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DEVELOPING HANDS-ON MODEL-MAKING SKILLS REMOTELY THROUGH AUGMENTED REALITY IN ARCHITECTURAL TECHNOLOGY PROGRAM

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Dedication

This work is dedicated to my parents, whose unexpressed and unconditional love has shone through my life even prior to my birth. My beloved parents blessed me with the Chinese name Yi, a special Chinese character that embodies their best wish for a girl: perseverance. Without this exact perseverance, I would not be who I am today.

This work is also dedicated to my husband and my son. This work would only be a mission-possible with their continuous support and love. They reminded me to take breaks while I was writing papers, encouraged me when I encountered roadblocks in studying, and cherished every achievement of mine, even the trivial ones.

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Abstract

Innovative technologies are transforming human society in unprecedented ways, creating a digital network that impacts human activities. One of these groundbreaking technological advancements is immersive technology. Although immersive technology, such as augmented reality (AR) and virtual reality (VR), provides some degree of a virtual experience for users, in the education sector, learning hands-on skills virtually and remotely remains challenging. The Architecture, Engineering and Construction (AEC) industry is at the forefront of adopting immersive technology in their practice. However, experiments with hands-on skills in distance learning are still in their early period. With distance education becoming a norm in modern society, especially after COVID-19's emergence, learning hands-on skills remotely is an urgent matter to solve. Drawing from my own teaching practice in the AEC higher education field, I explored how immersive technology may assist in developing hands-on skills remotely. In particular, I explored learning architectural model-making skills remotely through augmented reality in this study. I followed the principles of Morris' Experiential Learning theory to design the intervention, which was composed of two technologies available in the commercial and educational markets. Subsequently, I evaluated the iterative experiment processes through the Technology Acceptance Model (TAM) and a portion of the SECTIONS (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy) framework based on my practical situation. Data collected from this study included answers to three questionnaires and 15 progress reports contributed by five research participants who were learners in the architectural technician and technology program at Centennial College, as well as information gathered from my past teaching experience. Findings obtained from the mixed methods approach indicated that using a specific AR tool within a well-designed intervention could assist students in developing hands-on model-making skills remotely. The quality and inclusiveness of the adopted AR tool significantly impacted participants' learning experiences. In conclusion, this study sheds light on the possible ways of conducting remote hands-on skills learning in AEC higher education. Most importantly, this research created a prototype of teaching hands-on skills that other educators can follow if they want to adopt specific AR tools to teach hands-on skills remotely.

Keywords: augmented reality, hands-on skills, experiential learning, construction, architectural technology, design-based research, technology acceptance model

Table of Contents

List of Tables

List of Figures

List of Definitions and Abbreviations

Terminology	**Definition**
3ds Max®	is a professional computer graphics application (https://www.autodesk.com/ca-en/products/3ds-max/features) for creating three-dimensional models through simple two-dimensional objects, such as surfaces, and producing immersive animations and images.
Affordances	were first coined by Gibson and referred to the complementary relationship between animals and the environment that the animals interact with (Gibson, 1979, p. 127). It implies that the environment affords opportunities for individuals to perform measurable activities, and affordances are related to the capabilities of the individuals (ELMCIP, n.d.).
App	is an abbreviation of application, which refers to a software program primarily used in mobile devices, such as smartphones (Christensson, 2012).
Architectural Digital Fabrication	Digital fabrication is "any manufacturing process controlled by a computer." It involves "one of three types of methods: additive manufacturing, subtractive manufacturing and robotic manipulation of any kind." (Cutieru, 2020) In architectural applications, a 3D-printed house can be constructed by using concrete (https://www.youtube.com/watch?v=vL2KoMNzGTo), or a 3D building model can be created by using resin (https://formlabs.com/blog/3d-printing-architectural-models/).
Architecture, Engineering, and Construction (AEC)	refers to the three main stages in the lifecycle of a building project (Messner, 2019, p. 22). Each phase involves a series of interdisciplinary tasks completed by a team of associated professionals in the building industry.
Artificial Intelligence (AI)	uses machine learning to simulate human intelligence to perform cognitive tasks such as learning and reasoning (IBM, n.d.-a).
Augmented Reality (AR)	projects visual images and/or annotations over whatever the user looks at in the real world while enabling the user to move freely in a physical environment (Greenwald, 2023; Peddie, 2017, p. 20). The technological requirements for AR surpass those for virtual reality, and several technologies, such as mobile devices, are used in AR rendering (Peddie, 2017, p. 20). The world's first HMD (Head Mounted Display), developed by Sutherland in 1968, paved the way for AR experiments.
AutoCAD®	is a software application that can be used to create, annotate, and present 2D geometry and 3D model drawings about one object. It is mainly used by building professionals, such as architects, engineers, and construction professionals, enabling team members to communicate digitally and remotely (Autodesk, n.d.-b). It can be used throughout the entire AEC lifecycle.

Balsa Wood	is "known as one of the lightest woods in the world" (International Timber, 2017). In AEC HE, sheets of balsa wood are typically cut into various dimensions and used to construct physical 3D architectural building models with specific attachment methods, such as a glue gun and glue sticks or School White Glue.
Building Information Modeling (BIM)	"is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle from inception onward" (National BIM Standard, n.d.). A BIM in the AEC industries is an intelligent 3D building model embedded with needed digital data. It enables AEC professionals to work efficiently on AEC projects (Sanner, 2019). For example, a window BIM contains instance parameters such as window width, height, and the window specifications from the window manufacturer. AEC professionals with digital access to this window BIM will know about this information set and, thus, can work with other trades collaboratively and remotely.
Computer Aided Design (CAD)	is a computer program enabling users to generate 2D or 3D images or drawings explaining design ideas. Users can create a 3D model or a 2D plan view of one geometric object with annotations, such as texts and dimensions (Autodesk, n.d.-c). AutoCAD® and Revit® applications are examples of CAD.
ChatGPT	is an AI-powered language model that can generate human-like text conversations based on the collected data, such as the previous input content (OpenAI, n.d.).
Desktop-Set	is a computer set with a monitor that displays the user interface and a computer that relies on individual operating systems to process the input information and calculation.
Digital Generation	refers to people born in a digital era and who grew up in a society with easy access to digital information and technologies (Lengsfeld, n.d.).
Education 4.0	"focuses on transforming the future of education through advanced technology and automation" (Joshi, n.d.).
Extensible Markup Language (XML)	is a file format and a markup language that "defines and stores arbitrary sets of data in a standardized way" (Pickle, 2022).
Float	refers to the project float time in this study. Project float time is the amount of time when a task can be delayed without impacting subsequent tasks' schedules or overall project completion (Landau, 2020).
Fourth Industrial Revolution (Industry 4.0)	is characterized by increasing automation to improve production efficiency, employing intelligent machines in smart buildings to improve production, and collecting data to integrate operation processes (IBM, n.d.-b).

Hands-on Skills	refers to the practical capabilities and specific knowledge that a person has to perform related tasks manually, such as an employee at a construction job site erecting wood studs to build a residential building according to the associated design and construction drawings or a student creating a physical 3D house building using balsa wood according to its design document.
Head Mounted Display (HMD)	enables a simulated virtual environment experienced by the users who wear this device on their heads. It is a device for experiencing virtual and augmented realities. Most HMDs do not require additional hardware to operate (Christensson, 2022). The first example of HMD was invented by Heilig and patented in 1960 (Brockwell, 2016; Virtual Reality Society, n.d.).
Higher Education (HE)	refers to the post-secondary education sector.
Mixed Reality (MR)	refers to a digital environment created by a computer system where “physical reality and a pervasive digital layer mix seamlessly according to the logic of software and the richness of highly contextual data” (Rousseau, 2016). MR is sometimes referred to as hybrid reality or extended reality (XR) (Moore, n.d.). MS remarks, “Most augmented reality and virtual reality experiences available today represent a small subset of the larger mixed reality spectrum” (Qian et al., 2023).
Revit®	refers to Revit® for Architecture in this project. (https://www.autodesk.com/ca-en/products/revit/architecture). It is a professional application that assists architectural professionals in designing, drafting, documenting, and managing their architecture projects in a three-dimensional way. It can be used throughout the entire AEC lifecycle. Many BIMs are created and managed using Revit®.
SketchUp®	is a modelling application (https://www.sketchup.com/) that enables users to create three-dimensional objects to help them visualize their abstract ideas. Architectural professionals also use it to create and develop their preliminary design concepts.
Smart City	uses information and communication technology (ICT) to empower the effectiveness of sharing information with society and serving the public (TWI Ltd, n.d.).
Smartphone	is a “combination of cellphone and handheld computer that created the greatest tech revolution since the Internet” (The Computer Language Co Inc., n.d.). The two smartphone platforms are iPhone (Kerner et al., n.d.) and Android (https://www.android.com/intl/en_ca/what-is-android/), which run third-party applications that provide users with “limitless functionality” (Christensson, 2010).
Technology Affordances	refers to the specific features and qualities of the digital devices that “allow individuals to perform a specific action” (Defense Support Services Center, n.d.) when designing for mLearning. It relies on the “combination of hardware and software capabilities” and is realized by

	the "portability of the device, coupled with a specific capability of the device." (Defense Support Services Center, n.d.) For instance, AR becomes possible when the camera in a smartphone is equipped with a specific software application.
Three-Dimensional (3D)	is an adjective that describes an object with three dimensions: length, width, and height. In the building industry, "3D drawing(s)" refers to one or more or a series of graphic presentations of one geometry seen from various angles and shown on a flat piece of paper or a computer screen; the drawing is usually called perspective(s), such as one-point perspective, three-point perspective, or orthographic view, depending on the methods and angles that create these drawings.
Traditional Learning	refers to a learning environment where educators deliver learning content directly to learners in a typical face-to-face format in a brick-and-mortar classroom setting (De, 2018).
Two-Dimensional (2D)	is an adjective that describes an object that has two dimensions: length and width. In the building industry, "2D drawing(s)" refers to one or more or a series of graphic presentations of one geometry seen from the X-axis and Y-axis and shown on a flat piece of paper or a computer screen; the drawing usually is called plans, elevations, section, details and so on, such as site plan, first-floor plan, south elevation, building section, wall section detail, depending on the methods and axis that create these drawings.
Virtual Reality (VR)	is a technology that uses a computer system to generate a simulated environment. Viewers can move without restraint while wearing specific hardware equipment, and their visions are entirely replaced with virtual reality. Users are immersed in a completely virtual environment and interact with virtual content (Bardi, 2019; Pickle, 2023). The world's first "ultimate display" HMD was developed by Sutherland in 1968, making VR viewers unable to distinguish the virtual experience from the real world.
Wood Member	In wood frame structure or wood frame construction, a wood member refers to an individual piece of processed wood lumber that is used to construct a building's wood frame structure, and it has different types, such as joist, stud, and header. For example, a wood stud is a wood member used to vertically form the wall, and a header is a member used to horizontally span over a door or window opening (Burrows & Canada Mortgage and Housing Corporation, 2006).

Chapter 1. Introduction

Overall Context

Technology is ubiquitous in human society today, from smartphones enabling citizens worldwide to shop online to artificial intelligence (AI)-empowered solutions that ignited controversy among educational institutions shortly after its emergence in November 2022 (Roose, 2023). Innovations such as AI, virtual reality (VR), augmented reality (AR) and their applications, such as increasing automation in factory operations, are driving the Fourth Industrial Revolution (Industry 4.0) (IBM, n.d.-b).

As various technologies keep evolving and becoming indispensable in human activities, the World Economic Forum (WEF) proposed a framework—Education 4.0, which includes four mechanisms for skills adaptation, to prepare our future young generations for Industry 4.0. According to WEF, Technology Skills are one of these proficiencies (World Economic Forum, 2023). The Government of Canada echoed WEF's scheme and advised that possessing digital skills is essential to succeeding in society and at work (Service Canada, 2021).

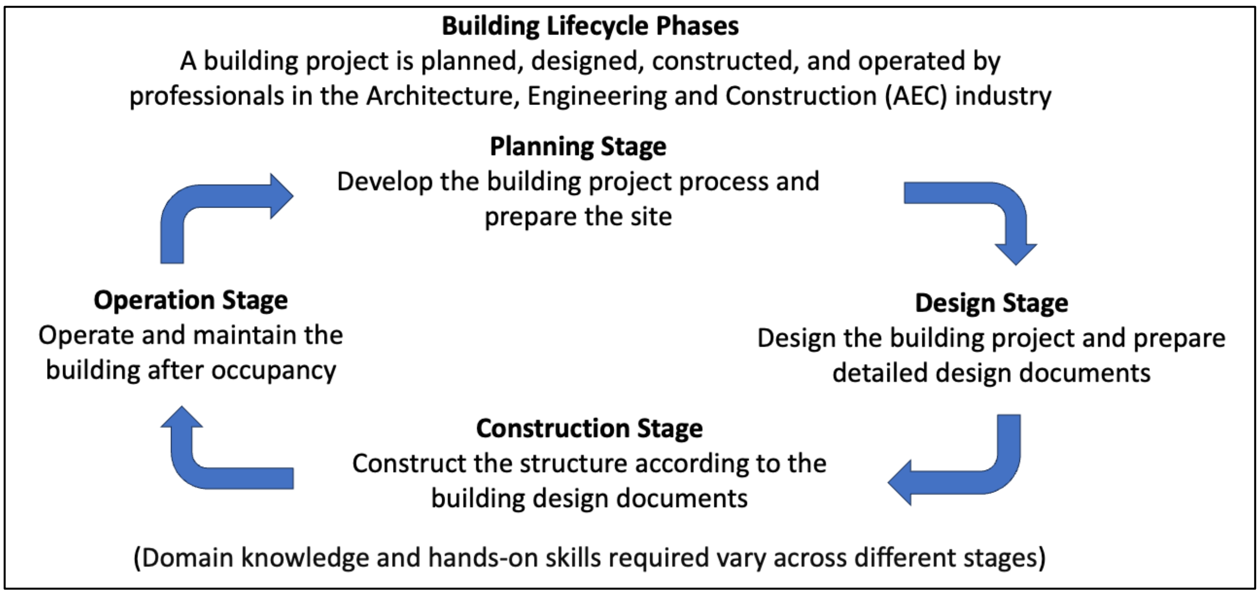
Higher education institutions must integrate technology into the curriculum to prepare future workers across all industries. With a combination of numerous innovations, learners living anywhere on earth can study in institutions located anywhere worldwide. Learners can remotely study various subjects, such as chemistry and architecture, and gain multiple skills, such as reading and numeracy, through this innovative educational format. However, does any technology enable learners to learn hands-on skills remotely?

