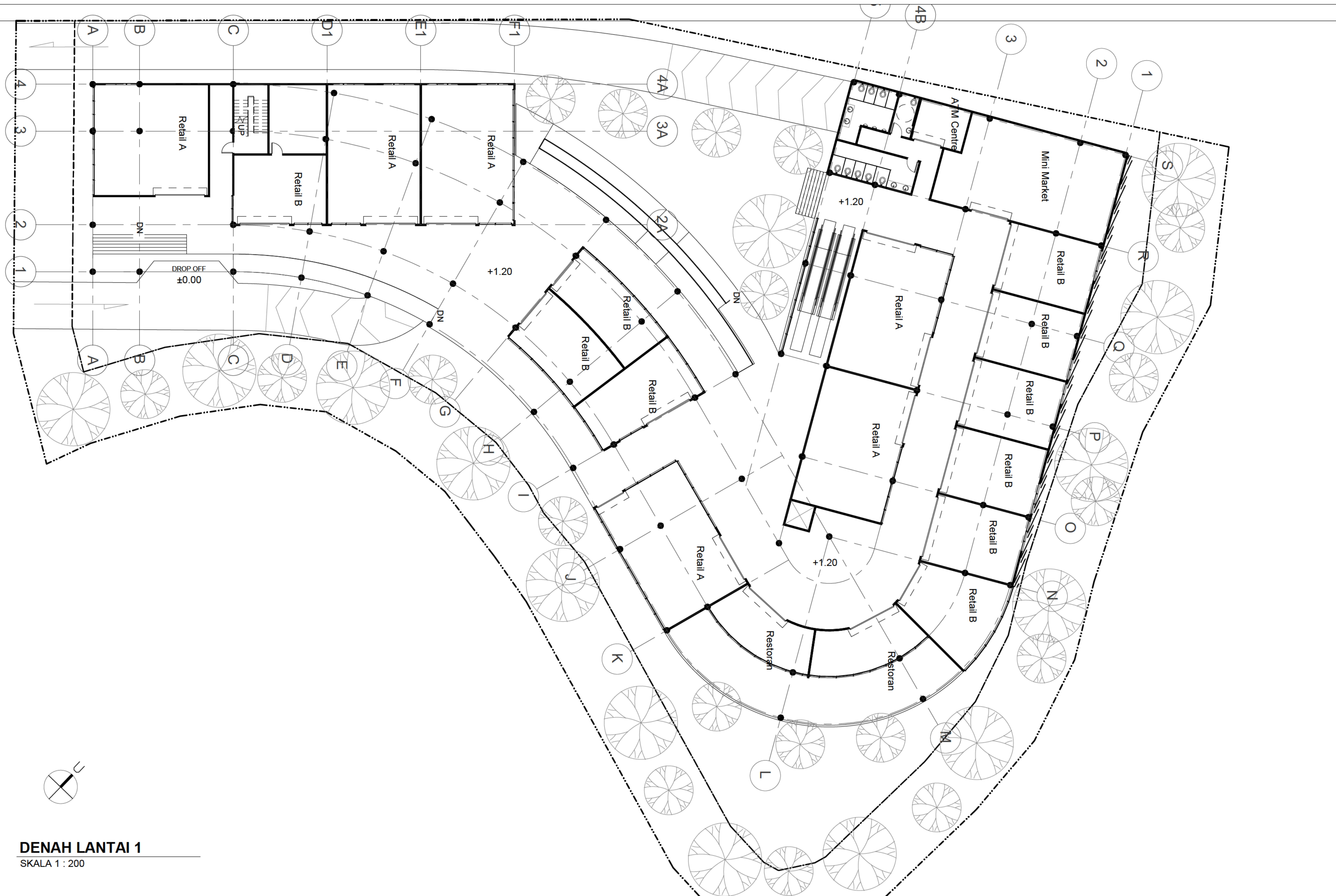
[redacted]

[redacted]

Appendix D Drawing of Project Z (Chapter 6)



[redacted]



DENAH LANTAI 1

SKALA 1 : 200

PROGRAM STUDI ARSITEKTUR SEKOLAH ARSITEKTUR PERENCANAAN DAN PENGEMBANGAN KEBIJAKAN INSTITUT TEKNOLOGI BANDUNG	AR 3290 STUDIO PERANCANGAN ARSITEKTUR IV SEM 2 - 2019/2020	TUGAS 1: *LIFESTYLE CENTER*	KOORDINATOR : [redacted] PEMBIMBING: [redacted]	NAMA : [redacted] NIM: [redacted]	TANGGAL : [redacted] NO/JML LBR: [redacted]

Appendix E Design Brief for LC Project – Chapter 7

Program Studi Arsitektur
Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan
Institut Teknologi Bandung

AR 3290 – Studio Perancangan Arsitektur IV
Semester II – 2020/2021

TUGAS 1

Lifestyle Center bagi Kaum Muda: Merancang dengan Pendekatan *Placemaking*

Koordinator: Dr. Ir. Lily Tambunan, M.T.

Pembimbing:
Dr. Ir. Lily Tambunan, M.T.
Ir. Budi Faisal, MAUD., M.L.A., Ph.D.
Dr. Mochamad Prasetiyo Effendi Yasin, M.Arch., MAUD.
Dr. Ir. Agustinus Adib Abadi, M.Sc.
Dr. Agus Suharjono Ekomadyo, ST., MT.
Dr.Eng. Bambang Setia Budi, S.T., M.T.
Ir. Wiwik Dwi Pratiwi, MES., Ph.D.
Dr.Ing. Ir. Heru Wibowo Poerbo, , MURP.
Dr.Eng M. Donny Koerniawan, S.T., M.T.
M. Jehansyah Siregar, S.T., M.T., Ph.D.
Permana, S.T., M.T.
Ir. Tri Yuwono, MT.
Dr. I. Nyoman Teguh Pradisha, S.T., M.T.
Harry Mufrizon, S.T., M.T., M.S.E., M.Ars.
Annisa Safira Riska, S.Ars., M. Ars
Feni Kurniati, S. Ars., M.T.

Asisten Akademik:
Ahmad Zuhdi 'Allam, ST., M.Hum.

Asisten Studio:
Heidi Aisha, S.Ars.

Penjelasan Tugas 1:
Selasa, 19 Januari 2021

Pengumpulan Tugas 1 (Bagian A):
Selasa, 2 Februari 2021, 15.00 WIB

***Pin-up* Kelompok ke-1**:
Kamis, 4 Februari 2021, 07.00-10.30 WIB

Pengumpulan Tugas 1 (Bagian B):
Kamis, 4 Maret 2021, 10.30 WIB

***Pin-up* Kelompok ke-2**:
Selasa, 9 Maret 2021, 08.50-12.20 atau 13.20-15.00 WIB

Pengumpulan untuk *Studio Jury* (Bagian A, B, dan C):
Selasa, 16 Maret 2021, 12.20 WIB (Bagian A & B)
Selasa, 16 Maret 2021, 15.00 WIB (Bagian C)

***Studio Jury* (Lintas Kelompok)**:
Kamis, 18 Maret 2021, 08.50-12.20 atau 13.20-15.00 WIB

Waktu:
9 Minggu

"Ruang yang awalnya tidak dapat dibedakan dapat berubah menjadi sebuah tempat seiring dengan kita mengenalnya dengan lebih baik dan memberikannya nilai … Ide dari "ruang" dan "tempat" membutuhkan satu sama lain dalam menghadirkan makna … Selanjutnya, jika kita mengartikan ruang sebagai yang memungkinkan gerakan, maka tempat adalah sebuah jeda; ***setiap jeda dalam gerakan memungkinkan sebuah lokasi bertransformasi menjadi tempat****". (Tuan, 1977)*

"Tempat ada karena kegiatan. Orang-orang melangsungkan aktivitas dalam sebuah tempat. Apa yang mereka lakukan, dalam hal ini, bertanggung jawab dalam memberikan makna yang dimiliki sebuah tempat. … ***Ruang menjadi sebuah tempat saat ia digunakan dan memiliki kehidupan****". (Cresswell, 2009)*

1

Program Studi Arsitektur
Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan
Institut Teknologi Bandung

AR 3290 – Studio Perancangan Arsitektur IV
Semester II – 2020/2021

TUGAS 1

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Annisa Safira Riska, S.Ars., M. Ars
Feni Kurniati, S. Ars., M.T.

Asisten Akademik:
Ahmad Zuhdi 'Allam, ST., M.Hum.

Asisten Studio:
Heidi Aisha, S.Ars.

Penjelasan Tugas 1:
Selasa, 19 Januari 2021

Pengumpulan Tugas 1 (Bagian A):
Selasa, 2 Februari 2021, 15.00 WIB

***Pin-up* Kelompok ke-1**:
Kamis, 4 Februari 2021, 07.00-10.30 WIB

Pengumpulan Tugas 1 (Bagian B):
Kamis, 4 Maret 2021, 10.30 WIB

***Pin-up* Kelompok ke-2**:
Selasa, 9 Maret 2021, 08.50-12.20 atau 13.20-15.00 WIB

Pengumpulan untuk *Studio Jury* (Bagian A, B, dan C):
Selasa, 16 Maret 2021, 12.20 WIB (Bagian A & B)
Selasa, 16 Maret 2021, 15.00 WIB (Bagian C)

***Studio Jury* (Lintas Kelompok)**:
Kamis, 18 Maret 2021, 08.50-12.20 atau 13.20-15.00 WIB

Waktu:
9 Minggu

*"Ruang yang awalnya tidak dapat dibedakan dapat berubah menjadi sebuah tempat seiring dengan kita mengenalnya dengan lebih baik dan memberikannya nilai … Ide dari "ruang" dan "tempat" membutuhkan satu sama lain dalam menghadirkan makna … Selanjutnya, jika kita mengartikan ruang sebagai yang memungkinkan gerakan, maka tempat adalah sebuah jeda; **setiap jeda dalam gerakan memungkinkan sebuah lokasi bertransformasi menjadi tempat**". (Tuan, 1977)*

*"Tempat ada karena kegiatan. Orang-orang melangsungkan aktivitas dalam sebuah tempat. Apa yang mereka lakukan, dalam hal ini, bertanggung jawab dalam memberikan makna yang dimiliki sebuah tempat. … **Ruang menjadi sebuah tempat saat ia digunakan dan memiliki kehidupan**". (Cresswell, 2009)*

PENDAHULUAN

Konsep *place* (tempat) dalam perancangan arsitektur, secara sederhana digunakan untuk membedakan antara *space* (ruang) dengan *place* (tempat), di mana *place* (tempat) adalah *space* (ruang) yang mempunyai makna. Secara tata bentuk, ruang bisa dibentuk mengomposisi elemen horizontal, vertikal, dan gabungan keduanya (Ching, 2007:96-160). *Place* tercipta karena komposisi bentuk pada ruang tersebut (*form*), aktivitas pengguna (*activities*), dan citra dari penggunaan ruang tersebut (*images*) (Montgomery, 1998:98). Desain arsitektur bertema *place-making* secara sederhana adalah menggubah ruang dan bentuk dengan membayangkan bagaimana tempat tersebut akan hidup oleh aktivitas dan memberikan citra yang baik bagi pengggunanya. Proses tersebut akan tergantung dari interpretasi dan reaksi terhadap setting ruang yang ada (Stokowski, 2002 ; Williams, 2002).