Background in Building Industry

Construction, which accounted for 7% of Canada's GDP in 2022 (BuildForce Canada, 2023), is one of Canada's most prominent industries. A highly-trained labour force is needed for a successful building industry. As Service Canada (2021) considers that digital literacy is essential, analogically, computer use is regarded as an essential skill in the construction field (BuildForce Canada & SkillPlan Canada, n.d.). Figure 1 shows the lifecycle of a building project, which consists of four stages: planning, design, construction, and operation (Messner, 2019).

Figure 1

Building Lifecycle Phases



Note. Inspired by the concepts presented in chapter 2 of Messner (2019).

The building industry involves a chain of professional tasks that comprise constructing a structure based on its project-specific design blueprints and construction detail documentation, managing the construction site activities, and preparing the building for occupancy. It is common for professionals to refer to the building industry as the architecture, engineering, and construction (AEC) industry (Messner, 2019). While architecture and engineering focus on the pre-construction design phase, where practitioners in these two fields produce design and construction document sets for a building, construction itself is the post-design stage, where site professionals perform hands-on job duties at construction sites to construct structures based on the designated drawing set (Messner, 2019).

Over the past few decades, the AEC industry has gradually converted its traditional approaches to technology-entwined practices. For example, the industry-renowned drafting software AutoCAD® originated in 1979 (Riddle, 2016) and was a game-changer in the AEC business. It relieves building professionals from using old-fashioned manual apparatus during the design process. Transformative tools replace traditional drafting, measuring, and calculating equipment. For instance, a desktop computer equipped with the AutoCAD® application and a mouse can replace all the conventional drafting tools, such as pencils, pens, and drafting tables. Today, a collection of Building Information Modeling (BIM) and Computer Aided Design (CAD) applications empower the building industry with an accelerated design and construction process from the preliminary building design stage to the project's construction (Autodesk, n.d.-a; Sanner, 2019).

Emerging technologies, such as VR and AR, have been proven to benefit AEC businesses in various capacities. For instance, they demonstrate designers' concepts to the public, communicate design processes to stakeholders, and manage construction costs and milestones (Autodesk, n.d.-a; Richardson, 2015; Scope AR, 2021). In addition, innovations that enable remote communications transform traditional in-person styles in the AEC field into unprecedented formats. For example, online meetings with consultants worldwide have become a common practice, online distribution of digital design and construction documents takes several minutes instead of days if delivered in person, and online electronic banking transfer methods guarantee safety and punctual payment to consultants.

Building Industry Learning in Higher Education

Professional programs in the AEC field align closely with how the industry works. Post-secondary courses foster creativity in the professions, such as introducing new schools of building design philosophy and addressing the importance of strictly complying with industry standards, such as explaining building or energy codes. Specifically, vocational programs at the college level train students in settings that mimic professional working environments. For example, a design course in an Architectural Technology program simulates a real-world architectural office environment for learners by offering a computer lab course combined with the lecture. The hardware and software used in this type of studio course are precisely those used by practicing professionals in their offices. One example is building a three-dimensional (3D) physical architectural model. While the quality of the building model represents the professional capability of a real-world office, students in architectural programs strive to achieve professional quality when practicing 3D model-making.

Teaching and Learning at a Distance in Higher Education

The unexpected emergence of the global pandemic in the winter of 2020 changed how humans live and work. Remote teaching and learning have become commonplace today. Educators who used to stand at the podium teaching face-to-face classes now teach the same content through online platforms, such as Zoom (https://zoom.us/) or Google Classroom (https://edu.google.com/workspace-for-education/classroom/). Learners who used to sit in brick-and-mortar classrooms listening to lectures now receive the same learning through smart devices such as smartphones or computers. While some institutions and programs gradually transition back to face-to-face teaching and learning as the pandemic has subsided (Kombaté, 2022), online platforms remain widely used.

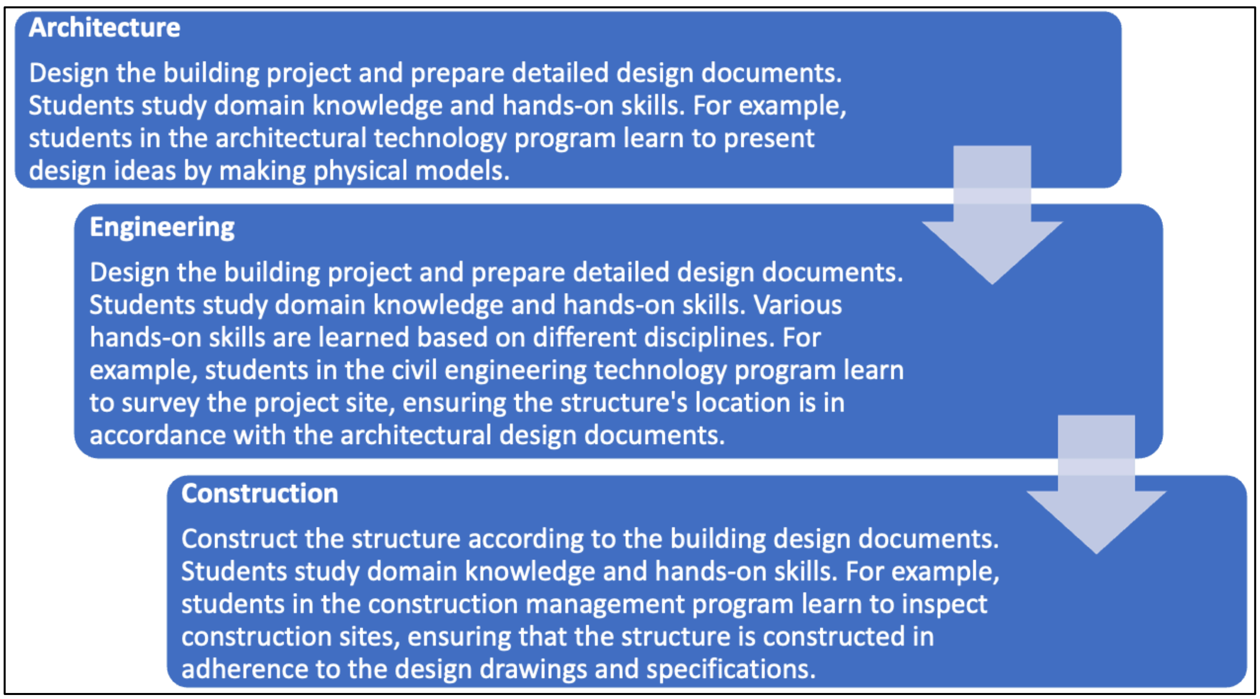
Still, how to learn hands-on skills remotely? Can students transfer their experience with mobile phones or computers to learn hands-on skills at a distance?

Teaching and Learning Hands-On Skills in Architectural Programs

Hands-on skills learned in AEC higher education vary across disciplines. The hands-on skills needed in AEC are exemplified in Figure 2 below.

Figure 2

Hands-On Skills Needed in AEC



Hands-on skills, such as operating the crane at a construction site or creating an architectural 3D physical model, assist students in analyzing building structures and construction details and are as indispensable as other AEC lecture content. In fact, Vitruvius (1914), the Roman architect and engineer who was active in the first century B.C., stated that "the function of the architect requires a training in all the departments of learning" (p. 13).

The traditional method of learning hands-on skills depends on the content to be studied; however, all involve manual skills. For instance, an instructor explaining wood frame structure may take the learners to the learning lab site to demonstrate how to construct a physical partial wood frame structure, or an instructor teaching an architectural graphics course may use a pencil and a ruler to show students how to calculate and draw a perspective of a building.

Among all courses in an architectural program, constructing a physical building model based on the learner's design concept is a proven and standard way of teaching and learning universally adopted by all architectural programs. Through building the model using various model-building materials, learners study the building structure system, understand the construction details, and reinforce the knowledge they learn from interconnected subjects.

I wonder, is there a way to develop hands-on model-building skills remotely through immersive technology?

Statement of Problem

Project Scope

Defined Scopes of Technology and Industry. The terminology of technology spans a vast scope, from tangible tools such as telephones that enable distant voice transmission to intangible products such as software installed on a computer. Also, the terminology of industry blankets an immense area, from food processing to automobile manufacturing. The scope of this dissertation includes the literature review, methodology and findings of my research related to immersive technology used in the teaching of specific skills in the building industry.

Defined Scopes of Immersive Technology and Hands-on Skills. Immersive technology employed in AEC higher education covers a certain area, from immersing a student who is wearing a VR headset in a virtual urban park environment to assisting a learner in understanding complicated building design concepts through overlaying digital building component images in a real-world setting. In addition, hands-on skills learning covers a wide range, from learning how to install a toilet in a building to figuring out how to fix the leaking oil pipe in the car garage. Moreover, the types of architectural models range broadly from conceptual models constructed during the preliminary design stage to structural analytic models used in the design development stage. This dissertation explores how the selected innovations may assist in developing hands-on wood frame structure model-making skills remotely in an architectural technology program.

Project Context

The architectural technology program at the College where I teach offers courses systematically associated with the AEC industry, and the teaching materials thoroughly comply with industry standards.

The program has two types of courses: computer design labs and lectures. Both types address two primary ways of learning, traditional learning and hands-on skills learning, and offer different learning outcomes.

Before the global pandemic, the primary teaching and learning delivery method for lab and lecture classes was in person on the brick-and-mortar campus. On the one hand, the studio lab courses mimic the real-world professional office working environment. During the lab periods, students study architectural design principles, building codes, municipal zoning regulations, professional software, hand-sketching skills, and computer drafting skills. Students will prepare a set of construction drawings that includes a 3D hand-sketched building perspective at the end of each semester. On the other hand, lecture courses discuss various academic topics, such as building structural design and calculation, sustainable building design strategies, and building science. In some lecture courses, students complete several hand sketches of building sections or construct a 3D physical building model.

However, when COVID-19 unexpectedly struck the world, instructors needed to transfer all teaching materials and activities online. Lecture components were comparatively easy to convert to suit online distance learning by adopting several instructional design strategies, such as integrating the discussion forum function in the course shell to enhance online class participation and content comprehension. Still, hands-on skills learning remains challenging. How do teachers teach hands-on model-making skills at a distance?

Courses taught in each semester are different, but all subjects are intended to be complementary to each other and sequenced such that knowledge is gained gradually.

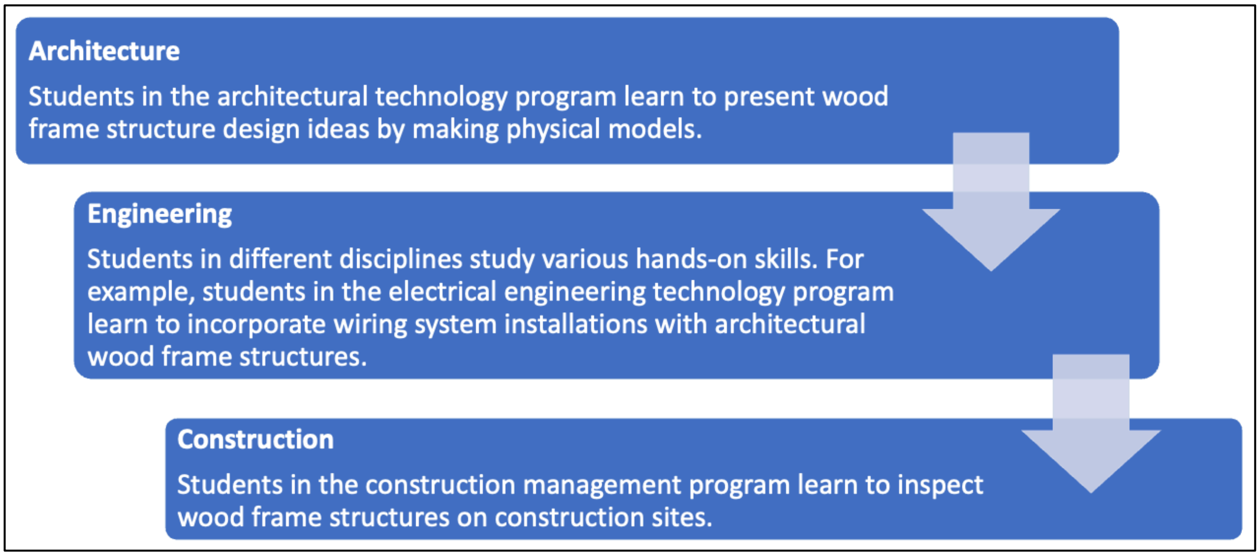
The Teaching and Learning Problems

I taught a course that discussed building materials and construction methods, and this experience enabled me to comprehensively assess learning needs firsthand.