Creative Placemaking adalah proses berbasis komunitas/ kelompok kreatif komprehensif yang menggunakan seni dan ekspresi budaya untuk menciptakan atau meremajakan ruang. Proses ini bertujuan untuk menganalisis nilai karakter suatu tempat dan dapat menginspirasi masyarakat di dalamnya. (Clarke, 2017)

Tugas 1 AR3290 ini menitikberatkan pada tema "penciptaan tempat" *(place-making*). Kasus proyek yang dipilih adalah fasilitas *Lifestyle Center* di kota Bandung. "*Place-making*" yang dimaksud dalam tugas ini adalah menciptakan tempat yang aman, nyaman yang dapat menjadi wadah aktualisasi diri bagi seluruh masyarakat Kota Bandung.

Kota Bandung memiliki potensi besar dalam bidang kreatif, terutama pada kalangan muda yang aktivitas kreatifnya dikenal menjadi salah satu aktivitas yang mampu menarik minat pengunjung dan menghidupkan lokasi-lokasi di Bandung. Kota kreatif adalah konsep yang muncul di akhir abad 20, kota kreatif memiliki konteks spasial terkait kreativitas, pencarian kreativitas individual dan industri, serta menyarankan potensi pembangunan ekonomi. (Nallari, Griffith dan Yusuf, 2012 : 65-72). Pada konteks yang lebih kecil, prinsip-prinsip kreatif tersebut dapat diaplikasikan kepada lahan perancangan yaitu area Pasar Kosambi. Pasar Kosambi merupakan salah satu pasar yang sudah lama berdiri di Kota Bandung. Meski sempat terbakar, aktivitas area tersebut kembali hidup setelah mengalami renovasi. Tidak hanya toko-toko, aktivitas pasar kini juga diramaikan dengan adanya ruang kreatif bagi kalangan muda untuk mengembangkan industri kreatif. Salah satunya adalah kehadiran *creative space* di area tersebut.

Melalui tugas ini, mahasiswa diharapkan mampu mengembangkan kemampuan untuk merancang bangunan melalui eksplorasi gubahan ruang dan bentuk dan mengintegrasikannya dengan konteks tapak, aspek fungsi dan aspek keterbangunan. Beberapa mata kuliah yang terkait seperti AR2250 Gubahan Bentuk Arsitektur dan AR3110 Perancangan Tapak menjadi relevan untuk dilihat kembali perannya pada studio ini. Melalui tugas ini pula mahasiswa dengan sadar mengimplementasikan konsep "*place*" dalam rancangan bangunan, untuk menjadikan arsitektur lebih mempunyai makna bagi penggunanya.

TUJUAN

1. Menyusun program arsitektur meliputi kajian tapak, kajian pengguna, dan studi preseden, untuk merumuskan tujuan dan sasaran perancangan, program ruang, hubungan antar ruang, dan gagasan atau konsep awal yang mampu memberikan bayangan tentang keberhasilan bangunan yang akan dirancang.
2. Menyusun berbagai alternatif zonasi ruang pada tapak yang memandu perancangan bangunan melalui proses analisis tapak meliputi: kajian peraturan bangunan, analisis konteks sekitar tapak, analisis pencapaian lahan, analisis topografi lahan, dan analisis potensi tapak.
3. Membuat rancangan skematis yang menunjukkan organisasi ruang dan gagasan wujud 3 dimensi bangunan
4. Mengembangkan gubahan bentuk/ruang bangunan sesuai dengan kaidah-kaidah estetika dengan mempertimbangkan konteks tapak dan integrasi dengan organisasi ruang yang telah disusun sebelumnya
5. Mengembangkan pra-rancangan (*preliminary design*) bangunan dengan mempertimbangkan aspek keterbangunan, fungsi, dan keindahan bangunan.

6. Menyajikan hasil rancangan secara grafis sesuai standar gambar pra-rancangan.
7. Mengembangkan sikap belajar yang positif selama proses mengerjakan tugas.

KRITERIA KINERJA

Kriteria kinerja mahasiswa (*Students Performance Criteria*/SPC) merupakan indikator kompetensi yang harus dicapai oleh mahasiswa setelah mengerjakan tugas, meliputi:

1. Mampu merumuskan program arsitektur yang memandu rancangan fungsional bangunan (SPC KAAB 16).
2. Mahasiswa mampu memahami prinsip-prinsip estetika visual dan menerapkannya dalam perancangan arsitektur secara dua dan tiga dimensi (SPC KAAB 15)
3. Mampu merancang arsitektur secara komprehensif berbasis pertimbangan aspek lingkungan dan keberlanjutan (SPC KAAB 17) dan memanfaatkan konsep yang dihasilkan terhadap dari analisis pengguna dan konteks lingkungan (SPC KAAB 18)
4. Mampu memilih material, komponen, dan sistem struktur bangunan yang terintegrasi dalam rancangan bangunan (SPC KAAB 20)
5. Mahasiswa mampu merancang arsitektur dengan prinsip "*barrier free*" bagi penyandang disabilitas dan lansia (SPC KAAB 19)
6. Mampu menyajikan gagasan arsitektur secara grafis (SPC KAAB 04) dengan memanfaatkan aneka media dan teknologi informasi untuk menunjukkan proses desain yang dilakukan (SPC KAAB 05 dan 06).
7. Mahasiswa mampu menyajikan gambar arsitektur sesuai dengan standar gambar pra-rancangan (SPC KAAB 02)
8. Mahasiswa menyadari pentingnya sikap positif dan bekerja secara kolektif untuk mencapai hasil yang terbaik (SPC KAAB 03)

TINJAUAN TUGAS

Pemerintah Kota Bandung berencana untuk membangun satu buah *Lifestyle Center* yang berdampingan dengan ITC Kosambi di daerah Jalan Baranangsiang. Luas lahan keseluruhan kurang lebih 6.200 m². Peserta harus merancang sebuah bangunan Lifestyle Center pada lokasi yang telah ditunjukkan di peta terlampir. Peserta harus mempertimbangkan kondisi lahan dan lingkungan di sekitarnya untuk mengkaji potensi dan kendala perancangan pada lahan tersebut. Sesuai dengan RDTR Kota Bandung tahun 2015 aturan membangun yang berlaku pada lahan tersebut adalah: KDB maksimum 70% ; KLB: 3,5 ; KDH: min. 20%, GSB depan: 10 m, GSB samping: 4 m. Peserta diminta untuk memenuhi kebutuhan ruang seperti yang tertera pada tabel program ruang di bawah ini.

No.	Nama Ruang	Jumlah Ruang	Ukuran Ruang	Luas Ruang	Total
A	**FASILITAS UTAMA**				
1	**Retail Lot (produk untuk anak muda: *crafts*, fesyen, dll.)**				**500 m²**
	Lots (area penjualan dan counter) (termasuk sirkulasi 30%)	5-10 unit	50 -100 m²/lot		
2	**Minimarket (produk organik, *pastry artisan*, dll.)**				**117 m²**
	R. Penjualan	1 unit	70 m²/unit	70 m²	
	Kasir	2 unit	5 m²/unit	10 m²	
	Gudang	1 unit	10 m²/unit	10 m²	
	Sirkulasi 30%			27 m²	
3	**ATM Center**				**4 m²**

	ATM Booth	2	unit	2	m²/unit	4 m²	
4	**Restoran**						**172,4 m²**
	Area makan *indoor* per restoran	50	orang	1,8	m²/orang	90 m²	
	Counter	2	unit	1,2	m²/unit	2.4 m²	
	Dapur (15-20% luas restoran)	1	unit	20	m²/unit	20 m²	
	Gudang	1	unit	5	m²/unit	5 m²	
	Ruang karyawan	6	orang	2,5	m²/orang	15 m²	
	Sirkulasi 30%					40 m²	
5	**Kafe**						**800 m²**
	Lots kafe	8-16	unit	50-100	m²/lot		
	Area makan *indoor*	15-30	orang	1,8	m²/orang		
	Counter	1	unit	1,2	m²/unit		
	Dapur (15-20% luas kafe)	1	unit	1	m²/orang		
	Gudang	1	unit	4	m²/unit		
	(termasuk sirkulasi 30%)						
6	**Kantor Pengelola**						**48 m²**
	Ruang Manajer, Sekretaris, Personalia, Keuangan	4	orang	5	m²/orang	20 m²	
	Ruang Marketing	2	orang	5	m²/orang	10 m²	
	Toilet, wastafel	1	unit	2,5	m²/orang	2,5 m²	
	Sirkulasi 30%					15,5 m²	
7	**Toilet**						**32,5 m²**
	Toilet Pria						
	WC kubikal	2	unit	1,8	m²/orang	3,6 m²	
	Urinal	2	unit	0,9	m²/orang	1,8 m²	
	Wastafel	2	unit	0,75	m²/orang	1,5 m²	
	Toilet Wanita						
	WC kubikal	4	unit	1,8	m²/orang	7,2 m²	
	Wastafel	4	unit	0,75	m²/orang	3 m²	
	Toilet Difabel	1	unit	4,9	m²/orang	4.9 m²	
	Janitor	2	unit	1,5	m²/orang	3 m²	
	Sirkulasi 30%					7,5 m²	
8	**Ruang terbuka (ruang multifungsi dan sirkulasi *outdoor*)** (termasuk area *outdoor* untuk masing-masing kafe [2 meja @4 kursi])						**540 m²**
	LUAS TOTAL FASILITAS UTAMA						**2.213,9 m²**
B	**FASILITAS PARKIR KENDARAAN DAN TAXI (POOL)**						
1	**Area tunggu transportasi online**						**88 m²**
	Ojek online	15	unit	1,2	m²/motor	18 m²	
	Taksi online	4	unit	12,5	m²/mobil	50 m²	
	Ruang tunggu driver pesan online (tersebar di beberapa titik)	5-6	unit	3-4	m²	20 m²	
2	**Parkir kendaraan (*basement*)** (tidak termasuk sepeda; sepeda dapat dibawa/disimpan di dekat retail/kafe)						**408,5 m²**

	Sepeda motor	80	unit	1,2	m²/motor	96 m²	
	Mobil	17	unit	12,5	m²/mobil	212,5 m²	
	Sirkulasi 30%					100 m²	
	LUAS TOTAL FASILITAS PARKIR DAN TAXI						**496,5 m²**
	LUAS TOTAL A DAN B						**2710,4 m²**
C	**FASILITAS PENUNJANG/UTILITAS (dihitung oleh mahasiswa)**						
	Ruang ME (Genset, Ruang Pompa, *ground tank*, Ruang Panel Listrik)						
	Tempat Penyimpanan Sampah Sementara						
	Loading dock terpusat						
	Ruang Karyawan						
	Sirkulasi 30%						
	TOTAL LUAS FASILITAS PENUNJANG/UTILITAS (10% LUAS A+ B)						**271,04 m²**
	TOTAL LUAS LIFE STYLE CENTER						**2.981,44 m²**
	(PEMBULATAN)						**3.000 m²**

LUARAN TUGAS

Bagian A: Analisis, Konsep, *One line Plan*, Maket Studi

Jadwal:
Selasa, 2 Februari 2021, 15.00 WIB. Pengumpulan melalui fitur Assignment MS Teams.