In North America, understanding the structure of wood frames is considered fundamental knowledge in AEC (Burrows & Canada Mortgage and Housing Corporation, 2006). Although all students in AEC study hands-on skills related to wood frame structures, their specific focus areas vary depending on their discipline. For example, students in architectural programs focus on learning whether the wood frame design ideas meet the requirements of construction details. In contrast, students in construction management programs emphasize the constructability of the wood frame structure on a specific job site. An illustration explaining the different focuses of various disciplines regarding a wood frame structure is shown in Figure 3 below.

Figure 3

Different Focuses of Various Disciplines



This course I taught discusses the building materials that are generally used in residential buildings and the technical ways of constructing a house in North America. At the end of the semester, students are required to individually construct a physical cut-away wood frame house model based on their design project corresponding to the interconnected design studio course to demonstrate their understanding of wood frame structure and construction methods. Students have four academic weeks to complete this model after gaining knowledge of construction details and methods from this specific course and the design studio.

The AEC knowledge involved in building this model includes how various wood components in a residential wood frame structure are constructed and their associated construction details and sequence. The knowledge gained and consolidated through making a physical wood frame structure model is essential for students not only in architectural programs but also in construction management programs (Burrows & Canada Mortgage and Housing Corporation, 2006; McCord et al., 2022). A sample of a wood frame structure is shown in Figure 4 below.

Figure 4

Wood Frame Construction

The photo above shows that lumbers of various sizes and grades are used for wood frame construction in residential buildings. Wood members are placed in sequence, such as in a wall framing construction; wood studs are constructed vertically on top of the bottom plates that are laid horizontally on top of the sub-floor, while the two top plates are placed horizontally on top of the vertical wall studs. Together, these top plates, wood studs, and bottom plates form a portion of a wood panel wall. (https://www.ecohome.net/guides/2283/best-material-choices-for-wood-frame-construction/)

The requirements related to this 2-storey wood frame model-making assignment are as follows: the model must have foundation walls and footings, exterior and interior stud walls, floor joists, ceiling joists, supporting beams and columns where needed, and a roof system that comprises standard roof elements such as rafters and roof joists (Rosen et al., n.d.). In addition, the materials to construct this model are balsa wood sheets or sticks, which can be purchased at art supply stores city-wide in Ontario or through online marketplaces such as Amazon (https://www.amazon.ca/balsa-wood/s?k=balsa+wood).

Issues With the Current Model-Making Assignment. The assignment of building this physical model unveils a series of issues, which I outline below.

Immense Cognitive Load. Students must master the wood construction knowledge to complete this model, such as the roofing and flooring systems; otherwise, the wood elements built within this model may be incorrect compared with the actual construction at the job site. For instance, bottom plates used to connect the wall to the floor should be placed before constructing wood studs. Misunderstanding this will lead to structural problems after the building's occupancy. Although this model-making task is well-aligned with knowledge learned in the design studio course, the timing of this assignment does not reflect the current learners' demographics. Recently, many new learners in our program are international students who have not had any wood frame structure exposure before; thus, they need more time and effort to understand the construction details and methods of wood frame structures.

Time Consuming. Building the physical model is time consuming. While this is a one-hour weekly lecture course, a group of students told me they spent around three full weekends (six days) completing the model (several learners, personal communication, dates varied in March and April 2023). Data collected from another survey (Lu, 2023b) confirmed that the average time needed to complete this model was around 40 hours. Additionally, to ensure the task is completed on time, students must rush to shop for art supplies and build the physical model; thus, learning may be impeded.

Financial Burden. Several students stated that the cost of purchasing balsa wood materials was around $200 Canadian dollars (several learners, personal communication, dates varied in March 2023). A survey (Lu, 2023b) conducted in November 2023 revealed that the average amount spent on making this model ranged from $60 to $250 dollars. The wide spectrum of expenses reflected the variety of the wood materials chosen, with popsicle sticks purchased from dollar stores at the lowest end and formal balsa wood purchased from craft stores at the highest mark. Considering the student minimum wage of $14.60 per hour in Ontario in March 2023 (Bonnar, 2023), students must work about 14 hours to make $200.

Enormous Workload. The workload is immense. Generally speaking, architecture is always regarded as a most challenging major, with students spending an average of 22.2 hours weekly on preparation for classes (Muniz, 2021). A recent study (Xie et al., 2021) confirmed that architectural students experienced “stress due to heavy and constant workloads” (p. 8). The academic and mental workloads of making a physical building model are heavy in conjunction with assignments and final exams from other subjects. The semester with the model-making course has seven courses, totaling 24 instructional hours (credit hours) per week (Kusminder, 2018). While it is a norm that instructors suggest that students spend approximately 2–3 hours studying for each credit hour outside of class (Nelson, 2022), a simple mathematical calculation results in a weekly 48–72 hours of studying time outside of class in this architectural program.

Other Time Commitments. Timewise, a learner will also need to travel from residence to school or from workplace to school or vice versa. Witnessing the time challenges that students encountered, I conducted a three-year longitudinal survey study in our architectural program to investigate how much time per week students spent on commuting between work, home, and school. The collected data revealed the striking time commitment contributed by learners.

The data from the survey in the 2021 Fall semester revealed that 20% of students spent less than 5 hours commuting, 40% between 5–10 hours, and the rest commuted more than 11 hours per week, with 20% of responses stating that they commuted 16–20 hours (Lu, 2021a). Similarly, the survey (Lu, 2022a) in the 2022 Fall semester showed that 70% of the students commuted for less than 5 hours per week, and 30% commuted 5–10 hours per week. The accumulation of data in a two-year period illustrated that 70% of students required 5–10 weekly commute hours. Thus, mathematically speaking, the total time commitment for a learner studying in this architectural program was 77–106 hours per week.

Research Questions

The Development of Research Questions

Innovative technologies greatly benefit AEC online teaching and learning in higher education (Wrike Team, 2023). While converting traditional learning to a remote learning environment can be realized by employing a series of innovations, hands-on skills learning online has so far proved challenging. Knowing the apparent problems of the model-making assignment in this specific course, I raise the question: "Is it possible to develop hands-on model-making skills through emerging technologies, such as immersive technology?"

In their meta-analysis of various immersive technologies, Suh and Prophet (2018) synthesized that the core of immersive technology is the affordances that "engage users in the immersive environment, and thus provide the immersive experience" (p. 82); therefore, what kind of affordance does virtual reality or augmented reality provide? Can virtual reality or augmented reality be used to improve the quality of hands-on skills learning? Are other technologies, such as headsets, smartphones, or tablets, also needed to aid in realizing an immersive environment? What tools can be used to evaluate users' experiences? Furthermore, as smartphones are ubiquitous in human society, especially among younger generations (Taylor & Silver, 2019), will using smartphones to learn hands-on model-making skills be possible in online classrooms?

Research Questions

My overarching research question (RQ) is:

How can immersive technologies assist in developing hands-on skills remotely?

The sub-questions evolved from the central question:

RQ1. How does augmented reality aid in developing hands-on skills remotely?

RQ2. What are the perceptions of individuals regarding using augmented reality in learning hands-on skills at a distance?

RQ3. How feasible is it to adopt augmented reality in developing hands-on skills at a distance?

RQ4. How does employing augmented reality to teach hands-on skills online affect the learning experience?

Purpose of the Study

One of the particular features of traditional AEC higher education is that the design concept is an abstract idea usually shown as 2D representations or 3D perspectives of that project on a pile of flat 2D papers or on levelled 2D computer screens. Still, it has become clear to me over several years of communicating with my students that it is challenging for many learners to understand complicated and abstract concepts (multiple learners and instructors, personal communication, multiple years) via a 2D paper or computer screen format with a 3D perspective illustration. Although students in construction programs study different hands-on skills and domain knowledge than students in architecture programs, understanding the wood frame structure is a common and universal requirement in AEC in North America (Burrows & Canada Mortgage and Housing Corporation, 2006; McCord et al., 2022). Feiner et al. (1995) stated that "traditional forms of representation (photos and drawings) severely inhibit learning about how architectural structures are made, how they work, and how they influence an inhabitant's perception of architectural space" (Chapter 5). Combining a built physical 3D model with 2D representations should enhance understanding tremendously. If applying a hands-on model-making strategy to the target topic can improve learners' understanding of the complex wood frame structure in architecture programs, then, as architectural knowledge is the foundation of construction knowledge, students in construction programs can also theoretically benefit from the results of this research study (McCord et al., 2022).

Learning hands-on skills is as crucial as studying textbook contents in AEC. Both types of learning are relatively uncomplicated to realize in a traditional face-to-face teaching format. While converting a lecture component learning format to a remote learning platform from a traditional learning environment can be realized by employing a series of innovations, converting traditional hands-on learning to a remote learning format remains a challenging mission. Among all emerging technologies, VR and AR get significant attention in AEC higher education, much like their industry counterparts. However, although AEC higher education strives to adopt innovations and continuously explores the adaptation of innovative technologies in its teaching and learning practices, remote hands-on skills learning still needs more exploration.

This research study selected two augmented reality tools that have the potential to realize hands-on learning, specifically model-making, at a distance and assess their technology affordance using two established frameworks.

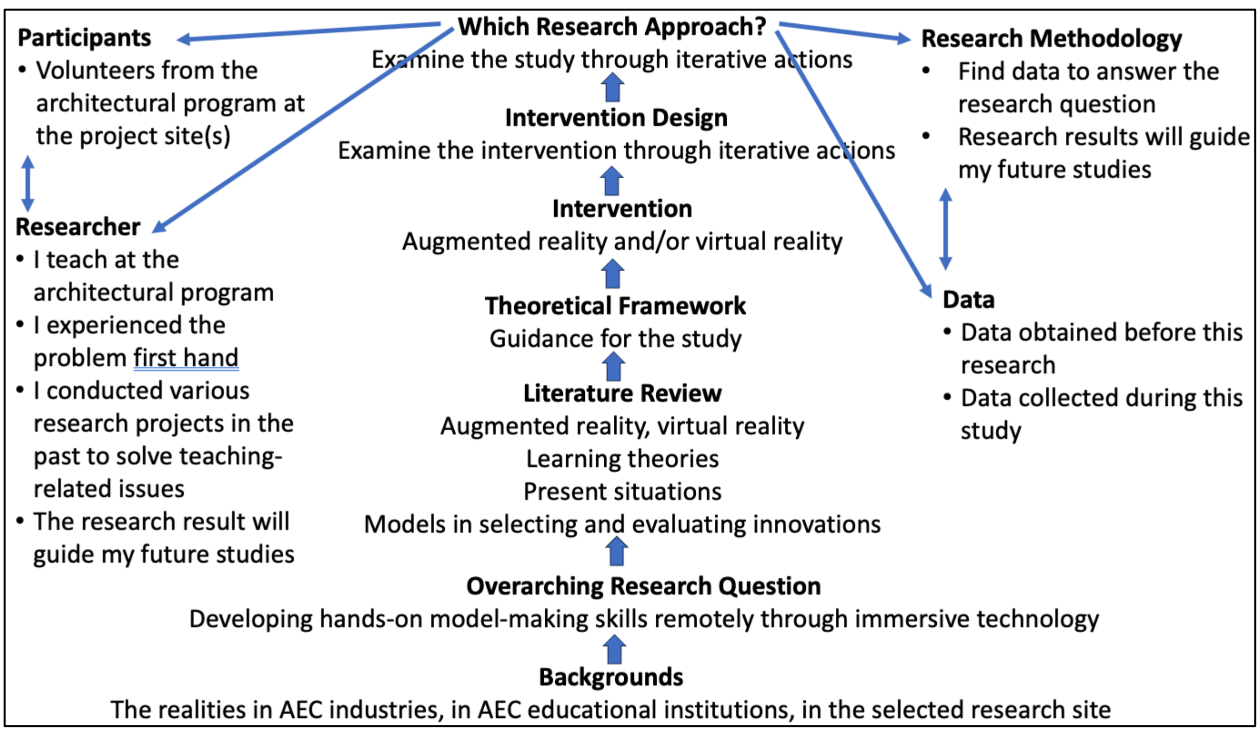
Conceptual Framework

The conceptual framework below illustrates how my research evolved. Crawford (2019) generalized three types of conceptual frameworks: argumentation, explanation, and generation. Crawford explained that argumentation emphasizes the importance of the study, explanation focuses on the "relationships among who and what will be studied," and generation "gives rise to the problem, research questions, and methods of a study" (p. 41). My conceptual framework is generative, based on Crawford's categorizations.

My concepts developed through various situations that I experienced: the overall AEC industry and my professional work environment, the general AEC educational realities, and the real classroom situations in my teaching jobs. The overarching research question was distilled through these realities and evolved over my years of personal explorations of seeking whether an intervention (with a tool or series of tools) could assist in developing hands-on learning online. My conceptual framework is shown in Figure 5 below.

Figure 5

Conceptual Framework



Note. The arrow direction indicates the direction of information feeding from the starting point to the termination point.

The scope of the literature review in this study was extensive. Still, I limited it to emphasizing the application of immersive technology, such as AR and VR, because I wanted to adopt these innovations in my teaching practice. I have been experimenting with them since around 2017. The literature review also combined related learning theories that helped explain pedagogical insights and provide actionable strategies that could be used in my research study (Tprestianni, 2022).

The conceptual framework also included a possible theoretical framework that guided my research, an intervention implemented to test the research questions. The linear path of the wide-blue arrows illustrates how my contemplation led to a potential research approach for investigation. Additionally, my conceptual model included divergent thoughts and actionable steps interrelated with the intervention and research approach. For example, I used data from my previous research projects or experiments to form a partial baseline for the current new project, and data obtained from the first iteration of implementing intervention improved the next steps of the study. In addition, I wanted to examine the roles of potential project participants and myself in this project. I also planned to use the results obtained from this new study to guide my future teaching practice or the next research project.

Summary of Chapter 1

In Chapter 1, after briefly introducing the building industry and its impact on Canada's economy, I unveiled the intertwined relationship between the AEC industry and AEC higher education. I subsequently presented how the industry employs innovations in its practices and how these practices influence AEC higher education. I further exposed an unsolved issue in the AEC industry and a mirrored issue in the teaching and learning sector. In particular, I introduced a specific course in the architectural technology program where I teach, and I discussed the problems presented in this course. I further brought up several hypothetical questions I wanted to explore. I finally illustrated a conceptual framework that described how my thoughts evolved and how I planned to design this research study and explore the investigation.

In Chapter 2, I emphasize literature reviews related to my research study. I discuss the characteristics of contemporary learning and digital generation and how modern innovations impact modern learners. I also introduce studies about VR and AR experiments in the AEC educational sectors that were conducted over the past ten years.

Chapter 2. Review of the Literature

Introduction

The literature review in this chapter consists of four sections. To paint a general picture of the population in AEC higher education, the first section explores modern learners who are avid users of technologies in daily life, especially in academic learning situations. To set the stage for my research project, I discuss current societal situations related to how humans use technology and which technology is most commonly used in daily life. The second section focuses on learning theories that are applicable in the hands-on learning environment. The third part reviews studies that utilized VR and AR as interventions in AEC higher education and, as a result, the outcomes from these projects lead to a solution for remotely developing hands-on model-making skills. The fourth part reviews two technology evaluation models, which assist in assessing whether the intervention described in Chapter 4 meets the learners' needs and expectations.

Context

Technology giant Google declares that immersive reality technology blending the "digital and physical" world empowers humans to "experience the world and access knowledge" through new dimensions (Google, n.d.). As an umbrella term, immersive reality refers to VR, AR, and mixed reality (MR). For the purpose of this dissertation, I use the terms VR and AR to indicate innovative immersive technology.

The technological development timelines of VR, AR, and MR differ, with VR attracting greater limelight exposure and MR in its early stage. VR made big progress in 1960 when the first head-mounted display (HMD) was patented (Vardomatski, 2018). Peddie (2017) discussed that even though the key components, such as computers and software, needed to construct an

AR environment are the same as those needed for constructing a VR environment, the development of AR took much longer than that of VR because "the technological requirements of augmented reality are much greater than those for virtual reality" (p. 20). Around that time, Rousseau (2016) pronounced that "we're not there yet (using MR in human society), though this vision is far from science fiction" (para. 2). Several years later, Rosenberg (2023) claimed that MR is "an ongoing process, with amazing new products poised to take off" (para. 17); however, Narasimhan (2023) argued that several technical challenges, such as processing power, still impede software developers from creating MR applications and impact user experiences in e-learning. Thus, the literature review of the technology portion of this study focuses on VR and AR. Moreover, as technology advances at an unprecedented rate in human society, the research projects I selected in this literature review were conducted within the past ten years (2013–2023).

Since my teaching background is in architecture, the technological literature review was confined to VR and AR experiments in higher education architecture. As Architecture is under the umbrella of AEC, I explored VR and AR research projects from Engineering and Construction to generate a comprehensive literature review as well as reviewing research projects in the architectural field. Additionally, based on my research focus, the literature review on learning theories covered concepts related to teaching hands-on activities in the educational setting.

Literature Review Criteria

The definition of saturation was first proposed in 1967 by Glaser and Strauss (2017): "saturation means that no additional data are being found whereby the sociologist can develop properties of the category" (p. 61). Firstly, the criterion for determining saturation in my literature review process about VR and AR was when I found one or more in-text citations I had read before appearing repeatedly in the current articles I was reading (Pacheco-Vega, 2016). Secondly, because the dissertation process is lengthy, the dates of all references to VR and AR used in this dissertation end in September 2023. Thirdly, the saturation criterion of the literature review for learning theories and methodologies was the objectives and contents of the research projects fitting my research interests. Lastly, although I understood that it was impossible to exhaust all related academic resources, I strived to present a thorough picture of my literature review in this dissertation.

Summary of Introduction

This section describes how modern technology plays a role in human society and impacts our lives. I also outline four criteria that bound my literature review. In the next section, I paint a general picture of the landscape of modern learners and our modern learning world.

Present Situations

Contemporary Learners

In Chapter 1, I introduced the idea that the building industry has progressively switched its traditional methods of practice to more innovative, technology-driven approaches. Thus, workers in the AEC field will need higher literacy in digital skills. Reigeluth et al. (2017) asserted that "we need graduates who are equipped to embrace change, who are prepared to make sense of the vast amounts of information at their fingertips, and who are curious and eager to communicate, collaborate, innovate, and create new knowledge" (p. 2). Whether the skill required is merely joining the online meeting with other consultants or showing design ideas to the public, preparing students for the contemporary labour market is inevitably the job of higher education training (multiple sources, personal communication, 2018–2023).

On the one hand, regarding smartphone market share, a study (Kemp, 2021a) reported that more than two-thirds of the world's population used a mobile device at the end of 2021. Similarly, Turner (2018) reported that 85.88% of the world's population owned a smartphone in 2023, and the number of mobile device users is expected to climb 15.14% by 2026. Diao and Shih (2019) concluded that smartphones "continue to be the most commonly used devices" (p. 14) in AR studies in the AEC educational community because today's university students use smartphones ubiquitously. Therefore, smartphone-based AR is more convenient for "immediate responses to various occasions" than other digital devices such as tablets (Diao & Shih, 2019, p. 14). On the other hand, regarding Internet usage, a report (Kemp, 2021b) revealed that more than 60% of people worldwide use the Internet. In another study, Turner (2018) predicted that 72% of all Internet users will solely use smartphones to access the Internet by 2025. A more recent study (Taylor & Silver, 2019), published by the Pew Research Center, disclosed that younger generations are much more digitally connected with the world, socially and academically, in developed and economy-emerging countries.

It can be reasonably deduced from these data that younger people tend to use smartphones for academic and social activities, and the Internet plays a significant role in making these remote connections possible.

Contemporary Learning

The government of Ontario's plan to modernize high school education with e-learning was stonewalled by some educators and parents when it was introduced in 2019. A study (Research and Development, 2020) revealed that "two-thirds of students and parents and 91% of secondary teachers answered 'no' when asked if they believed mandatory e-learning would benefit students" (p. 3) and "87% of students, 81% of parents and 97% of secondary teachers answered ‘no’ when asked if they supported the Ministry’s decision to make two e-learning credits a graduation requirement” (p. 2).

However, people’s perception of online learning has drastically and swiftly shifted after the emergence of the COVID-19 pandemic at the end of 2019 (Bennett, 2021; J. Patton, 2021). In fact, long before the global pandemic hit the world, Garrison (2011) suggested that educators must “design purposeful educational experiences using the potential of the Internet to bring teachers and learners together…” (p. 20). Bates (2019) further discussed various online teaching and learning tools and strategies. Specifically, Bates encouraged a learner-centred teaching approach where the focus enables student access to online learning content through the Internet without time and location constraints. Garrison (2020) echoed that advancement in communication technology empowers virtual collaboration in our connected society. Chao (2019) reported that mobile self-efficacy significantly improves users’ enjoyment of mobile devices. Chao further discovered that in current society, with the “popularity of the internet and mobile devices for various uses” (p. 10), students in higher education institutions have high mobile efficacy and enjoy using their mobile devices to complete different life and academic tasks.

Spencer and Lange (2014) defined education as an “organized way of providing for the possibility of learning” (p. 7). In educational settings, educators provide “planned learning” (Spencer & Lange, 2014, pp. 7, 8) to enrich students’ knowledge and develop their abilities. Whether it is teaching a synchronous online class or writing an email corresponding to students, communication technologies are “deeply connected” to distance education (Evans & Pauling, 2020, p. 122).

Similarly, Swan (2020) stated that innovative digital technologies empower interactive learning environments at a distance, thus supporting social constructivist teaching and learning activities. Swan pinpointed that "online learning is grounded in social constructivist learning theory" (p. 67). In a world digitally connected through the Internet, numerous multimedia technologies integrated into the learning platform can create an interactive, remote, cost-saving learning solution; learners worldwide can access information and conduct learning activities anytime, anywhere (Swan, 2020).

Summary of Present Situation

The advancement of technologies creates a digital and virtual web that connects everyone worldwide, and digital trends are shaping future educational practices (Maryville University, 2019). Integrating digital tools into our current social and academic life becomes inevitable. In the AEC industry, contractors at the job site can use their smartphones to remotely review ACAD drawings created in the architectural office and stored in the architectural office's server and provide feedback over the digital network (Autodesk, n.d.-c), such as adding project-related comments directly on the digital drawing platform remotely (Autodesk Customer Success Hub, n.d.). In the next section, I discuss several learning theories related to hands-on learning.

Learning Theories

Introduction

Spencer and Lange (2014) referred to learning as "any elements that together produce a change in mental constructs or behaviour" (p. 7). Laurillard (2012) stated that learning occurs when people imitate the skills developed by others, study knowledge discovered or proven by others, or communicate with others in a social setting. While Laurillard's discussion on communication was focused on verbal content delivery, Dewey (2004) claimed that communication is “a process of sharing experiences till it becomes a common possession” and “education is to social life” (p. 9). These notions imply that in a social setting, communication has many forms and is not limited to the language-based type. Dewey (2004) further discoursed that education is a “process of accommodating the future to the past” or is “a utilization of the past for a resource in a developing future” (p. 76). This discussion suggests that people learn from past experiences, and new knowledge is constructed based on the foundation of prior knowledge. Therefore, learning occurs within a community where people share their experiences and knowledge verbally or through other communication formats, and new understanding is constructed on the established prior knowledge. Constructivists believe that people learn about the world through individual interpretations of unique experiences and interactions with the world (Ertmer & Newby, 2017).

Learning in AEC Higher Education

Learning in AEC higher education typically consists of learning from textbooks and hands-on activities, as well as working individually and collaboratively.

The hands-on approach forms a primary part of the learning experience in AEC society. On the Western side, Michelangelo, the historic icon whose works influenced Western civilization over centuries (Britannica, 2023), was a painter, sculptor, and architect himself and mastered various hands-on skills. On the Eastern side, the Yingzao Fashi (State Building Standards), the oldest extant Chinese technical guidebook on building construction dating back to the mid-Song Dynasty of China, detailed numerous practical and complex construction methods of wood frame buildings (Guo, 1998). From Michelangelo’s design of the construction of St. Peter’s Basilica (Nast, 2019) to architectural design programs worldwide (ArchDaily, 2015) and construction learning programs in Ontario (Ontariocolleges.ca, n.d.), the hands-on method empowers people to apply their theoretical knowledge to solve real-world problems in a real-world work environment.

Historically, the architecture business adopted an apprenticeship format in which mentors provided apprentices with on-the-job guidance. Novices studied the skills and knowledge passed by their mentors and worked collaboratively with professionals from other trades. Prior knowledge and experience underpinned new building constructions and novel areas of expertise.

In modern architectural educational history, Gropius (Museum für Gestaltung, Berlin, n.d.) pioneered a pedagogy mode for architectural apprenticeship training at Bauhaus in 1922. The learning structure guided learners to obtain knowledge by experimenting with various "colours, shapes and materials" before formal architectural training began and conducted practical tasks in workshops with different subjects once students gained supplementary hands-on experiences (Museum für Gestaltung, Berlin, n.d.). Following Gropius's concepts, numerous architectural schools worldwide nurture students' creativities through a hands-on approach that includes "model making as an analog for the building process" (MassArt, 2016). Specifically, Voulgarelis and Morkel (2010) confirmed that making working architectural models helps students understand their initial design ideas and reflect on them in the design process. Many architectural professionals hold the same confidence in the learning-by-doing methodology and believe it is "a hands-on approach for learning technical subjects such as building construction, structure and environmental science" (ArchiDiaries, n.d.).

Social Constructivist Learning

Theory Discussions. Vaughan et al. (2014) discussed that learners comprehend new concepts and content with the support provided by their peers and instructors. Eventually, learners construct knowledge through discussion and interactions in a collaborative learning environment (Bates, 2019). Social interaction is crucial in continuing collaborative activities and maintaining relationships among all group members (Vaughan et al., 2014). Social constructivist learning focuses on the "social nature of learning" (Cohen et al., 2018, p. 23). Cohen et al. (2018) further discussed that learning is constructed through social interaction and communication. While Cohen et al. (2018) did not specify what format of communication they referred to in this discussion, in her discussion of social constructivism, Laurillard (2012) proposed that communication is language-based because language can convey complex concepts.

In social constructivism, individuals seek an understanding of the world through their own experiences (Creswell & Poth, 2018). In a research project, on the one hand, project participants construct or co-construct their subjective opinions or new concepts through the intertwining of prior experience from the study, work, and life, project involvement at the current moment, and interaction with others, such as other participants or the researcher (Bressler et al., 2018; Ertmer & Newby, 2017). On the other hand, researchers interpret research data and achieve conclusions through participants' views, knowing that learners acquire more experience as the research project progresses (Creswell & Poth, 2018).

Moreover, while knowledge is constructed primarily through a collaborative learning process where learners and educators interact with each other in a traditional brick-and-mortar classroom (GSI Teaching & Resource Center, 2022), the way of constructing knowledge has transformed into a digital collaborative learning process where learners and educators interact through various kinds of technologies in digital platforms as innovations gradually become dominant in the modern world (xTalks Office of Digital Learning, 2021).

Theory Applications. The apprenticeship element in the AEC industry, where all apprentices study with mentors, work collaboratively with a group of trade professionals or other apprentices, and create new structures or understandings grounded on prior knowledge, reflects the core value in social constructivist learning theory. Interactions and communications form the primary vehicle of knowledge creation. However, in AEC, communication involves a broad terminology consisting of verbal and visual communication.