Luaran:
1. Analisis tapak (kondisi fisik lingkungan tapak, bentuk tapak, topografi, termal (suhu, hujan, matahari), bentuk bangunan di sekitar tapak, akses ke dan dari tapak, vegetasi, utilitas)
2. Analisis jenis aktivitas dan pengguna (jenis pengguna, jumlah, durasi, alur kegiatan/*flow of activity*)
3. Studi Preseden dan kesimpulan hasil studi preseden
4. Konsep tapak (zonasi tapak, bentuk dan pola massa, sirkulasi, ruang terbuka, vegetasi, utilitas, keamanan/aksesibilitas, integrasi dengan konteks)
5. Konsep bangunan (zonasi ruang, bentuk dan susunan ruang, sirkulasi, selubung, struktur, material, utilitas)
6. Maket Studi, skala 1:200
7. Rencana Tapak (Site Plan), skala 1:200
8. Denah masing-masing lantai pada setiap massa bangunan, skala 1:200

Ketentuan:
- Seluruh berkas pengumpulan dikumpulkan dalam format ukuran standar A2 (420mm x 594mm) dengan orientasi lanskap. Kop sudah tertera di kertas tersebut.
- Maket studi menggunakan bahan berwarna monokrom: putih atau abu-abu atau coklat atau krem.
- Seluruh gambar dikerjakan dengan menggunakan teknik manual.
- Gambar dikumpulkan menjadi satu berkas berformat *.pdf dengan format penamaan: **[Kel X]_[NIM]_[Nama]_[Tugas 1A]**
- Ukuran berkas tidak melebihi 20 MB.
- Berkas yang telat dan tidak sesuai ketentuan akan ditolak.

Bagian B: Gambar Pra-rancangan

Jadwal:
Kamis, 4 Maret 2021, 10.30 WIB. Pengumpulan melalui fitur Assignment Ms. Teams.

Luaran:

1.	Rencana Induk (Master Plan)	skala 1:500
2.	Rencana Tapak (Site Plan)	skala 1:250
3.	Denah Lantai 1 (Ground Plan)	skala 1:250
4.	Denah Lantai 2 (2nd Floor Plan)	skala 1:250
5.	Denah Lantai 3 (3rd Floor Plan)	skala 1:250
6.	Tampak 1 (Elevation 1)	skala 1:250
7.	Tampak 2 (Elevation 2)	skala 1:250
8.	Tampak 3 (Elevation 3)	skala 1:250
9.	Tampak 4 (Elevation 4)	skala 1:250
10.	Potongan 1 (Section 1)	skala 1:250
11.	Potongan 2 (Section 2)	skala 1:250
12.	Potongan Prinsip 1 (Detailed Section 1)	skala 1:50
13.	Potongan Prinsip 2 (Detailed Section 2)	skala 1:50
14.	Exploded Axonometric atau Gambar lain yang memberikan informasi penting (skala disesuaikan)	

Ketentuan:

- Seluruh berkas pengumpulan dikumpulkan dalam format ukuran standar A2 (420mm x 594mm) dengan orientasi lanskap. Kop sudah tertera di kertas tersebut.
- Mahasiswa diperkenankan untuk menggunakan teknik gambar manual maupun digital.
- Gambar dikumpulkan menjadi satu berkas berformat *.pdf dengan format penamaan: **[Kel X]_[NIM]_[Nama]_[Tugas 1B]**
- Ukuran berkas tidak melebihi 20 MB.
- Berkas yang telat dan tidak sesuai ketentuan akan ditolak.

Bagian C: Poster Rancangan

Jadwal:
Selasa, 16 Maret 2021, 15.00 WIB. Pengumpulan melalui fitur Assignment Ms. Teams.

Luaran:

1. **Poster Rancangan**, memperlihatkan:
   a. Konsep dan berbagai kajian utama dalam perancangan.
   b. Perspektif Suasana, minimal 4 gambar yang memperlihatkan konsep perilaku pada rancangan.
   c. Perspektif Mata Burung, minimal 1 gambar.
2. **Berkas Digital Final**, meliputi berkas pengumpulan Bagian A, Bagian B dan Bagian C, dengan foto maket sebanyak minimal 4 foto dari sudut pandang yang berbeda.

Ketentuan:

- Poster dikumpulkan dalam format kertas gambar ukuran standar internasional A2 (420mm x 594mm) dengan orientasi potret, berjumlah maksimum 2 lembar.
- Diperkenankan untuk menggunakan teknik gambar manual maupun digital.
- Berkas digital final dikumpulkan melalui proses unggah ke alamat web yang akan ditentukan kemudian.
- Gambar dikumpulkan menjadi satu berkas berformat *.pdf dengan format penamaan: **[Kel X]_[NIM]_[Nama]_[Tugas 1 PinUp]**

Appendix F Design Brief for APT Project – Chapter 7

Program Studi Arsitektur
Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan
Institut Teknologi Bandung

AR 3290 – Studio Perancangan Arsitektur IV
Semester II – 2020/2021

TUGAS 2
Apartemen

Koordinator: Dr. Ir. Lily Tambunan, M.T.

Pembimbing:
Dr. Ir. Lily Tambunan, M.T.
Ir. Budi Faisal, MAUD., M.L.A., Ph.D.
Dr. Mochamad Prasetiyo Effendi Yasin, M.Arch., MAUD.
Dr. Ir. Agustinus Adib Abadi, M.Sc.
Dr. Agus Suharjono Ekomadyo, ST., MT.
Dr.Eng. Bambang Setia Budi, S.T., M.T.
Ir. Wiwik Dwi Pratiwi, MES., Ph.D.
Dr.Ing. Ir. Heru Wibowo Poerbo, , MURP.
Dr.Eng M. Donny Koerniawan, S.T., M.T.
M. Jehansyah Siregar, S.T., M.T., Ph.D.
Permana, S.T., M.T.
Ir. Tri Yuwono, MT.
Dr. I. Nyoman Teguh Prasidha, S.T., M.T.
Harry Mufrizon, S.T., M.T., M.S.E., M.Ars.
Annisa Safira Riska, S.Ars., M. Ars
Feni Kurniati, S. Ars., M.T.

Asisten Akademik:
Ahmad Zuhdi 'Allam, ST., M.Hum.

Asisten Studio:
Heidi Aisha, S.Ars.

Penjelasan Tugas 2:
Selasa, 16 Maret 2021

Pengumpulan Tugas 2 (Bagian A):
Selasa, 30 Maret 2021, 07.30 WIB

***Pin-up* Kelompok ke-1**:
Selasa, 30 Maret 2021, 07.30-12.20 WIB

Pengumpulan Tugas 1 (Bagian B):
Jumat, 23 April 2021, 21.00 WIB

Pengumpulan Tugas 1 (Bagian C):
Sabtu, 24 April 2021, 21.00 WIB

***Pin-up* Kelompok ke-2**:
Selasa, 27 April 2021, 07.30-15.00 WIB

***Studio Jury* (Lintas Kelompok)**:
Selasa, 4 Mei 2021, 07.00-15.00 WIB

Waktu:
6,5 Minggu

PENDAHULUAN

Untuk tugas 2 AR3290 Studio Perancangan Arsitektur IV, kompetensi utama yang harus dikuasai mahasiswa adalah merancang bangunan sebagai sebuah sistem. Pendekatan ini cocok untuk merancang bangunan tinggi (*highrise*) atau semi-tinggi (*midrise*) dengan ruang-ruang yang tipikal, seperti hotel, kantor sewa, atau apartemen. Pendekatan ini menjadikan rancangan bangunan disandarkan pada aturan-aturan tertentu dan relevan, dan mengintegrasikan persyaratan fungsional dan persyaratan keterbangunan sebagai fokus utama perancangan. Dengan pendekatan ini, maka fokus perancangan adalah

Program Studi Arsitektur
Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan
Institut Teknologi Bandung

AR 3290 – Studio Perancangan Arsitektur IV
Semester II – 2020/2021

TUGAS 2
Apartemen

Koordinator: Dr. Ir. Lily Tambunan, M.T.

Pembimbing:
Dr. Ir. Lily Tambunan, M.T.
Ir. Budi Faisal, MAUD., M.L.A., Ph.D.
Dr. Mochamad Prasetiyo Effendi Yasin, M.Arch., MAUD.
Dr. Ir. Agustinus Adib Abadi, M.Sc.
Dr. Agus Suharjono Ekomadyo, ST., MT.
Dr.Eng. Bambang Setia Budi, S.T., M.T.
Ir. Wiwik Dwi Pratiwi, MES., Ph.D.
Dr.Ing. Ir. Heru Wibowo Poerbo, , MURP.
Dr.Eng M. Donny Koerniawan, S.T., M.T.
M. Jehansyah Siregar, S.T., M.T., Ph.D.
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Feni Kurniati, S. Ars., M.T.

Asisten Akademik:
Ahmad Zuhdi ‘Allam, ST., M.Hum.

Asisten Studio:
Heidi Aisha, S.Ars.

Penjelasan Tugas 2:
Selasa, 16 Maret 2021

Pengumpulan Tugas 2 (Bagian A):
Selasa, 30 Maret 2021, 07.30 WIB

***Pin-up* Kelompok ke-1**:
Selasa, 30 Maret 2021, 07.30-12.20 WIB

Pengumpulan Tugas 1 (Bagian B):
Jumat, 23 April 2021, 21.00 WIB

Pengumpulan Tugas 1 (Bagian C):
Sabtu, 24 April 2021, 21.00 WIB

***Pin-up* Kelompok ke-2**:
Selasa, 27 April 2021, 07.30-15.00 WIB

***Studio Jury* (Lintas Kelompok)**:
Selasa, 4 Mei 2021, 07.00-15.00 WIB

Waktu:
6,5 Minggu

PENDAHULUAN

Untuk tugas 2 AR3290 Studio Perancangan Arsitektur IV, kompetensi utama yang harus dikuasai mahasiswa adalah merancang bangunan sebagai sebuah sistem. Pendekatan ini cocok untuk merancang bangunan tinggi (*highrise*) atau semi-tinggi (*midrise*) dengan ruang-ruang yang tipikal, seperti hotel, kantor sewa, atau apartemen. Pendekatan ini menjadikan rancangan bangunan disandarkan pada aturan-aturan tertentu dan relevan, dan mengintegrasikan persyaratan fungsional dan persyaratan keterbangunan sebagai fokus utama perancangan. Dengan pendekatan ini, maka fokus perancangan adalah mengintegrasikan antara modul struktur dengan modul ruang tipikal dan merancang sistem struktur dengan memperhatikan *lay-out* ruang tipikal, sirkulasi untuk keselamatan bangunan, dan aspek mekanikal/elektrikal yang melayani bangunan. Untuk tugas ini, kasus proyek yang dipilih adalah apartemen dengan ketinggian sedang（8 lantai）sehingga disebut sebagai *midrise apartment*. Fasilitas ini dibangun terutama untuk merespons kebutuhan hunian masyarakat kota Bandung, terutama hunian vertikal. Diharapkan selain belajar tentang pendekatan sistem dalam perancangan bangunan, mahasiswa juga mempelajari perilaku penghuni yang harus dipertimbangkan dalam merancang hunian vertikal.

TUJUAN

1. Merancang bangunan *midrise* dengan fungsi apartemen ketinggian 8 lantai dengan basemen 2 lantai.
2. Membuat konsep dan rancangan skematis, berupa a) studi massa bangunan dengan mengikuti aturan tentang intensitas bangunan (KDB, KLB, GSB); dan b) denah skematis yang memperlihatkan *lay-out* ruang tipikal, area sirkulasi, ruang bersama, dan area servis.
3. Merancang rencana tapak yang memperhatikan dan mempertimbangkan: a) fungsi dan gubahan massa bangunan yang sudah ada (eksisting); b) aksesibilitas dan sirkulasi tapak; c) fasilitas yang disediakan pada ruang luar (area penghijauan, dan area perkerasan); dan d) konteks sekitar tapak.
4. Mengembangkan pra-rancangan (*preliminary design*) apartemen yang mengintegrasikan sistem bangunan, meliputi sistem sirkulasi, sistem struktur, sistem utilitas, dan sistem selubung.
5. Menyajikan hasil rancangan secara grafis sesuai dengan standar gambar pra-rancangan.

KRITERIA KINERJA

1. Mahasiswa mampu merancang bangunan *midrise* di kawasan urban dengan pendekatan sistem bangunan (SPC KAAB 15)
2. Mahasiswa mampu menyusun program arsitektur dengan melakukan interpretasi terhadap misi dari pemrakarsa proyek, mengumpulkan data-data yang relevan, dan menurunkannya ke dalam tujuan, isu, dan konsep perancangan (SPC KAAB 10)
3. Mahasiswa mampu merancang tapak dengan mempertimbangkan:
    a. Aturan kota meliputi: Koefisien Dasar Bangunan (KDB), Koefisien Lantai Bangunan (KLB), Garis Sempadan Bangunan (GSB), dan Koefisien daerah Hijau (KDH) (SPC KAAB 29).
    b. Gubahan massa bangunan yang merespons arsitektur kota (SPC KAAB 17)
    c. Rancangan area terbuka di luar bangunan, berupa rancangan aksesibilitas dan sirkulasi, area parkir, area perkerasan, dan area hijau.
4. Mahasiswa mampu menyusun organisasi ruang (SPC KAAB 09) dengan mempertimbangkan sistem bangunan yang terintegrasi (SPC KAAB 15) termasuk integrasi dengan sistem utilitas dan servis bangunan (SPC KAAB 23)
5. Mahasiswa mampu menerapkan prinsip-prinsip keselamatan, kesehatan, dan kemudahan bangunan meliputi:
    a. Penyediaan akses untuk pemadam kebakaran, serta jalur dan sarana evakuasi saat terjadi bencana (SPC KAAB 14)
    b. Persyaratan kesehatan bangunan pada ruang-ruang yang disediakan (meliputi persyaratan pencahayaan dan penghawaan) (SPC KAAB 21)
    c. Akses dan fasilitas untuk penyandang disabilitas (SPC KAAB 13)
6. Mahasiswa mampu mempertimbangkan aspek perilaku manusia (SPC KAAB 7), dalam hal ini perilaku dan preferensi konsumen apartemen, misalnya dalam merancang penampilan bangunan atau menyediakan fasilitas tertentu
7. Mahasiswa mampu menerapkan prinsip-prinsip estetika dalam merancang bangunan, terutama dalam menggubah bentuk/ruang dan fasad bangunan (SPC KAAB 09)

8. Mahasiswa mampu merancang sistem struktur bangunan yang terintegrasi dengan organisasi ruang dan bentuk bangunan (SPC KAAB 19) dan menerapkan prinsip struktur bangunan ke dalam rancangan bangunan (SPC KAAB 20), meliputi:
    a. Rancangan sistem dan pemilihan material struktur bangunan
    b. Rancangan sistem dan pemilihan material struktur atap
    c. Penyelesaian struktur basemen
2. Mahasiswa mampu menyelesaikan detail konstruksi meliputi material yang digunakan (SPC KAAB 25) dan teknik penyambungan pada:
    a. Detail sambungan penutup atap dan detail talang
    b. Detail elemen fasad
    c. Detail hubungan permukaan tanah dan bangunan (rabat, saluran air, dll.) termasuk hubungannya dengan *basemen*
3. Mahasiswa mampu menyajikan hasil rancangan bangunan dalam luaran Gambar Prarancangan yang disajikan melalui *pin-up* (SPC KAAB 1 dan 2)

TINJAUAN TUGAS

Pemerintah Kota Bandung dan pengembang berencana untuk membangun apartemen kelas menengah yang berada dalam satu kompleks dengan Lifestyle Center di kawasan Kosambi Trade Center di Jalan Baranangsiang, Kota Bandung, dengan luas lahan untuk apartemen 1.722 m^2. Adapun luas bangunan yang dirancang adalah ± 11.500 m^2 dan memiliki 1 lantai podium, 7 lantai tipikal hunian, dan 3 lantai basemen untuk parkir dan utilitas.

Sebagai kelanjutan dari Tugas 1, peserta diminta untuk merancang apartemen pada lokasi yang telah ditetapkan pada tugas tersebut. Peserta harus mempertimbangkan kondisi lingkungan sekitar, terutama bangunan Lifestyle Center yang telah dirancang pada Tugas 1. Kajian potensi dan kendala perancangan pada lahan harus dilakukan oleh masing-masing peserta dengan melihat kondisi lahan dan daerah di sekitarnya.

Isu Perancangan

1. Interaksi sosial pada hunian berkepadatan tinggi.
2. Sistem bangunan: mengintegrasikan sistem sirkulasi, sistem struktur, sistem utilitas, dan sistem selubung dalam rancangan bangunan.
3. Efisiensi: mengoptimalkan nilai lahan untuk hunian berkepadatan tinggi.
4. Persyaratan kelayakan fungsi bangunan: meliputi keselamatan (kebakaran, gempa bumi), keamanan (kriminalitas), kenyamanan/kesehatan, dan aksesibilitas pada bangunan.
5. Preferensi dan perilaku penghuni.

Fasilitas yang Harus Disediakan

1. *Entrance* diperbolehkan dari Lifestyle Center
2. *Entrance* parkir di basemen diperbolehkan dari Lifestyle Center, tetapi ramp menuju basemen 2 dan/atas basemen 3 tetap ada di lahan apartemen.
3. Unit hunian apartemen, berupa unit dengan tipe:
    - Studio (luas kotor 24-32 m^2)
    - Tipe 1 Kamar Tidur (1 KT) (luas kotor 32-36 m^2)
    - Tipe 2 Kamar Tidur (2 KT) (luas kotor 48-54 m^2)

    Unit hunian apartemen disediakan pada lantai 2 sampai lantai 8 bangunan. Perbandingan jumlah unit Studio, 1 KT, dan 2 KT adalah 3 : 2 : 1.
4. Fasilitas bersama (kantor pengelola, penitipan anak/*playground*, dll.), fasilitas komersial (*minimarket, laundry,* dll.), yang diletakkan pada lantai dasar bangunan.

5. Fasilitas olahraga (*gym* dan kolam renang rekreasi) untuk kegiatan penghuni.
6. Fasilitas serba guna *indoor/outdoor* untuk kegiatan penghuni atau perhimpunan penghuni
7. Fasilitas parkir untuk mobil dan motor yang diletakkan basemen (3 lantai). Jumlah parkir mobil: 1 mobil/5 unit apartemen. Jumlah parkir motor: 1 motor/1 unit apartemen.
8. Fasilitas transportasi vertikal (lift penghuni) yang dihitung sesuai kebutuhan dan *shaft* pemadam kebakaran yang dihitung sesuai persyaratan peraturan yang berlaku.
9. Fasilitas pendukung: genset, ruang ME, ruang satpam, *ground water tank*, tempat penampungan sampah, dan fasilitas lain sesuai dengan hasil studi preseden dan literatur
10. Lokasi titik kumpul (*assembly point*).

Peraturan bangunan yang diberlakukan pada kedua lahan tersebut adalah:
KDB: 70%; KLB: 3,5; KDH: minimal 20%; serta GSB dan GSS yang tertera pada gambar. **Perhitungan KLB menggunakan asumsi bahwa apartemen adalah satu kesatuan dengan *Lifestyle Center*.**

LUARAN TUGAS

Bagian A: Analisis, Konsep, dan *One-line Drawing*

Jadwal pengumpulan:
Selasa, 30 Maret 2021 pukul 07.30 WIB. Pengumpulan melalui fitur Assignment Ms. Teams.

Luaran:
1. Analisis tapak
2. Analisis jenis aktivitas dan pengguna (jenis pengguna, jumlah, durasi, alur kegiatan/*flow of activity*)
3. Studi Preseden dan kesimpulan hasil studi preseden
4. Konsep tapak (zonasi tapak, bentuk massa, sirkulasi, ruang terbuka, vegetasi, utilitas, keamanan/aksesibilitas, integrasi dengan konteks)
5. Konsep bangunan (zonasi ruang, bentuk dan susunan ruang, sirkulasi, selubung, struktur, material, utilitas)
6. Rencana Tapak *(Site Plan)* skala 1:200
7. Denah Lantai 1 *(Ground Plan)* skala 1:200
8. Denah Lantai Tipikal skala 1:200
9. Denah Lantai Lainnya skala 1:200
10. Maket Studi skala bebas (opsional)

Ketentuan:
- Seluruh berkas pengumpulan dikumpulkan dalam format ukuran standar A2 (420mm x 594mm) dengan orientasi lanskap. Kop sudah tertera di kertas tersebut.
- Maket studi menggunakan bahan berwarna monokrom: putih atau abu-abu atau coklat atau krem.
- Seluruh gambar dikerjakan dengan menggunakan teknik manual.
- Gambar dikumpulkan menjadi satu berkas berformat *.pdf dengan format penamaan: **[Kel X]_[NIM]_[Nama]_[Tugas 2A]**
- Ukuran berkas tidak melebihi 20 MB.
- Berkas yang telat dan tidak sesuai ketentuan akan ditolak.

Bagian B: Gambar Pra-rancangan

Jadwal pengumpulan:
Jumat, 23 April 2021, pukul 21.00 WIB. Pengumpulan melalui Assignment Ms. Teams.

Luaran:

1.	Master Plan yang memperlihatkan *Lifestyle Center* dan Apartemen (skala bebas)	
2.	Rencana Tapak *(Site Plan)*	skala 1:500
3.	Denah Lantai 1 *(Ground Plan)*	skala 1:200
4.	Denah Lantai Tipikal	skala 1:200
5.	Denah Basemen	skala 1:200
6.	Denah Lantai Lainnya	skala 1:200
7.	Denah Core	skala 1:100
8.	Tampak (4 sisi)	skala 1:200
9.	Potongan Memanjang	skala 1:200
10.	Potongan Melintang	skala 1:200
11.	Potongan Prinsip	skala 1:50
12.	Potongan perspektif	(skala bebas)
13.	Rencana Skematik Sistem Utilitas	(skala bebas)
14.	Perspektif mata burung dan mata manusia	
15.	Gambar lain yang memberikan informasi integrasi sistem bangunan	

Ketentuan:

- Seluruh berkas pengumpulan dikumpulkan dalam format ukuran standar A2 (420mm x 594mm) dengan orientasi lanskap. Kop sudah tertera di kertas tersebut.
- Mahasiswa diperkenankan untuk menggunakan teknik gambar manual maupun digital.
- Gambar dikumpulkan menjadi satu berkas berformat *.pdf dengan format penamaan: **[Kel X]_[NIM]_[Nama]_[Tugas 2B]**
- Ukuran berkas tidak melebihi 20 MB.
- Berkas yang telat dan tidak sesuai ketentuan akan ditolak.

Bagian C: Poster Rancangan

Jadwal pengumpulan:

Paling lambat Sabtu, 24 April 2021, pukul 21.00 WIB. Pengumpulan melalui fitur Assignment Ms. Teams.