Hands-on Learning

Theory Discussions. Dewey (2015) asserted that "every experience is a moving force. Its value can be judged only on the ground of what it moves toward and into" (p. 38), and "the quality of the present experience influences the way in which the principle applies" (p. 37). Dewey (2015) further pointed out that what a person did in the past or what the person is doing has "an active side" (p. 39) that influences the current and future experiences of this person.

The hands-on learning experience is one of a person's many life experiences. Ekwueme et al. (2015) defined the hands-on learning approach as "a method of instruction where students are guided to gain knowledge by experience" (Ekwueme et al., 2015, p. 47). Haury and Rillero (1992) stated that a hands-on learning experience would help learners remember the learning materials better, improve their confidence after completing the learning activity, and transfer their experience to other and future learning circumstances. Unlike other traditional learning methods, such as reading a textbook or having group discussions in class, the hands-on learning technique empowers learners to not only understand and acquire current knowledge through manual activities designed to align with the learning content but also reprocess attained knowledge or construct new knowledge building on prior knowledge (Haury & Rillero, 1992).

Theory Applications. The hands-on learning approach provides learners with physical access to the learning objects they need to study, and it has been employed widely as one powerful teaching technique in the STEM field (science, technology, engineering, and mathematics) in higher education, especially in vocational career preparation programs (Porter and Chester Institute, 2020). The hands-on activities in each academic program vary based on the learning components. For example, hands-on model-making in architectural study has been proven to be an effective and successful learning strategy to improve understanding of abstract ideas and enhance design conceptualization (Afify et al., 2021). In a welding apprenticeship program, students will learn how to use specific equipment to weld a plumbing pipe in a physical lab that mimics actual job site conditions (BCIT Piping Department, n.d.).

Experiential Learning

Theory Discussions. Another term with a similar concept of hands-on learning is learning-by-doing, also referred to as experiential learning by some scholars (Bates, 2019; Morris, 2020). Dewey (2015) claimed that "there is an intimate and necessary relation between the process of actual experience and education" (p. 20). If there was a link, he wondered, how could experience be turned into knowledge? Dewey asserted that "everything depends upon the quality of the experience which is had" (p. 27). Laurillard (2012) stated that educators' task is to structure appropriate learning steps for realistic experiential problems to enable learners to work through sequential actions to solve problems.

Seaman et al. (2017) identified that one of the challenges of experiential learning is that it impedes knowledge acquisition and progress development because "it simultaneously expresses an empirical phenomenon, a set of pedagogical strategies, and an ideology" (p. 15). Spencer and Lange (2014) even stated that "experience can be very problematic" (p. 9) because it is "constantly being interpreted, by individuals and by others," and "the same experience can lead to radically different conclusions" (p. 9). Thus, Spencer and Lange noted that, in some cases, people "may have to unlearn" (p. 9) prior incorrect, unpleasant, or undesirable experiences to learn new experiences.

Realizing that experiential learning created many mistakes, March (2010) pondered whether learning from experience starts "with observing associations between actions and outcomes" and learning "takes place when the observation of associations produces changes in actions or rules for actions" (p. 14). March elaborated on three mechanisms in the "low-intellect" (p. 18) mode of learning from experience. Of these three, March considered trial-and-error learning to be achieved by modifying actions "as a result of realized outcomes" (p. 19) and described imitation as a process of "having actions associated with success when executed by one actor imitated by another actor" (p. 20).

Inspired by Dewey's and other scholars' contributions to exploring how experience impacted education, Kolb (1984) created a framework which was referred to as a "widely influential model" by other scholars (Seaman et al., 2017, p. 3). Kolb's cyclic model explicitly quantified four dimensions of experiential learning theory, describing four basic processes: concrete experience, reflective observation, abstract conceptualization, and active experimentation.

Kolb (1984) explained that experiences occur in real-world situations, and they establish the foundation for observations and reflections. Individuals comprehend, interpret, and transform the information obtained from experiences and actively act on that information to create new experiences and/or knowledge. Kolb's model emphasizes that life experience is the "central and necessary part of the learning process" (Morris, 2020, p. 1064). Kolb stated that learning is the result of adaptation during the process of comprehending existing information with prior acquired information, is constantly “created and recreated” (p. 38), and is a combined experience of grasping, applying, and transforming acquired information.

Similar to Kolb, who argued that “knowledge is created through the transformation of experience” (p. 38), Cranton (2013) asserted that the essence of experiential learning is that knowledge is constructed “by reflecting on concrete experience” (p. 103). Cranton further expanded the experiential learning concept and claimed that knowledge is developed by working in a group environment and collaborating with others.

Morris (2020) proposed a revised experiential learning cycle which stemmed from Kolb’s model. Based on his research, Morris added one modifier to each stage of Kolb’s model because real-world problems are “inherently contextual-specific,” and thus, learners must “act pragmatically” (pp. 1072, 1073). In this revised model, Morris (2020) added “contextually rich” to concrete experience and used “critical” to modify reflective observation; he also embellished abstract conceptualization with “contextual-specific” and active experimentation with “pragmatic” (p. 1070). Morris’s finding suggested that concrete experience is contextually rich because learners often worked in a physical, collaborative learning environment that enabled a genuine and hands-on concrete experience. Additionally, to solve context-specific problems that exist in the real-world environment in the learning process, Morris stated that learners must adopt an “investigator-like manner” (p. 1070) to evaluate details and critically reflect on their observations. Moreover, as location and time change, so do learning environments, learning conditions, and learners; therefore, abstract conceptualization is context-specific. Morris further cited active experimentation as a stage in which learners act based on experiences obtained in context-specific, concrete experiences, and it “involves testing the fittingness of abstract conceptualizations formulated against new concrete experiences” (p. 1072).

Theory Applications. Experiential learning focuses on the process of how learners comprehend concepts and how learners apply learned knowledge to solve real-world problems. Ummihusna and Zairul (2022) developed a VR simulation experience rooted in the experiential learning model and uncovered that the experiment significantly increased learners’ spatial understanding of an architectural design process. Avci and Beyhan (2022) stated that AEC in higher education, as a subject area that focuses on delivering multi-disciplinary and interrelated theoretical design principles and applied knowledge, typically applies experiential learning theory. Avci and Beyhan asserted that this teaching technique assisted students in “retransforming the knowledge acquired by experience” (p. 20).

Task-Centred Instructional Strategy

Theory Discussions. Task-centred learning is a similar concept to hands-on learning. Merrill (2007) presented a task-centred instructional approach that promoted undertaking real-world tasks to acquire knowledge. Compared to traditional instruction, where learners are often unclear about the actual application of skills and knowledge learned at school in a real-world setting, Merrill’s task-centred instructional strategy requires the learners to “apply the topic knowledge and skills that they have been taught” (p. 15) to real-world problems.

Echoing Merrill, Francom and Gardner (2014) suggested that task-centred learning focuses on learning tasks in which learners apply acquired knowledge to solve real-world problems in a specific area. Francom and Gardner classified four essential components in task-centred learning theory, which included the learning of the task itself, the activation of the learner’s prior knowledge before commencing the task, the instructor demonstrating how to conduct the task and providing feedback during the process, and the learner exploring how and where to apply acquired skills to solve a real problem that exists in the real world.

Theory Applications. This theory puts a lot of weight on creating the task and evaluating it through various instruments. For example, Doran (2022) adopted a task-centred learning praxis to explore whether a specifically designed intervention could approximate learning about the manual assembly of computer parts. While the AEC area focuses on acquiring actual hands-on skills through practical learning activities, task-centred learning theory is more applicable to fields other than AEC.

Game-Based Learning

Theory Discussions. Some scholars distinguished game-based learning as fundamentally game-like learning activities with game characteristics and principles, designed by educators and participated in by learners. In contrast, others differentiated gamification as instructors incorporating game elements into existing learning activities, such as learners winning badges after answering questions correctly (University of Waterloo, n.d.). However, the terms game-based learning and gamification have been used by various researchers interchangeably (Hartt et al., 2020). To simplify the discussion, I use game-based learning as an umbrella term in my study.

Deterding et al. (2011) defined gamification as “the use of game design elements in a non-game context” (p. 9). Hartt et al. (2020) demonstrated in a study that a learning activity that integrates “game elements, game thinking and game mechanics in non-game contexts” (p. 4) motivated learners to engage in the targeted activity. As well, the design process of game-based learning enabled users to achieve certain outcomes based on preset rules (Juul, 2010). In addition, the majority of gamification examples were designed with and to be deployed through various digital technologies (Deterding et al., 2011). Technologies employed when designing a game-based learning activity form an indispensable part of the design process. Widely adopted in universities and academic libraries, game-based learning technologies offer opportunities to promote learner engagement and motivation (Pho & Dinscore, 2015). Recognizing that the Internet and digital devices were the foundation of creating a technology-enhanced classroom space (Yang et al., 2018), educators adopted various digital technologies to create a fun and engaging learning experience (Pan et al., 2021).

Theory Applications. With emerging technologies available in the current information era, educators can design game-based learning activities to facilitate course content and improve interactions among learners (Pan et al., 2021). In the AR and VR literature review sections below, some of the researchers employed game-based engines as part of the intervention. For instance, Jamei et al. (2017) utilized a commercial game engine, Unity®, and a set of interactive VR hardware to create a simulated virtual environment.

Summary of Learning Theories

Laurillard (2012) noted that each learning theory has made a unique contribution to the educational community, and these theories together provide "a comprehensive account of what it takes to learn" (p. 45). Adopting Kolb's experiential learning model in their AR-based learning study, Huang et al. (2016) confirmed that immersive technology enhanced learners' performance by offering innovative, effective, and meaningful experiences. As discussed in the subsections above, social constructivist learning theory correlates most with my teaching environment. I strive to work with project participants and incorporate their feedback into my intervention design. Additionally, experiential learning theory fits the nature of my study the most closely: I explored how an innovation realizes learning hands-on skills at a distance. Moreover, game-learning theory evolves as technology, especially immersive technology, advances. In some of the journal articles about VR and AR that I reviewed, researchers incorporated market-available game engines into their experiments. Although these projects did not explicitly discuss game-learning principles, they did resemble computer game environments where users could play and progress to the next level once they reached some milestones.

In the next section, I describe my review of VR and AR experiments conducted in the AEC industry and AEC higher education.

Emerging Technology Experiments in AEC Higher Education

Educators and researchers in the AEC higher education sector have been experimenting with immersive technology, such as VR and AR, in their practices. They strive to investigate how these emerging technologies assist with teaching and learning activities and how learners perceive these innovations. Although the number of research projects related to immersive technology applications in the AEC field has recently increased, projects that explore teaching hands-on model-making skills remotely in AEC, using VR or AR, have yet to be found.

Reviewing the literature on VR and then AR in the AEC industry and understanding the development path of immersive technologies made me realize that VR is like a predecessor of AR. So, in the following subsections, I explain how these two technologies have evolved over the years and provide readers with a foundation in immersive technologies. In addition, the media often mentions VR and AR together, which leads to many people being unable to distinguish between VR and AR. Even within my faculty team, several professors have only heard about VR (several faculty members, personal communication, over the past few years). Readers may potentially ask: Why don’t you use VR? Why do you only select AR? In my opinion, discussing only AR without addressing VR would be insufficient. Therefore, in the subsection below, I discuss VR first and then focus on AR.

Virtual Reality (VR)

From a historical viewpoint, although Wheatstone first attempted to position two identical 2D images next to one another and enable viewers to see a 3D image with depth through a stereoscope in 1838, Heilig invented the first HMD set in 1960 (Virtual Reality Society, n.d.). Sutherland further developed the world's first ultimate display HMD in 1968, and the virtual experience was so real that human eyes could not differentiate the real world from the virtual simulation (Sutherland, 1968). Since then, stereoscopic design and assembly principles have been adopted widely, and a famous yet inexpensive modern application is Google Cardboard (https://arvr.google.com/cardboard/). Today, VR technology is widely used in computer video gaming (Pickle, 2023), and institutions are exploring and adopting VR in teaching practices (Lewington, 2020).

The number of VR experiments in AEC higher education has steadily increased over time. Among various VR studies conducted at numerous universities worldwide, the research approaches to experimenting with VR have differed. On the one hand, some developed their own VR platforms customized to their unique research situations and integrated with deliberately selected technologies available through institutional licensing (Abdelhameed, 2013; Agirachman & Shinozaki, 2021; Angulo & Velasco, 2013, 2015; Arnowitz et al., 2017; Raikwar et al., 2019; Wu et al., 2019). On the other hand, some have adopted standard VR technologies through commercial markets or institutional licensing channels (Abdelhameed, 2014; Davidson et al., 2020; Dinis et al., 2020; Erkan, 2020; Heydarian et al., 2014; Jamei et al., 2017; Kreutzberg, 2014). While improvements in communication among parties have been observed in various experiments, Wu et al.'s (2020) research findings suggested that the use of VR applications "did not show an expected advantage over paper drawings in facilitating students' apprenticeship learning in outdoor physical construction activities" (p. 9). Another study (Lu, 2022b) discovered that although VR improved the understanding of construction details by providing an interactive and immersive learning environment, this technology could not "fully and accurately represent" (p. 21) specific knowledge topics and, thus, might result in incorrect learning.

Augmented Reality (AR)

Francke and Alexander (2018) suggested that AR provided learners with a "livelier and more engaging experience," and it bridged the gap between learners' "virtual and physical world" (p. 99). The emergence of AR transformed the AEC education sector. Diao and Shih (2019) introduced the idea that the characteristic of AR, which involves superimposing 3D virtual images over a physical environment, presents a possible solution. This feature enables users to establish convincing connections between abstract design ideas and the real world, as the knowledge previously illustrated on 2D planes is now seen in the natural world with realistic 3D dimensions. In their systematic literature review of built environment research projects, Wang et al. (2013) revealed that architectural professionals were the leading adopters of AR technology because AEC projects were visually orientated and required visual aids in representations.