Luaran:

Poster Rancangan

Ketentuan:

- Poster dikumpulkan dalam format kertas gambar ukuran standar internasional A2 (420mm x 594mm) dengan orientasi potret, berjumlah maksimum 2 lembar.
- Diperkenankan untuk menggunakan teknik gambar manual maupun digital.
- Berkas digital final dikumpulkan melalui proses unggah ke alamat web yang akan ditentukan kemudian.
- Gambar dikumpulkan menjadi satu berkas berformat *.pdf dengan format penamaan: **[Kel X]_[NIM]_[Nama]_[Tugas 2C]**
- Ukuran berkas tidak melebihi 20 MB.
- Berkas yang telat dan tidak sesuai ketentuan yang diminta akan ditolak dan tidak dapat diikutsertakan dalam Studio Jury Tugas

KETENTUAN KEHADIRAN

Peserta wajib mengikuti seluruh perkuliahan dan kegiatan studio yang diadakan.

1. Kehadiran kuliah minimal sebanyak 6 kali dari 7 kali perkuliahan selama Tugas 1

2. Kehadiran studio minimal 80% selama Tugas 1 (7 pekan+)
3. Asistensi minimal 1 kali dalam 1 pekan (dibuktikan dengan kartu asistensi)

Peserta yang tidak memenuhi ketentuan di atas, akan dikenakan sanksi, mulai dari pengurangan nilai, tidak diperkenankan mengikuti UAS hingga mendapat nilai E.

TATA LAKSANA KULIAH DAN STUDIO

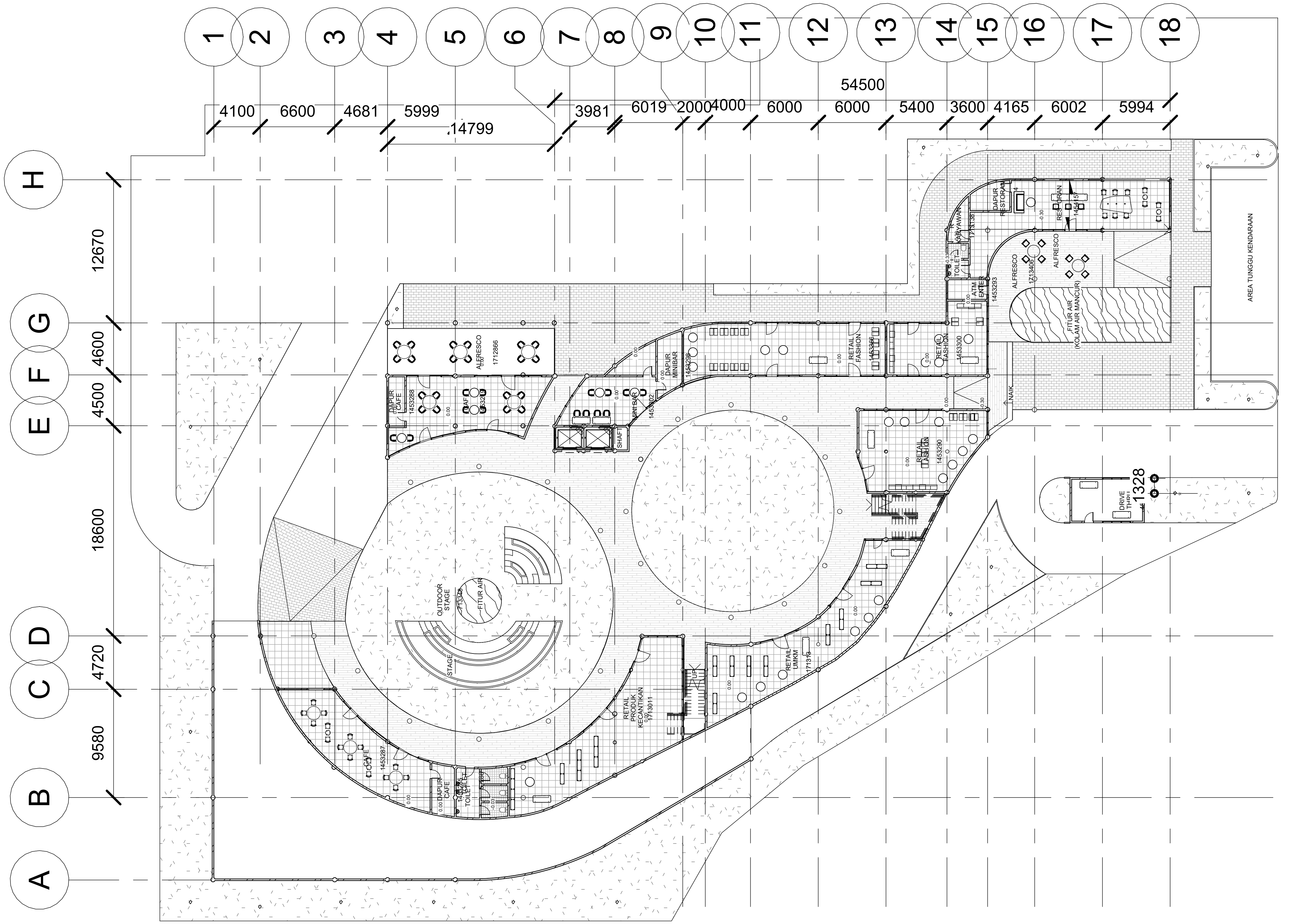
- Kuliah dimulai pada 7.00 WIB. Pengisian/pemeriksaan kehadiran ditutup pada 7.20 WIB.
- Peserta yang datang setelah 7.20 WIB diperkenankan mengikuti perkuliahan, namun tidak diperkenankan untuk mengisi daftar hadir, dan dalam perhitungan kehadiran dianggap tidak hadir.
- Prosedur permohonan izin ketidakhadiran maupun tidak hadir karena sakit, mengikuti ketentuan ITB.
- Tata tertib dan tata laksana studio mengacu pada prosedur studio yang telah diterbitkan oleh Program Studi AR ITB.

JADWAL PERKULIAHAN TUGAS 2 AR3290 2021

Pekan	Hari	Tanggal	Jam	Topik
9	Selasa	16-Mar-21	07:00-08:40	Kuliah 2.1 Pengantar tentang Apartemen (Tipologi)
				Penjelasan Tugas 2 Apartemen
			08:50-12:20	Asistensi Wajib
			13:20-15:00	Studio Mandiri
	Kamis	18-Mar-21	07:00-08.40	Asistensi Wajib
			08.50-12.20	Studio Mandiri
	Jumat	19-Mar-21	13:00-17:00	Studio Mandiri
10	Selasa	23-Mar-21	07:00-08:40	Kuliah 2.2 Sistem Struktur Bangunan *Mid-Rise* (Apartemen)
			08:50-12:20	Asistensi Wajib
			13:20-15:00	Studio Mandiri
	Kamis	25-Mar-21	07:00-08:40	Kuliah 2.3 Integrasi Sistem Utilitas
			08:50-10:30	Asistensi Wajib
	Jumat	26-Mar-21	13:00-17:00	Studio Mandiri
11	Selasa	30-Mar-21	07:30	Pengumpulan Tugas 2 Bagian A - Analisis, Konsep, dan *One-line Drawing* (pkl 7.30)
			07:30-12:20	*Pin-up* Kelompok: Tugas 2 Bagian A
			13:20-15:00	Studio Mandiri
	Kamis	1-Apr-21	07:00-08:40	Kuliah 2.4 Sistem Proteksi Kebakaran Bangunan Apartemen
			08:50-10:30	Studio Mandiri
	Jumat	2-Apr-21	13:00-17:00	Studio Mandiri
12	Selasa	6-Apr-21	07:00-08:40	Kuliah 2.5 Sistem Keamanan Bangunan Apartemen
			08:50-12:20	Asistensi Wajib
			13:20-15:00	Studio Mandiri
	Kamis	8-Apr-21	07:00-10:30	Asistensi Wajib
			08:50-10:30	Studio Mandiri
	Jumat	9-Apr-21		Wafat Isa Almasih

Pekan	Hari	Tanggal	Jam	Topik
13	Selasa	13-Apr-21	07:00-08:40	Kuliah 2.6 Contoh Diagram Sistem Utilitas dan Sistem Keamanan Bangunan
			08:50-12:20	Asistensi Wajib
			13:20-15:00	Studio Mandiri
	Kamis	15-Apr-21	07:00-08:40	Kuliah 2.7 Fasade Apartemen
			08:50-10:30	Asistensi Wajib
	Jumat	16-Apr-21	07:00-10:30	Studio Mandiri
14	Selasa	20-Apr-21	07:00-08:40	Asistensi Wajib
			08:50-12:20	Asistensi Wajib
			13:20-15:00	Studio Mandiri
	Kamis	22-Apr-21	07:00-10:30	Asistensi Wajib atau Studio Mandiri
	Jumat	23-Apr-21	13:00-17:00	Pengumpulan Tugas 2 Bagian B dan Pengumpulan C - Gambar Pra-Rancangan dan Poster (pkl 21:00)
15	Selasa	27-Apr-21	07:00-15:00	Pin-up Kelompok: Tugas 2 Bagian B dan C
	Kamis	29-Apr-21	07:00-10:30	Studio Mandiri
	Jumat	30-Apr-21	13:00-17:00	**Studio Jury Tugas 2 Apartemen**
16	Selasa	4-Mei-21	07:00-08:40	**UAS**

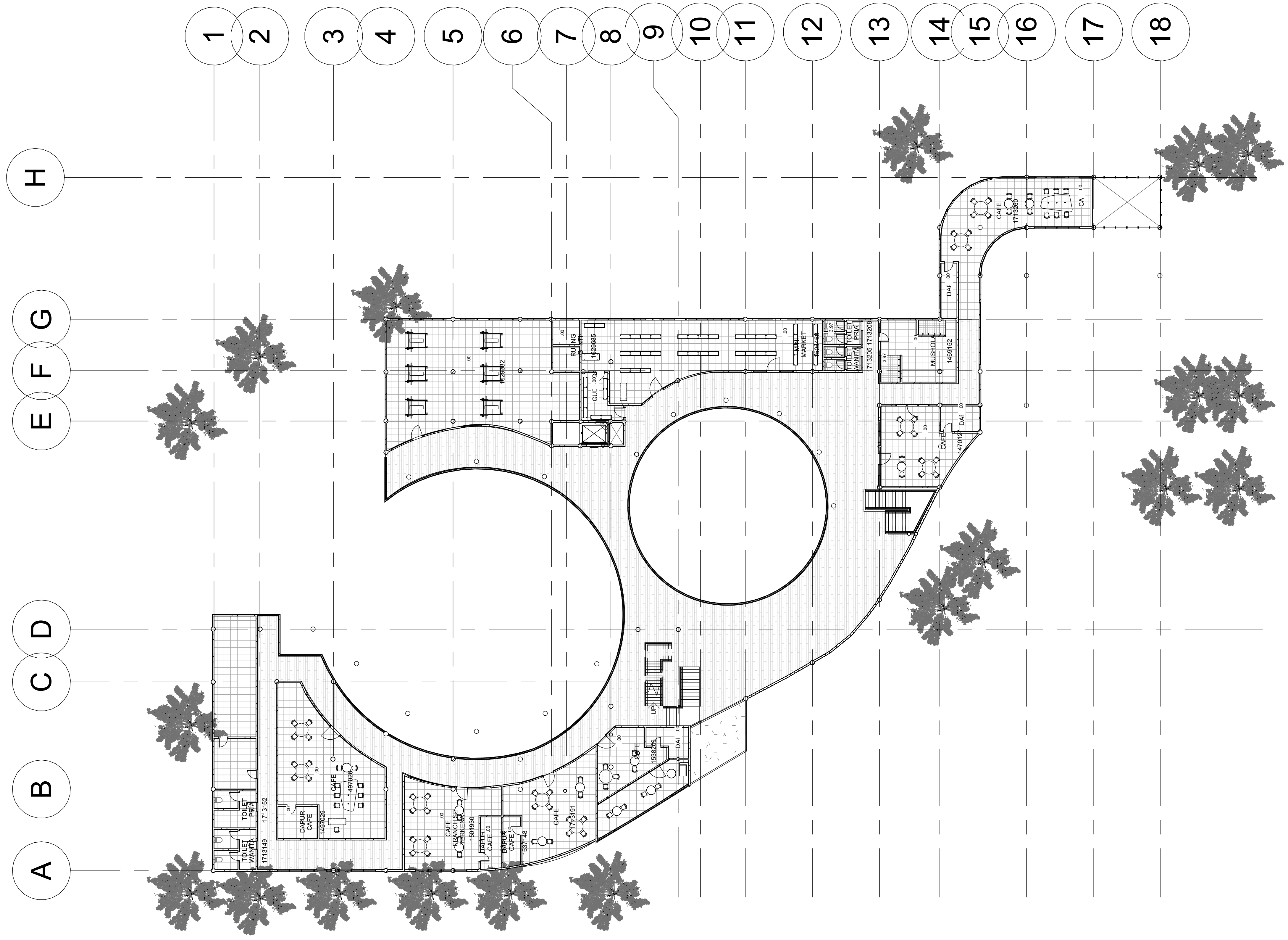
Appendix G Drawing of LC1 Project (Chapter 7)



GF FLOOR PLAN

2 1 : 400

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 1 Lifestyle Center bagi Kaum Muda: Merancang Pendekatan Placemaking LIFESTYLE CENTER MULTIFUNGSI DENGAN ADAPTASI NEW NORMAL "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	



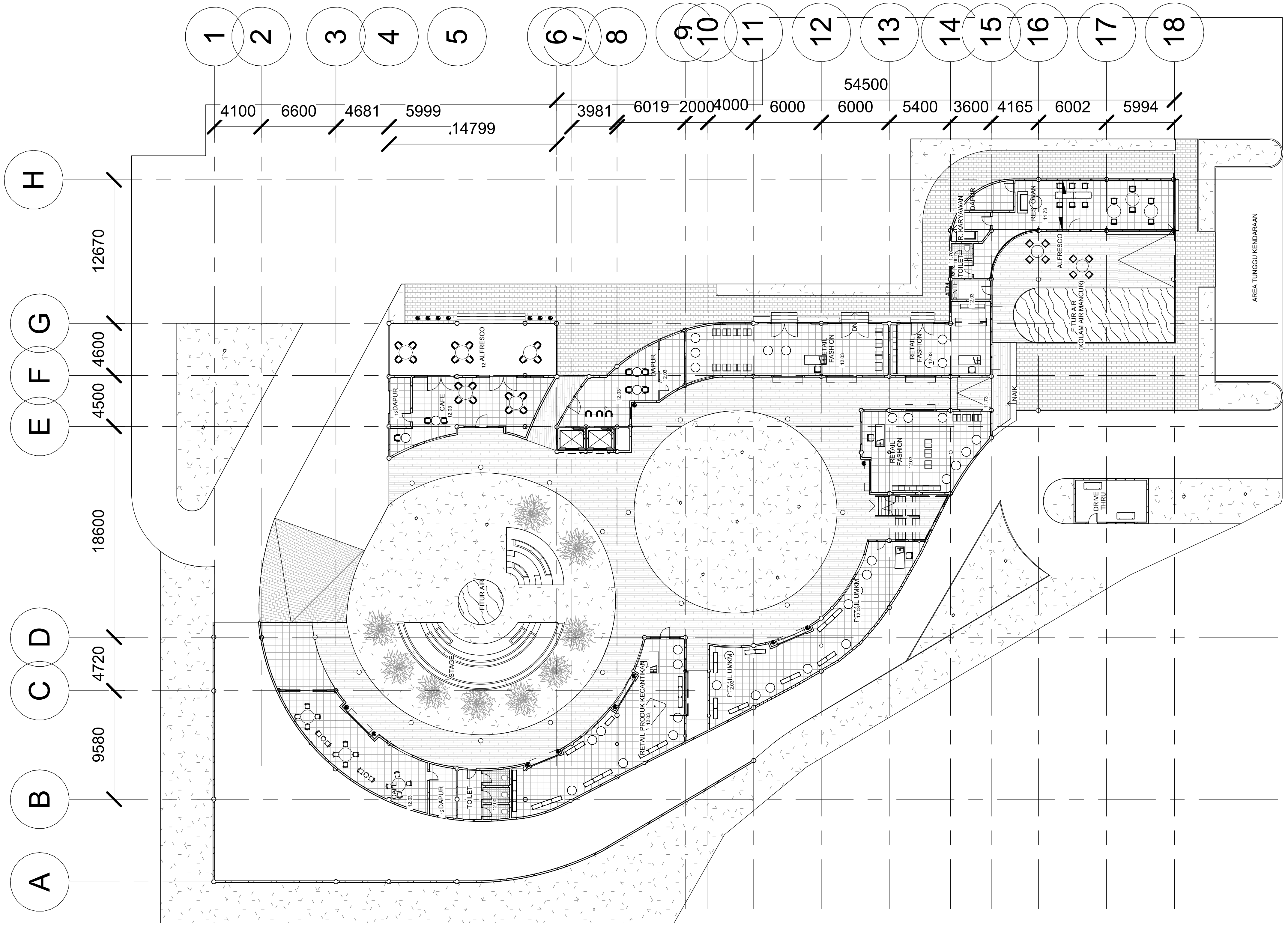
F2 FLOOR PLAN

1 : 400

1

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 1 Lifestyle Center bagi Kaum Muda: Merancang Pendekatan Placemaking LIFESTYLE CENTER MULTIFUNGSI DENGAN ADAPTASI NEW NORMAL "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	

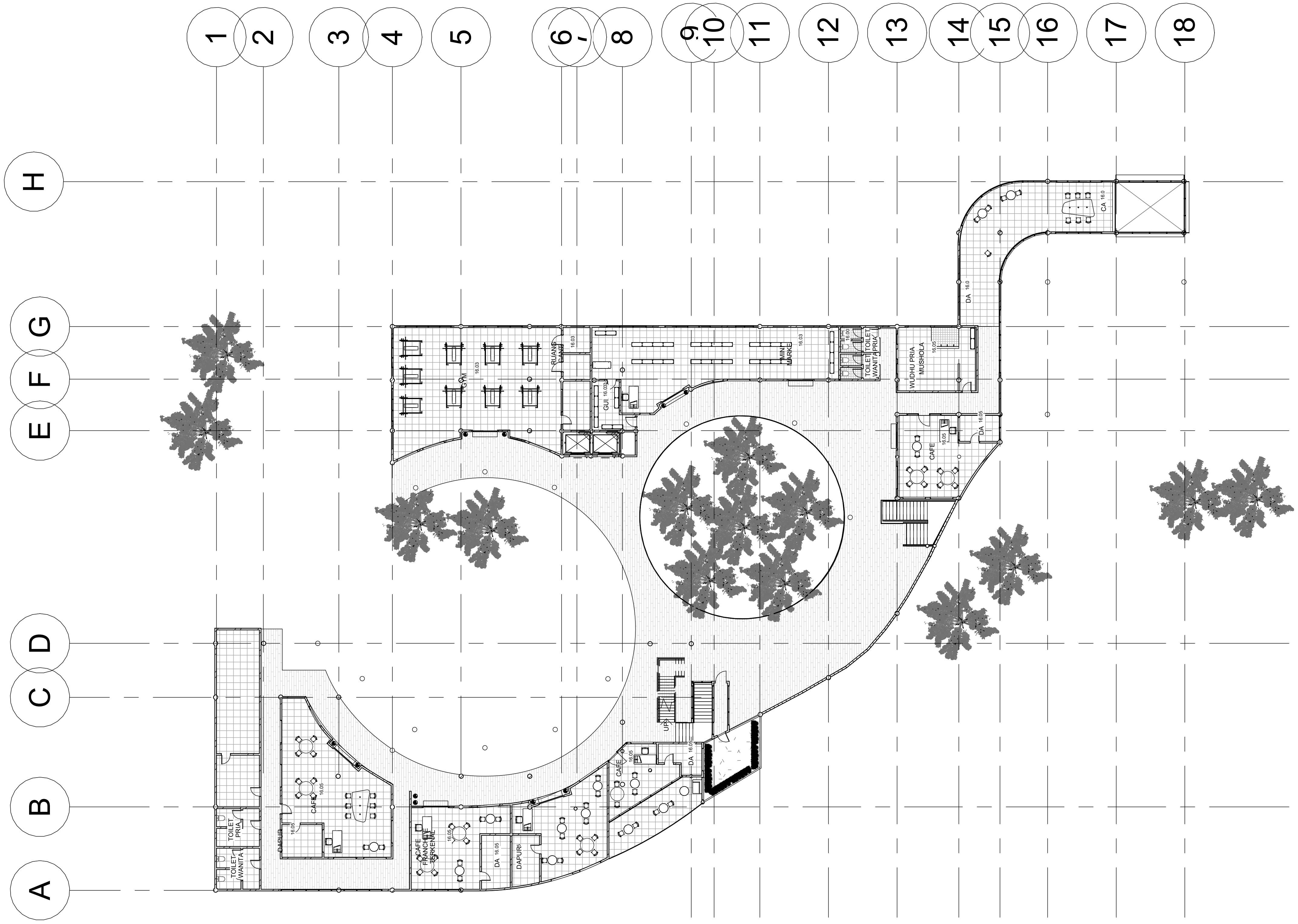
Appendix H Drawing of LC2 Project (Chapter 7)



GF FLOOR PLAN

2 — 1 : 400

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 1 Lifestyle Center bagi Kaum Muda: Merancang Pendekatan Placemaking LIFESTYLE CENTER MULTIFUNGSI DENGAN ADAPTASI NEW NORMAL "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	