Technically, AR requires a sophisticated and precise connection between the virtual object and the actual environment because the computer-generated virtual information is superimposed onto the user's view of the physical environment.

In contrast, in VR, the HMD user only views the virtual images without direct vision, connection, or interaction with the physical world (Peddie, 2017). AR is a collection of hardware and software capabilities with an "almost endless list of applications" (Peddie, 2017, p. 87). As new ideas and technologies emerge almost daily, the design of the AR experiment and the selection of AR tools for the experiment are only limited by the researchers' imaginations and their understanding of new technologies. AR technology has been widely experimented with in several industries, especially those that use CAD programs, and the AEC sector is one of them.

AR experiments in AEC rely heavily on combining various applications because of the complexity of advanced technologies and the simulated reality generated through these technologies. According to a mega-study of 120 AR projects in the architectural built environment, 18.3% of the research projects have been devoted to the development of a new algorithm or modelling and 27.5% of experiments were based on the "customization of off-the-shelf commercial or open-source AR software/toolkit" (Wang et al., 2013, p. 7).

Historically speaking, Feiner et al. (1995) conducted the first AR architectural project in a computer lab at Columbia University. The researchers first built a 3D computer model of a portion of a building's structural system with columns, beams, and so on based on the architectural design drawings, then overlaid this virtual 3D graphical representation in a real-world lab environment where the testers stood. Using an HMD, users could have a see-through virtual view of the structural system, enabling them to preview it before construction. This AR also allowed the users to interact with the virtual information embedded within the 3D structural model. For example, student users could study the detailed connection between the steel column and rebar when selecting a column. By immersing themselves in a 3D interactive virtual learning environment, learners could improve "both the rate and depth of comprehension of architectural structures" (Chapter 5, para. 2).

Since then, researchers have been striving to revolutionize industries through AR by combining customized developments and market-available technologies. As was recognized by

Diao and Shih (2019), professionals in the AEC or education fields found challenges in creating AR content in industrial and teaching practices, as AR systems are typically developed explicitly by computer specialists. Thus, it is logically deduced that AEC teaching professionals will opt to adopt the AR tools available on the market.

All scholars (Alp et al., 2023; Bademosi et al., 2019; Dudhee & Vukovic, 2021; Fonseca et al., 2017; Hendricks, 2022; Hussein, 2022; McCord et al., 2022; Symeonidou et al., 2022; Vassigh et al., 2016; Vassigh et al., 2020; Wang & Lin, 2023) created individual AR experiences utilizing self-developed, project-specific content based on the combination of various market-available applications.

The purpose of adopting AR in AEC research can be broadly categorized into three domains: advancing the comprehension of complex learning materials, investigating the learner's learning experiences, and presenting design ideas to various audiences. In the following three subsections, "Improvement of Learning Comprehension," "Enhancement of Learning Experiences," and "Presentation of Design Ideas," I review the technologies used in various AR projects and discuss the benefits these tools brought to the learners. In two subsequent subsections, "AR Mega Studies in AEC" and "Mega Study in AEC Education," I will introduce a number of mega studies and provide overall views of AR applications in AEC industrial and educational sectors.

Improvement of Learning Comprehension. Vassigh et al. (2016) developed an AR learning system, AR-Skope, integrating with BIM to improve students' spatial understanding of complex building design and construction systems and enhance multidisciplinary AEC collaborations. The application was built on Unity®, integrating Java (https://www.java.com/en/) and Android binding components to access the motion sensors equipped in Android smartphones or tablets. Using a smart device, student users could visualize preset building information overlaid on an actual building site through the application, such as the building envelope or mechanical system. AR-Skope enabled tracking users' locations and motion inside the actual building through their mobile devices and smartphone-embedded GPS (Global Positioning System). The interactive and visualized information was constantly updated based on the users' physical location and viewing projection, enabling users to better understand the relationships between the correlated 3D components and the real-world building site.

Vassigh et al. (2020) subsequently developed two virtual simulations built on the Skope platform prototype. The researchers investigated AEC learners' simulated VR and AR experiences. On the one hand, the AR-Skope interface enabled learners with hand-held devices, such as smartphones, to walk through the actual building site with overlaid virtual learning information and interact with the virtual learning components superimposed on the actual building site. For instance, learners could see the 3D model components of a mechanical system, such as heating ducts, overlaid on the underside of the actual building's floor slab. On the other hand, the VR-Skope development expanded the audience scope by enabling learners far from the building site to study the same virtual learning materials without engaging with the actual physical building site.

To coordinate with the research project, Vassigh et al. (2020) slightly modified three learning components to be experimented with and set up one control group, which did not adopt any immersive technology in the trial, and two experimental groups, which employed AR-Skope and VR-Skope tools in the investigation. Student participants were required to submit pre- and post-tests and pre- and post-attitude surveys, and complete a Technical Report after each learning unit. Data obtained from the control group served as a baseline for comparison. Students from two consecutive semesters joined two experimental groups. In addition, student users from the pilot experimental group provided feedback on the early version of the project design, resulting in researchers revising the project design for the subsequent experimental group. The research results indicated that students in the subsequent experimental group where AR-Skope and VR-Skope were used performed "significantly better on the post-tests than students in the control group" (p. 189).

To mitigate the most common challenge of studying complex construction situations firsthand in construction higher education, Bademosi et al. (2019) designed a two-phase project and executed three individual AR experiments to explain the construction methods of a small portion of one masonry wall, a segment of one metal roofing system, and a section of one steel structure. The experiments used several software packages, such as 3D modelling software, a developed camera-defining script, and video editing software. The researchers set up three user groups and assigned each group a random sequence to test each construction assembly with its AR-enabled video format, traditional lecture learning format, and combined AR-enabled video and lecture format.

In Bademosi et al. (2019) study, student users completed demographic and problem-solving skills questionnaires in the first and second phases and a quantity takeoff assignment related to the assembly being studied in the second phase. Bademosi et al. adopted Minitab (https://www.minitab.com/en-us/) statistical software to compare the pre-test and post-test results. After comparing data, the researchers concluded that the AR-enabled videos created for three construction assemblies helped students understand all assemblies better and potentially enhanced "the personal learning experiences of construction management students" (p. 75). The authors also revealed that the level of augmentation, whether it was advanced augmentation or simply highlighted in the AR video, significantly impacted students' understanding and recollection of the information learned. Bademosi et al. further noted that besides preparing videos and pictures taken on-site from three different assemblies, developing these three AR-enabled virtual learning platforms was critical.

Constant advancement in software and technology knowledge offers researchers a grander stage on which to conduct new experiments. Employing four commercially available model-superimposed software platforms, 3D viewer Beta (https://learn.MS.com/en-us/hololens/holographic-3d-viewer-beta), BIM Holoview (https://www.bimholoview.com/), HoloLive on MS HoloLens® (https://www.MS.com/en-us/hololens), and Model BIM on DAQRI Smart Glasses® (this product line was unfortunately shut down in September 2019 (Robertson, 2019)), Dudhee and Vukovic (2021) developed four experiments that superimposed a 3D room model with a partial 3D mechanical system, such as air ducts, to a real office room in an actual office building. The authors tested the affordances of these AR applications. Validating several approaches through virtual inspection of the model superimposed in the physical office environment, Dudhee and Vukovic discovered that the 3D building information models embedded with preset reference points and landmarks significantly improved the alignment when superimposing the models in the actual environment, thus resulting in a better visualization experience for users. However, the authors also concluded that at the current stage, "the functions of the AR devices and commercially available BIM–AR applications are limited and still under development" (p. 930).

In a recent study, McCord et al. (2022) developed an AR application to compare students' comprehension of wood wall panel construction sequencing depending on whether it was learned through a traditional 2D format or an innovative 3D AR format. McCord et al.

created a 3D wood wall panel model through Revit® and designed scripts in Unity® to enable student users to operate virtual wood pieces based on voice commands through MS HoloLens®. Student participants formed one group that used 2D worksheet drawings and another group that adopted the AR approach. Users in the AR placement group also took extra AR training via videoconference before the commencement of the experiment. All student users submitted a pre-activity survey that collected demographic information and wood-related knowledge self-assessment, provided verbal comments or reflections during the experiment stage for possible revision of their construction activity, and completed a post-activity survey that included cognitive load questions inspired by the NASA-Task Load Index (https://humansystems.arc.nasa.gov/groups/tlx/downloads/TLXScale.pdf).

To comprehensively understand the overall experience, McCord et al. (2022) also collected observational data when students performed the activities and further triangulated with activity video recordings containing user visual and auditory cues. Although recognizing that adopting AR in their activities was more challenging and less efficient than using a 2D drawing format, the researchers confirmed that student users in the AR intervention group "demonstrated more propensity for critical checks, mistake recognition, and self-reflection during their process" (p. 17).

To explore whether applying AR in teaching architectural technology could improve technical understanding, Hendricks (2022) adopted JigSpace (https://www.jig.space/) as the primary AR package on mobile devices. The researcher created a BIM demonstrating a construction detail and presented this BIM learning content in the AP platform. Hendricks adopted an action research approach and collected qualitative data from eight participating AEC experts. After experimenting with the AR tool, these instructors identified several concerns and benefits of adopting the AR tool in teaching architectural technology. A consensus was that adding AR enhanced the comprehension of complex knowledge as the dynamic model overlaid in a real-world environment presented true scales, much like what it looked like in a real-world physical building. This study also revealed that users who interacted with the various functions provided by this AR tool, such as exploding the model into small components, learned about the sequence of constructing such construction details in real life.

Enhancement of Learning Experiences. Fonseca et al. (2017) conducted a case study to evaluate students' levels of adaptation to technology in architectural spatial representation. This study consisted of two courses that employed various technologies. The first low-density technology course had five technologies, such as CAD and BIM, and the second high-density technology tryout used approximately 20 market-available applications, such as laser scanners and AR glasses. Each group of these technologies produced a 3D architectural model visualization. The authors analyzed the levels of students' adaptation to the VR and AR 3D architectural model visualizations through a pre-test survey, a user profile evaluation before the experiment, and a post-test survey. Fonseca et al. discovered that although students in the second experiment, where more technologies were employed, demonstrated increased interest in learning new technologies, they had higher stress levels than those using fewer technologies in the first stage. However, the authors also indicated that the negative aspects found in this study could be remedied by spending a longer time in the experiment stage or restructuring the previous course design to enable the explanation of how to use certain technologies adopted in the experiment.

In the other study, although they attained some degree of success in enhancing students' learning experience, Dudhee and Vukovic (2021) concluded that the functions in the current-available AR technologies were "limited and still under development" (p. 930), and as such, might impede the user experience.

Hendrick (2022) used selected AR with mobile devices to investigate whether employing AR in studying architectural technology could improve student engagement. The results confirmed that AR motivated learners to study complex knowledge and promoted autonomy in learning.

Meanwhile, identifying several problems and shortcomings in landscaping architecture education, Hussein (2022) proposed a specifically developed AR solution that could be experienced via smart mobile devices. Based on Unity®, the AR-Scape was coded using three computer languages: C++ (https://techterms.com/definition/cplusplus), C# (https://en.wikipedia.org/wiki/C_Sharp_(programming_language)), and JavaScript (https://en.wikipedia.org/wiki/JavaScript). Student participants used their Android devices, supported by Google ARCore (https://developers.google.com/ar), to perform five specifically designed trial tasks through the designed AR interface. After the experiment, each student user submitted a questionnaire that included three parts of formulated questions. In addition to tracking and evaluating student users' progress throughout five exercises, Hussein investigated the suitability of using AR-Scape in learning landscaping design, sought evaluative feedback on the performance and functionality of the developed AR tool, and measured users' feelings toward different 3D design approaches for the "ease of use, speed and accuracy" (p. 730). The study results unveiled that AR technology improved the understanding of landscape design principles, and participants' feelings about using AR in learning were encouraging.

Like Hussein's study, more AR research projects focus on exploring users' AR experiences. In a recent study, Alp et al. (2023) selected Fologram® (https://fologram.com/) in an architectural design studio to evaluate students' learning experiences, such as design skills and design alternatives in using AR for architectural representation. The experiment first trained participants to create 3D building models using Rhinoceros® (https://www.rhino3d.com/) and Grasshopper® (https://www.grasshopper3d.com/) and introduced the Fologram interface afterward. The design problems were embedded into the AR platform, and different virtual solutions to the design problem created by student users were overlaid in the actual interior room so that users could evaluate their own design ideas and finally select the best design alternative. Student users took a pre-intervention questionnaire that explored their tendency to use the new AR presentation format. They completed a post-intervention questionnaire that focused on measuring their AR experiences after completing the AR experiment. Alp et al. adopted SPSS® (https://www.ibm.com/spss) to conduct a two-tailed Pearson correlation analysis and discovered three significant relationships existed between research variables. As the results from this experiment demonstrated, AR adoption in an architectural design class significantly simplified the design complexity by virtually superimposing the abstract idea in a real-world environment; however, the success of this learning experience was also strongly related to users' computer literacy levels.

Presentation of Design Ideas. Today, the most popular application of AR in AEC is for project presentations. For example, AR creates a virtual yet real vision so that users can better visualize what the future neighborhood might look like in the general public consultation of an urban design project, or the same AR-generated environment can be presented in a remote job site meeting to smooth out collaboration among stakeholders such as engineers and contract professionals (Wayne, 2023).