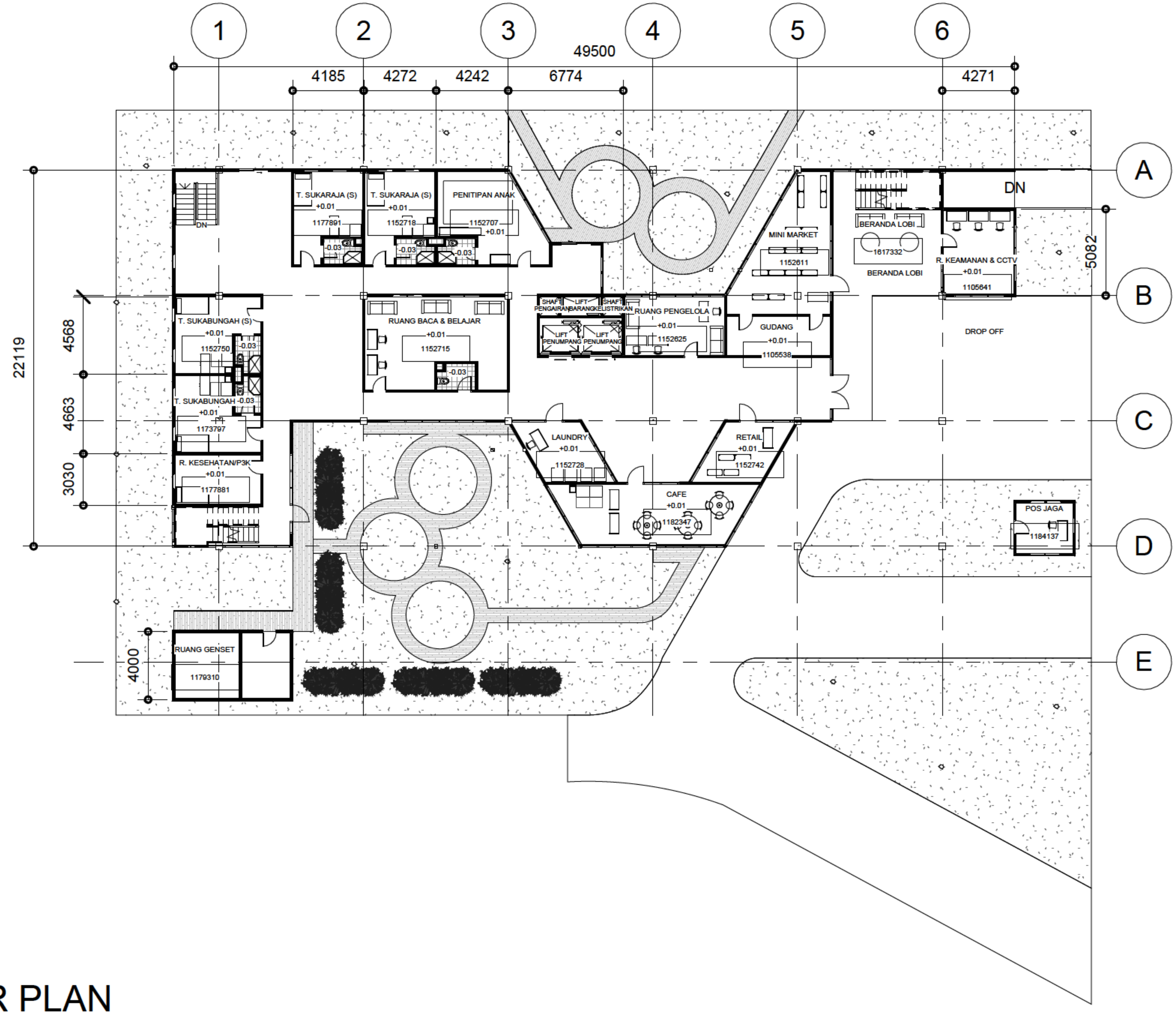


F2 FLOOR PLAN

1 : 400

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 1 Lifestyle Center bagi Kaum Muda: Merancang Pendekatan Placemaking LIFESTYLE CENTER MULTIFUNGSI DENGAN ADAPTASI NEW NORMAL "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	

Appendix I Drawing of APT2 Project (Chapter 7)

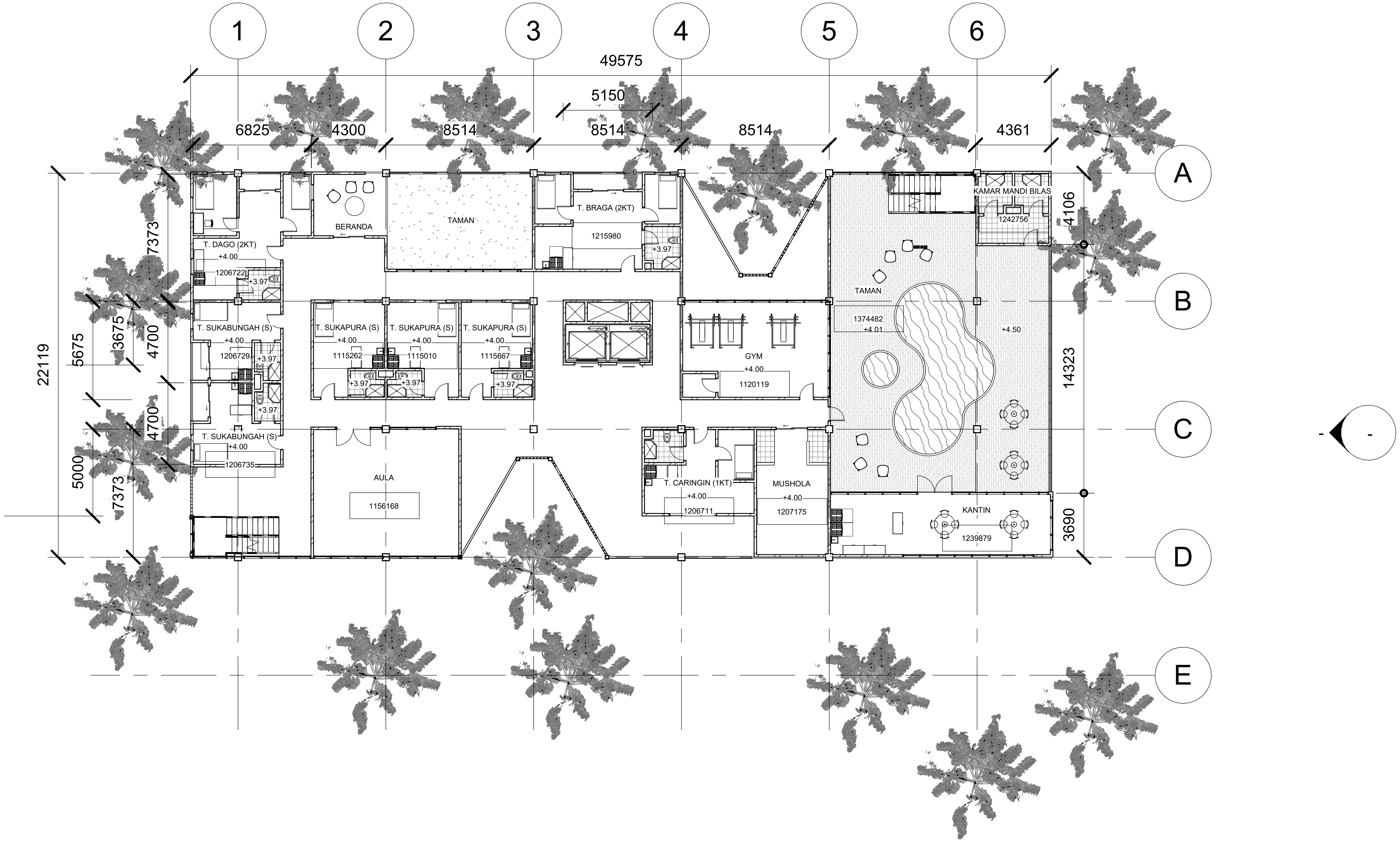


F1 FLOOR PLAN

1

1 : 250

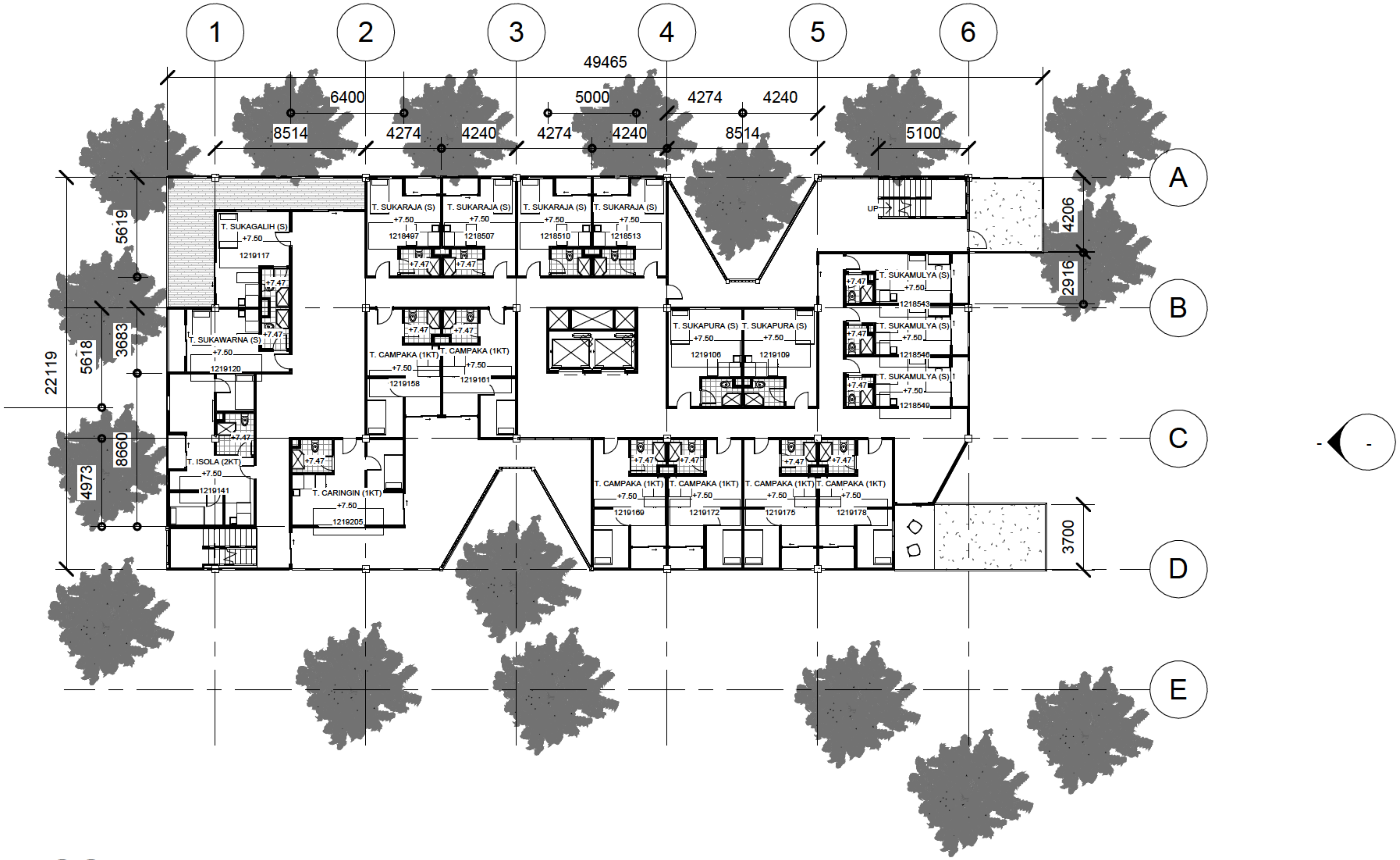
AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 2 APARTEMEN "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	



1 F2 FLOOR PLAN

1 : 250

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 2 APARTEMEN "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	