Wang and Lin (2023) developed an AR platform that enabled public participation in the early decision-making process in an urban design project. Wang and Lin first fabricated the required 3D building element models using professional architectural modelling software such as Revit® and SketchUp®. Then, they developed a framework that used Unity® on Microsoft's Windows 11® platform (https://blogs.windows.com/windowsexperience/2021/06/24/introducing-windows-11/) to create the AR experience. By adding correlated plugins such as the Android® system, this new AR system enabled users to interact with the virtual activities in the AR platform through their own smartphones.

In Wang and Lin (2023) study, participant users completed an initial questionnaire before using the AR application, and researchers explained imaginative urban design scenarios to better prepare project participants. During the experiment, participants modified indicators embedded in the AR application to view and assess different virtual urban design models and ranked them accordingly. Participants answered a post-intervention questionnaire to provide feedback on the improvement of the indicators and their attitudes toward the AR experience. Wang and Lin conducted a Pearson correlation analysis and revealed that users believed that adopting AR technology helped them understand urban design content and improve their living environment. However, as the authors commented, the development of this AR platform served as a "starting point and core part" (p. 15) of this project, and several technical limitations were observed during the experiment. For example, certain AR technologies could not successfully handle the urban project because of its large scale.

AR can assist in the preliminary design stage, including concept illustration, idea evaluation, and design presentation. Symeonidou et al. (2022) experimented in a bridge design studio class to evaluate various design concepts through AR mediums and smartphones. Before the experiment, student participants were introduced to and obtained technical training on the selected AR platform, Fologram® (https://fologram.com/). Each team of participants created a 3D bridge model through an AR-compatible software, Grasshopper® (https://www.grasshopper3d.com/), based on their own design concept.

One notable feature of this experiment (Symeonidou et al., 2022) was that each group of participants was instructed to embed several design parameters, such as bridge scale and proportion, that could be modified interactively before importing their bridge model to the AR platform. Once the connection between the AR medium and the users was established, participants could customize their bridge design with specific modifiers and instantly see the new design overlaid on a real bridge site. Symeonidou et al. deployed pre- and post-design surveys to examine how adopting AR in architectural design studios impacted student users' learning experiences and design practices. One of the results obtained from this study was that students generally agreed that the AR platform chosen was easy to use; however, students also expressed that their AR experience could be improved through more practice with and learning about using the AR tool. Symeonidou et al. noted that "a period for familiarization and transition to new media was necessary" (p. 754) if project participants had no prior AR experience.

AR Mega Studies in AEC. To identify emerging trends and to synthesize the current AR research studies in the AEC industry, Rankohi and Waugh (2013) analyzed 133 articles in eight prominent AEC academic journals about AR-based research projects in the construction industry, with eight classified dimensions: "improvement focus, industry sector, target audience, project phase, stage of technology maturity, application area, comparison role, and technology" (p. 1). This study revealed that only 8% of the projects targeted education and training aspects.

Meanwhile, to identify gaps in the AR literature and propose future research directions, Wang et al. (2013) systematically reviewed 120 AR articles over six years related to built environments, with a four-layer classified framework: “concept and theory, implementation, evaluation (effectiveness and usability) and industrial adoption” (p. 2). The authors revealed a similar result, which showed that only 7.5% of the segment studied the potential of technology adoption in AEC.

In contrast to Rankohi and Waugh (2013) and Wang et al. (2013)’s results, where only a small percentage of research projects found were focused on training and educational purposes, Song et al. (2021) conducted a recent study which analyzed the contents of 84 articles over ten years in the AEC field and pinpointed the three most common functions of AR in AEC: “AR 3D holographic instruction, AR data sharing, and AR for Human-Computer interaction” (p. 4). Song et al. identified that the research area that had been focused on the most was adopting AR technology to train novice workers virtually at architectural digital fabrication fields or construction sites.

Moreover, Wang et al. (2013)’s analysis showed that 52.5% of the research studies focused on technical development. Similarly, Rankohi and Waugh (2013) pointed out that the AR system is content-, features-, value- and audience-specific; as a result, the currently available AR experiments had been developed for specific trial and demonstration purposes. Song et al. (2021) echoed that the second-largest research topic was related to human-computer interaction achieved by AR technology.

Additionally, through systematically analyzing 39 AR studies in AEC, Hajirasouli and Banihashemi (2022) identified that most of the research emphasized the construction field instead of architecture, and most of the studies within the architecture category focused on "representation, communication and spatial skills and abilities" (p. 23).

Concerning the development of innovative technology, Rankohi and Waugh (2013) recommended that construction professionals should keep monitoring future AR development to learn about the latest updates as AR technology is "rapidly evolving" (p. 17). Song et al. (2021) pointed out that even though they aimed to achieve interactive tasks between human objects and machines through the physical, real-world visualization environment, these research studies were still in the "initial exploration stage" (p. 9).

Davila Delgado et al. (2020) studied the AR and VR applications in AEC from other angles. After thoroughly analyzing data obtained from participants in eight focus groups with 54 experts from 36 organizations from industry and academia, the authors discovered that the cost and immaturity of AR and VR technologies are the primary obstacles preventing their adoption. Moreover, because of the significant investment "required to implement AR and VR in terms of equipment, space, time, and upskilling," Davila Delgado et al. (2020) asserted that "only by developing AR and VR hardware and software specific for the AEC sectors the investment can be justified" (p. 17).

In another study based on the same data source, Davila Delgado et al. (2020) declared that AR and VR "are not ready to be fully adopted in the construction industry and that research and development gaps remain" (p. 17), even though AR and VR can be used in various areas throughout the lifecycle of a building.

Researchers have also analyzed which equipment is required to generate the AR experience. Rankohi and Waugh's (2013) results showed that lightweight mobile devices were recommended for easy mobility. Hajirasouli and Banihashemi (2022) discovered that although some scholars adopted market-accessible hardware and software to develop new AR-based technology, "most of the AR-based technologies used in the field of architecture higher education have followed very similar procedures and frameworks" (p. 21). Utilizing market-available AR applications such as BIM, HMD, or SketchUp® was a standard course design strategy.

Among all these systematic studies, Hajirasouli and Banihashemi (2022) assured readers that integrating AR applications into teaching effectively improved students' spatial and graphical skill development and the realistic comprehension of their abstract design proposals. Davila Delgado et al. (2020) identified four essential limitations, such as immature technologies, which impede the adoption of AR and VR in the construction industry as the industry demands highly accurate and reliable performances. Davila Delgado et al. subsequently proposed a roadmap that included short-term actions, such as increasing AR and VR training for AEC professionals, and medium-term actions, such as developing more AR and VR content, to help overcome these obstacles. Comparably, Song et al. (2021) asserted that shortcomings still exist and need to be improved in future even though AR promoted non-expert participation in the AEC process.

Mega Study in AEC Education. Although the research on AR technology adopted in AEC higher education is scarce, a systematic review (Garzón et al., 2019), which covers 61 studies selected from scientific journals and conference proceedings spanning from 2012 to 2018, revealed that 29.5% of the target group studies were in bachelor-level post-secondary education. This result implied that AR applications in institutions must consider learners' maturity and literacy skills. The research results also revealed that all the applications related to the engineering, manufacturing, and construction industries were focused on engineering

(Garzón, 2019). This outcome confirmed that AR offered many benefits in real-world applications, such as detecting defects in the design process and reducing the assumption, cost, and time related to modifying the product's design (Lloyd, 2022).

Summary of Emerging Technology Experiments in AEC Higher Education

In this section, I reviewed a series of AR and VR research studies conducted in recent years. I explored various components of these projects, including the immersive technology used or developed in each project, their research methods, user participants, and research results. I offer four final remarks below.

Based on my literature review, researchers have mainly adopted VR because VR development is faster and easier than AR development. VR is closely related to AR, and some researchers developed a VR system first and then developed its associated AR system. Scholars such as Vassigh et al. (2020), Fonseca et al. (2017), Davila Delgado et al. (2020), and Davila Delgado et al. (2020) conducted studies on VR and then AR in the AEC industry. One recent example is the VR project by McCord et al. (2022), whose research materials were adopted by a team of researchers at another university in the USA to develop a new AR system (W. Wu, personal communication, August 2023).

On the one hand, adopting VR in AEC higher education appears to present a promising future in teaching and learning. In one of the most recent reviews, by analyzing 11 industrial case studies other than AEC-specific sectors, Philippe et al. (2020) assumed that the evolution of VR "will support the development of new experiences for remote working" (p. 421). As well, a recent study (Perkins Coie LLP & XR Association, 2019) reported that immersive technologies, including VR and AR, will be "as ubiquitous as mobile devices" by the year 2025 (p. 2). However, a prior survey (Perkins Coie LLP, 2018) revealed that 41% of the survey respondents agreed that the biggest obstacle to mass adoption of VR innovation is related to user experience, such as technical malfunction (Perkins Coie LLP, 2018). Moreover, regrettably, Lu (2021b) stated that no published studies were found on applying VR to learning hands-on skills remotely in construction.

On the other hand, in their study, Francke and Alexander (2018) confirmed the potential benefit of using AR mobile apps in educational settings. They suggested that AR "offers a more dynamic educational experience with hands-on learning and collaboration in which learners can meaningfully solve real-world problems" (p. 99). However, among all experiments, there are still no projects using emerging technologies, especially AR, to teach hands-on skills in the AEC higher education sector, let alone teaching and learning these skills remotely through immersive technology. Moreover, as the literature review section here presents, a gap exists between research projects and teaching practice regarding developing hands-on skills remotely. It is imperative for educators to find ways to bridge this gap.

Since I aim to integrate new technologies into the classroom to explore how innovations enhance learning, assessing their effectiveness is crucial. In the next section, I review and discuss two established models that evaluate the acceptance and application of innovations.

Models for Evaluating Innovations

Davis (1985) first proposed the Technology Acceptance Model (TAM) to investigate a potential user's inclination toward using a given technology, determined by two major factors: perceived usefulness and perceived ease of use. According to Davis, design features of the target technology or system have a direct impact on these two elements and have an indirect influence on the user's attitude toward using it and the user's actual action of employing the given technology in a real-world setting. Davis suggested that "perceived ease of use has a causal effect on perceived usefulness" (p. 24). Davis further explained that, after measuring the degree of tendency to use the target system, an individual will realize how much the given system enhances their performance and subsequently determine the appropriateness of using the target technology in the future.

Considering a broader scope in evaluating technology, Bates (2019) proposed an updated SECTIONS model (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy) to determine the most appropriate technologies to be used in distance education. Bates expected that the set of criteria in this framework would assist instructors in deciding which technologies or media to use in the classroom.

Technology Acceptance Model (TAM)

Scholars in various academic disciplines have employed the TAM to evaluate user acceptance by assessing the perceived usefulness and the perceived ease of use of the selected technology in their research projects (Chandrasekera, 2014; Chao, 2019; Lee et al., 2019; Manis & Choi, 2019; Sagnier et al., 2020; Suh & Prophet, 2018). Although many research projects have employed various technologies, I only found a few studies that employed TAM to investigate user acceptance of VR (Sagnier et al., 2020).

Chandrasekera (2014) adopted a developed AR software in an architectural studio class to investigate whether the virtual AR model-making experience assisted students in understanding design solutions better than physical model-making. Chandrasekera used TAM to assess users' attitudes toward the selected AR tool. The results revealed that "physical models are comparable to augmented reality models and that they were easy to use" (p. 40). Chandrasekera suggested that research to examine whether any correlations existed between digital literacy and the inclination to use innovations should consider users' computer literacy.

Inspired by Chandrasekera's suggestion that users' digital literacy might play a role in promoting or discouraging users' willingness to use innovations, Sagnier et al. (2020) developed an extended TAM model stemming from Davis's original TAM that included exploring user characteristics, such as personal digital literacy and creativeness, and unexpected events that might emerge during the VR experiment, such as cybersickness. Sagnier et al. discovered that users who were interested in innovations tended to consider the technology as useful, and the pragmatic qualities of the chosen technology influenced users' perceptions of the ease of use of technology. The findings implied that the innovation does not need to be easy to use, and the users will still consider it useful and thus use it.

In contrast to the findings from Sagnier et al. (2020), Matsika and Zhou (2021) claimed that the complexity of technology impeded the use of AR/VR technology. Matsika and Zhou employed the TAM to explore factors that influence the adoption of AR/VR technologies in higher education. The results showed that although 60% of project participants agreed that training sessions for learning to operate the AR/VR technologies were easy, 40% perceived that AR/VR technologies were not easy to use.

Adopting TAM to investigate consumers' intention to use VR in the entertainment industry, Lee et al. (2019) uncovered that most people regarded ease of use as an essential feature of VR, and perceived enjoyment was the biggest factor that impacted their intention to use the technology. Lee et al. also suggested that the "social-network-related" (p. 46) characteristic of VR positively influenced users' acceptance of innovations.

Similarly, Manis and Choi (2019) extended the TAM by incorporating perceived enjoyment and cost of the innovation as two key variables in their study. The researchers discovered that even though perceived ease of use had the largest impact on perceived enjoyment, people who were willing to spend more on the innovative device had higher perceived enjoyment than those who were not.

SECTIONS (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy)

Bates' (2019) SECTIONS (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy) model comprehensively evaluates distance education technology choices. Assessing whether the technology is easy to use and whether it is student-centred, Bates' model also focuses on the cost of purchasing and operating such technology. Among all other contributing factors, the functions, interactivity, and networking capability of the technology imply that learners in the distance education environment are connected virtually. Thus, cyber safety is an essential consideration in selecting innovations for remote learning. Although instructors may be able to assess the security and privacy of the chosen technology, cyber-attacks in an educational institution may occur. The last vital factor is related to the organization implementing the technology.