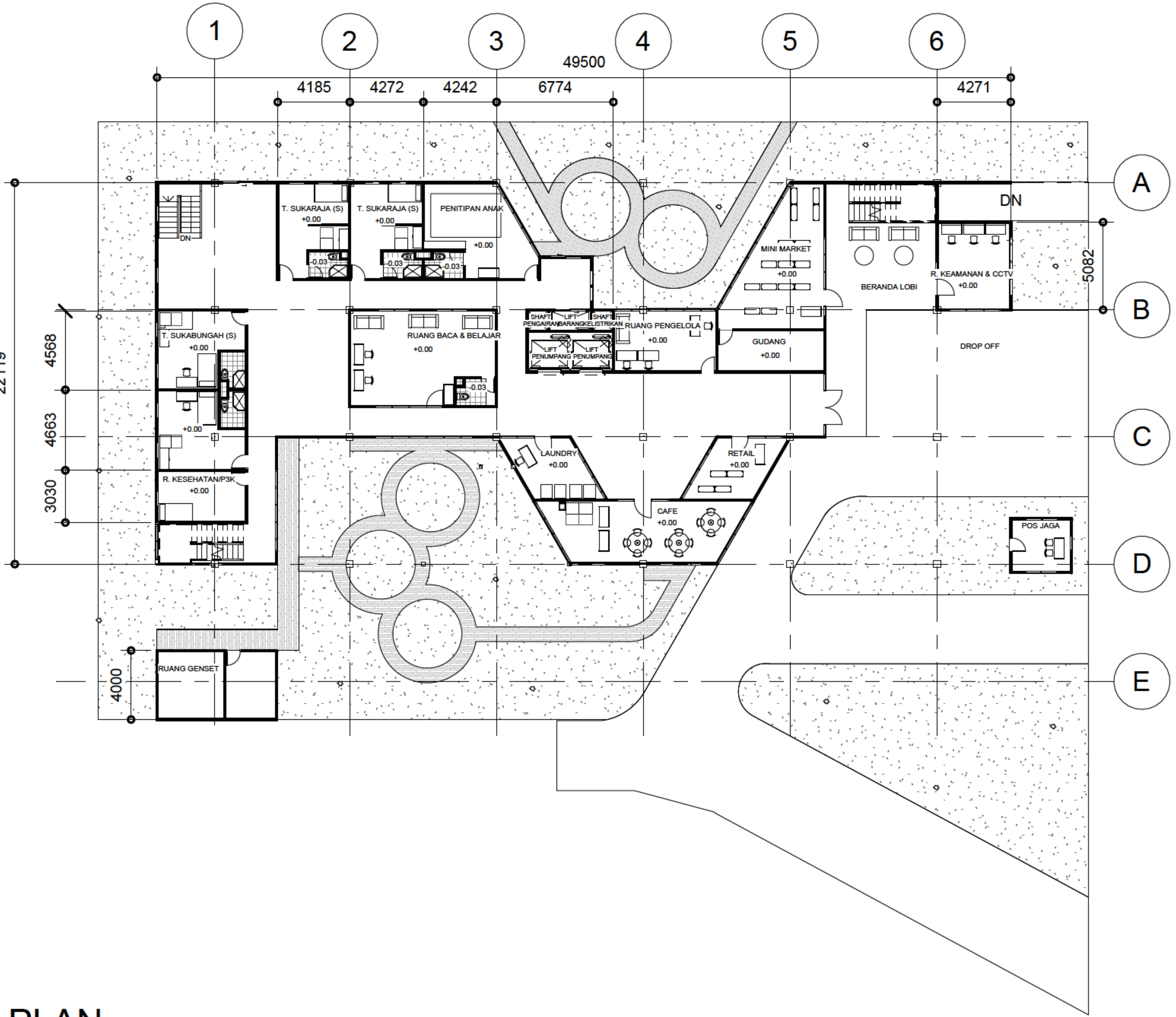
F3 FLOOR PLAN

1

1 : 250

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 2 APARTEMEN "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	

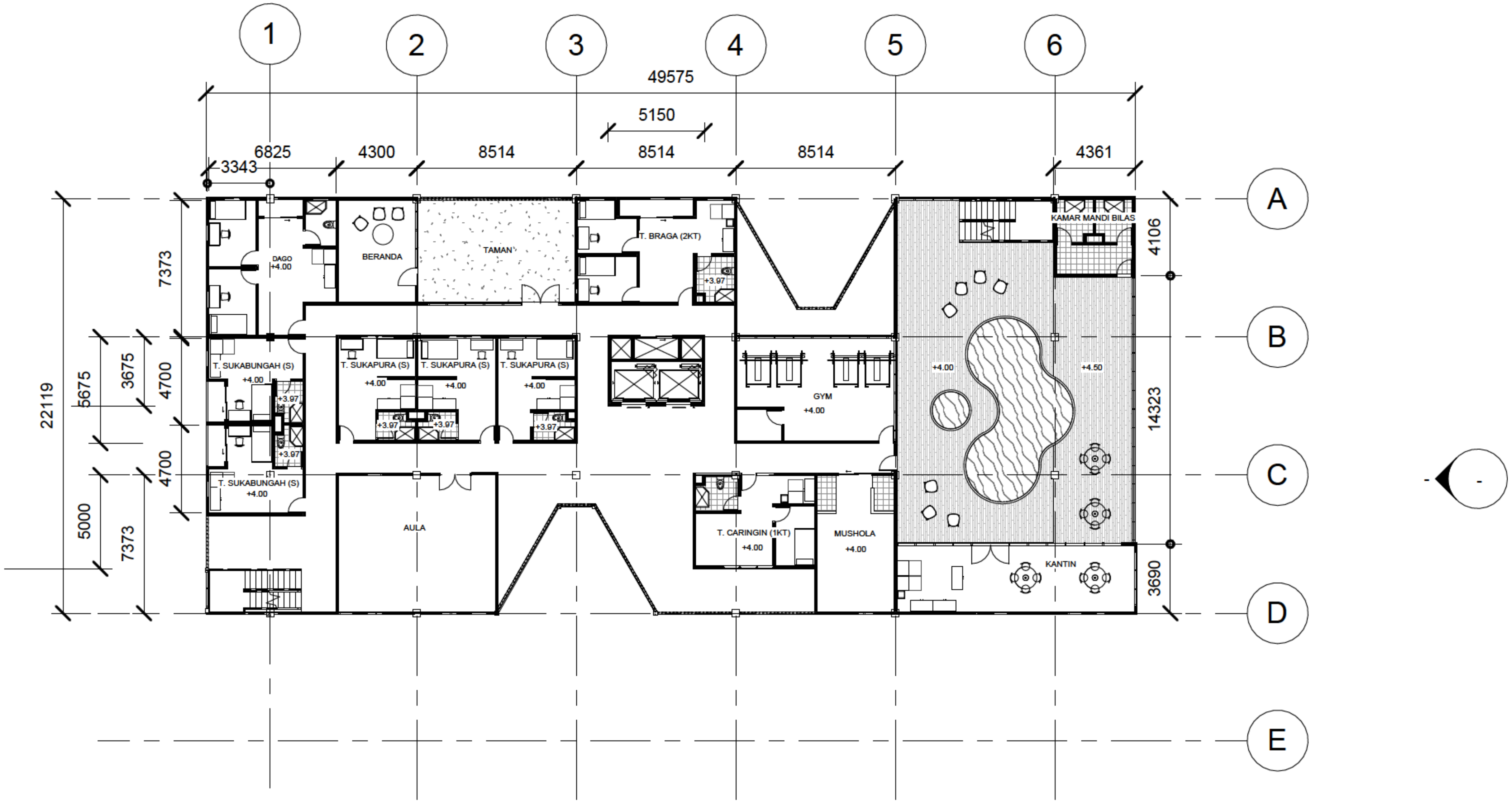
Appendix J Drawing of APT3 Project (Chapter 7)



GF FLOOR PLAN

1 : 250

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 2 APARTEMEN "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	

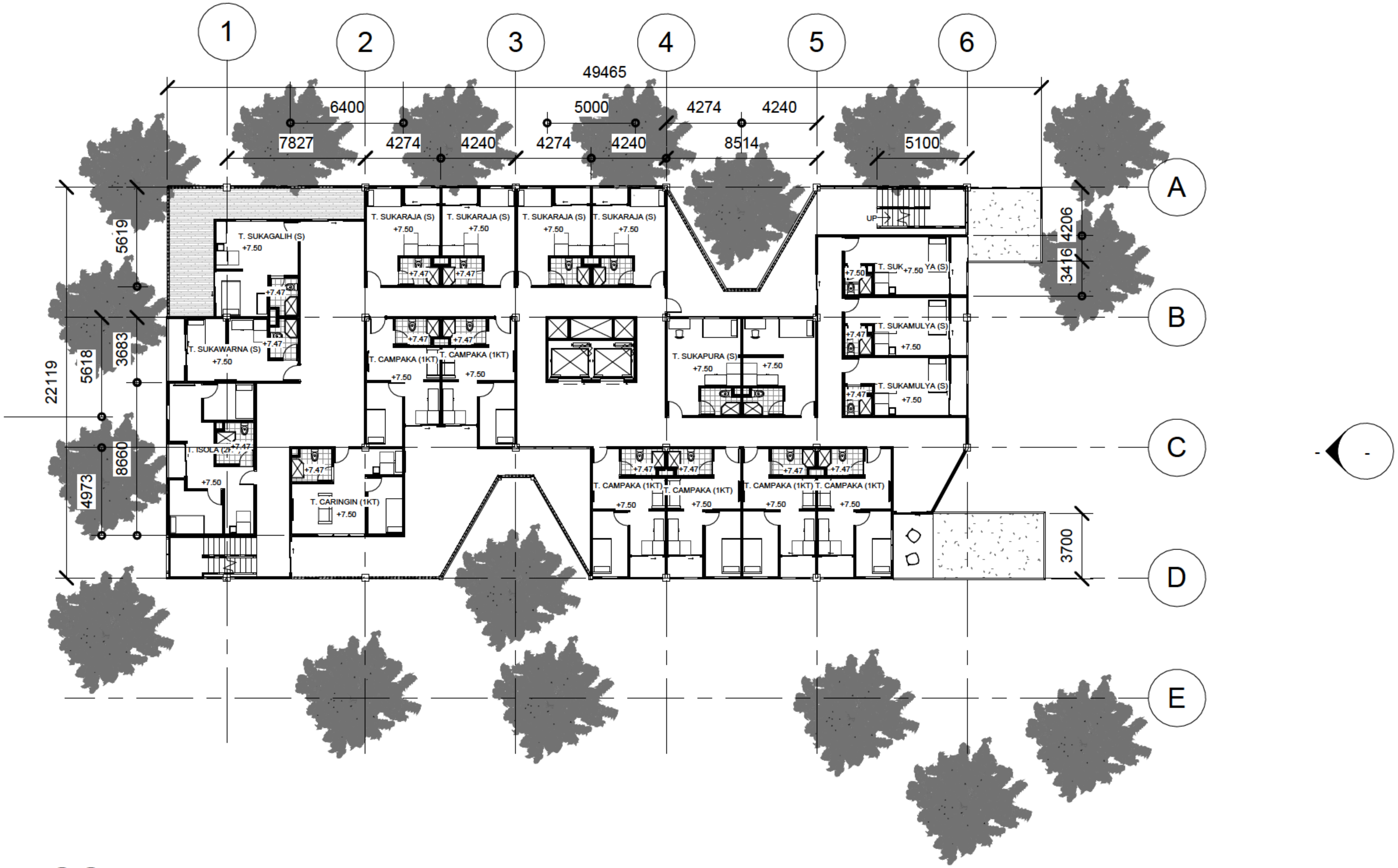


F2 FLOOR PLAN

1

1 : 250

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 2 APARTEMEN "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	



F3 FLOOR PLAN

1 : 250

AR3290 STUDIO PERANCANGAN ARSITEKTUR IV SEMESTER II 2020/2021 PROGRAM STUDI SARJANA ARSITEKTUR SAPPK ITB	TUGAS 2 APARTEMEN "THE GRAND KOSAMBI"	KOORDINATOR	NAMA	TANGGAL
		PEMBIMBING	NIM	