Summary of Models for Evaluating Innovations

Based on my literature review, although many researchers have employed various technologies, only several scholars have used TAM to investigate user acceptance of VR. These studies include Lee et al. (2019), Manis and Choi (2019), Sagnier et al. (2020), and Matsika and Zhou (2021) (the latter two used TAM to assess AR and VR). Additionally, I could only find one study—Chandrasekera (2014)—that applied TAM to evaluate the use of AR.

Through discussing two technology evaluation models, I decided to adopt the TAM in my study to evaluate whether an AR tool is logical and practical. In addition, since Bates' model offers evaluations from various angles that the TAM does not cover, such as cost, I integrated these criteria to evaluate the selected technology. Since I am a contract faculty member and do not have regular and informative insights related to the College's operational structures, I intentionally omitted the discussion of organizational issues in my study. However, I invited faculty members from the architectural program to be project participants so I could obtain limited insights related to operational aspects.

Summary of Chapter 2

In Chapter 2, I reviewed literature in several areas closely related to my research project. First, after introducing the selection criteria for my literature review, I presented the unique characteristics of modern learners and modern learning. I then introduced several learning theories related to hands-on learning, such as game-based learning theory. I emphasized social constructivist learning, hands-on learning, and experiential learning theories as the underpinning theories of my study. I also discussed the most up-to-date VR and AR projects experimented with in the AEC industry and in AEC higher education, focusing on AR. I finally explained two commonly used models for evaluating educational technological innovations.

In the next Chapter, "Theoretical Framework," after introducing my ontology, epistemology, and axiology, I describe pragmatism as the paradigm that led me to choose design-based research as my approach to designing and evaluating the intervention.

Chapter 3. Theoretical Framework

Introduction

In this chapter, I discuss how I perceive the world, what I believe, and how my views impact my role as an educator and a researcher. I then explore the philosophical assumptions that influence my teaching practices and research design. I further introduce the design-based research approach underpinning the design and evaluation of the intervention that I used in my research study. I wrap up this chapter by explaining my theoretical framework.

Backgrounds

Ontology

My ontology is that I believe that reality can be seen from different angles; thus, it can be interpreted differently based on viewers' perspectives (Creswell & Poth, 2018). Kuhn (2012) discussed that "what a man sees depends both upon what he looks at and also upon what his previous visual-conceptual experience has taught him to see" (p. 113). In education, we explore what constitutes knowledge. Is all learning beneficial? Are all experiences good? (Creswell & Poth, 2018; Spencer & Lange, 2014). In my view, educators should consider the complexity of intertwined factors that influence dynamic educational settings. Influential aspects such as individual, institutional, social, cultural, and political factors and the contexts among these factors should be examined to determine subsequent educational approaches (Cranton, 2013).

Epistemology

Creswell and Poth (2018) explained that the characteristics of epistemological assumption are that "subjective evidence is obtained from participants and the researcher attempts to lessen the distance between himself or herself and that being researched" (p. 20). They further suggested that researchers should stay in the field where the project participants live and work to learn first-hand information directly from participants. Creswell and Poth's concepts of the epistemological assumption, along with my ontology perspective, lead to my epistemology: I strive to understand reality through the lenses of participants, the relationships among various factors, and how they intertwine. While knowing that conducting research and research outcomes can benefit learning communities, I realize that biases may be present when researchers conduct their research. For example, researchers may distort the data analysis by unintentionally projecting their own views onto the data (Cohen et al., 2018).

Axiology

Based on the above discussion, my axiology is that my role as an educator and a researcher in the classroom enables me to gain first-hand information from the field and to improve my teaching practice by implementing outcomes from research. To avoid misrepresenting any information during the research process, I value the views of project participants.

Paradigm

Discussions of Paradigm

Cohen et al. (2018) stated that paradigms are how people assume what the world looks like and how to understand its phenomena. As people understand the world more over time and through the development of technology, old paradigms are replaced by novel prototypes (Cohen et al., 2018). Kuhn (2012) used the term "paradigm shift" (p. 134) to represent those new paradigms reconstructed from former prototypes based on newly discovered fundamentals, methods, and applications. Distinct differences exist between the old and new paradigms in the problems being investigated and the methodologies being applied to solve these issues. The transition periods from old paradigms to new ones are always complicated and overlap; new perspectives or knowledge are generated after these transition processes are completed (Kuhn, 2012).

Educational philosophers discuss various paradigms on understanding the world around us and concepts for investigating existing phenomena. Multiple perspectives provide me with a broad foundation for my study. Among all schools of thought, I am inclined to the four paradigms Creswell and Plano Clark (2011) categorized. Of these four, pragmatism best suits my research project based on my research interests and the characteristics of the AEC industry.

Pragmatism

Cohen et al. (2018) explained that the foundation of pragmatism is that "thought should lead to action, prediction and problem-solving" (p. 35). Creswell and Plano Clark (2011) stated that pragmatism focuses on creating appropriate ways to answer research questions. The research designs, methods of data collection, and ways to interpret the data are determined by the suitability of the research purpose. Intentionally, pragmatic researchers aim to explore "the *what* and *how* to research based on the intended consequences" (Creswell & Creswell, 2018, p. 11), and pragmatism provides multiple methods of collecting and analyzing various types of data to answer different assumptions. Denscombe (2008) concluded that pragmatism is "practice-driven" and the research itself is constructed "by a whole variety of practical issues and demands" (p. 280).

From a pragmatic perspective, there may be subjective or objective views, singular or multiple versions of reality, so it is imperative to align the "solution of the practical problems in the practical world" (Cohen et al., 2018, p. 36). As well, Cohen et al. (2018) stated that experimental methods "demonstrate causality" and that "an outcome has been used by a specific intervention" (p. 391). Similarly, Creswell and Creswell (2018) articulated that "causes determine effects or outcomes” (p. 6), in which the researcher needs to “identify and assess the causes that influence outcomes” (p. 6). In addition, the National Research Council (2002) suggested that researchers “use methods that permit direct investigation of the question” (p. 51). In pragmatism, “what something ‘means’ is manifested in its practical, observable consequences and success in practice, with its links to experiences” (Cohen et al., 2018, p. 36). Pragmatism emphasizes which methods are working in solving the problems and that “the research is driven by the research question” (Cohen et al., 2018, p. 35). According to Rossman and Wilson (1985), pragmatic researchers emphasize adopting all necessary methods to understand the research problems and answer the research questions. While collecting and analyzing both qualitative and quantitative data in their study, Rossman and Wilson (1985) noted that “qualitative data can be used to corroborate, elaborate, or initiate qualitative data. The same is true for quantitative data” (p. 641). Particularly, Creswell and Creswell (2018) elaborated that pragmatic researchers are free to choose the research “methods, techniques, and procedures” (p. 10) that best fit the research needs; mixed methods research approaches collect both quantitative and qualitative data and do not view the world through a single lens. Additionally, Ulysse and Lukenchuk (2013) stated that what is valuable in pragmatism is “what works” (p. 18). Pragmatic researchers are more concerned with whether an idea or solution can be found to solve a specific research problem.

Moreover, Ertmer and Newby (2017) explained that humans’ understandings of the world originate from the perceptions of individual involvement, and humans create new knowledge from experience. Cohen et al. (2018) stated that “knowledge and action are closely connected and mutually informing” (p. 36). Cohen et al. (2018) further elaborated that researchers “examine the situation in question through the multiple lenses of the individuals involved to obtain their definition of the situation, to see how they make sense of their situation and to focus on interactions, contexts, environments and biographies" (p. 23). Furthermore, Creswell and Poth (2018) noted that researchers apply the inductive procedure and emerging design technique to study the research topic, and the research questions may change during the research period as a response to the development of the research process. Thus, the data collection method may be modified accordingly.

Research Approach

Scholars have discussed various research approaches to assist in designing and conducting different research projects. One of them is design-based research.

Design-Based Research

An early-stage model of design-based research was proposed by MIT (The Massachusetts Institute of Technology) professor Woodie Flowers (Kelly, 2014; Minichiello & Caldwell, 2021), who pioneered a teamwork-based hands-on approach in engineering education while transitioning from student to teacher at MIT in the 1970s (Chandler, 2012).

Seeking a flexible and iterative process to assist in designing and evaluating educational design research, McKenney and Reeves (2013) proposed a generic model that consisted of three main stages: analysis and exploration, design and construction, and evaluation and reflection. Employing McKenney and Reeves' (2013) generic model for design research, Shattuck and Anderson (2013) investigated whether a course designed for training instructors who were transitioning to online teaching practices provided effective and accessible training solutions. Shattuck and Anderson echoed that design-based research is an "effective approach for other research projects focused on the design and evaluation processes" (p. 189).

Recognizing that researchers in the AEC field are proficient in the process of design and typically have prior experience, Kelly (2014) commented that design-based research "draws on engineering practices for some of its key values and approaches" (p. 497). Bakker (2018) explained that in the design-based research community, design refers not only to object design but also to process-like design, such as designing how "students or teachers are expected to communicate" (Chapter 1, p. 4). Scott et al. (2020) echoed that the design-based research approach aligns with research methods in the engineering field where "products are designed for specific purposes" (pp. 1, 2) and is iterative and user-oriented.

When experimenting with the design ideas in teaching and learning environments, Cook (2002) proposed that "experiments should be designed *to explain* the consequences of interventions and not just to describe them" (p. 189). Similarly, Sandoval's (2014) view of design research focused on "explicating causal processes" (p. 29). In comparison, Maxwell (2004) assumed that causal processes can be observed. Moreover, while the instructors or researchers are in charge of designing, implementing, and analyzing the intervention, design-based research "regards the role participants play in the experiment" (Scott et al., 2020, p. 3). This approach investigates users' cognitive transformation during the experiential stages, and it provides the research team flexibility to modify the instructional tools to bridge the gaps between interventions and the research problems (Scott et al., 2020).

In their comprehensive review of projects that adopted design-based research in engineering education, Minichiello and Caldwell (2021) examined publications spanning the period from 2005 to 2019 and concluded that one of the challenges of design-based research was to develop a team that included expertise from multiple disciplines to fully utilize the technology available in current society. Minichiello and Caldwell (2021) also discovered that about 40% of the sources developed interventions that adopted technology and had Internet access, such as technology-based classroom experiments conducted with web-based digital courseware in online learning communities.

Theoretical Structure

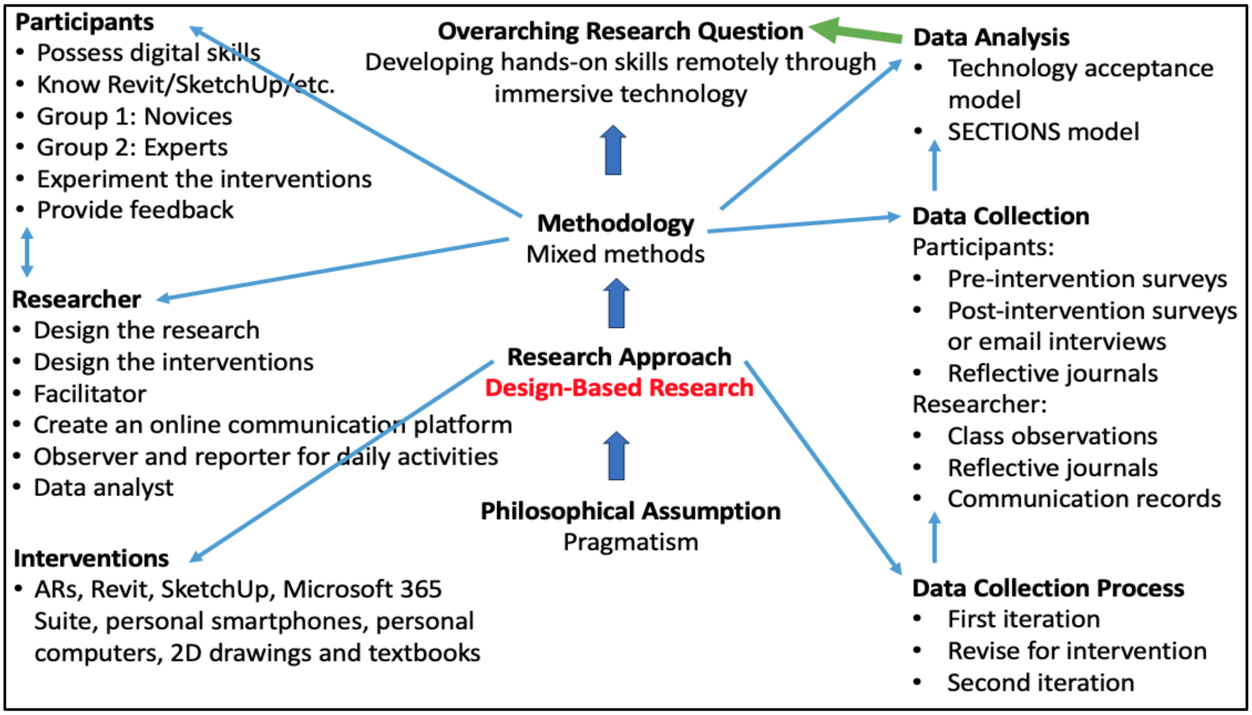
Crawford (2019) defined a theoretical framework as “an element of a conceptual framework that situates the relationships explored in the study into the context of developing or testing formal theories” (p. 38). Crawford further explained that a theoretical framework should “identify the theory cluster” and, subsequently, “identify specific theories relevant to that cluster” (p. 39); and finally, the researcher should describe “how the study will contribute to using the theory for explanation and prediction” (p. 40).

My theoretical framework for this research stemmed from my conceptual framework. My philosophical assumptions aligned with my ontology, epistemology, and axiology, forming the foundation for determining the research approach that applies to my study. The consideration of pragmatism ultimately led me to select a design-based research approach as my research approach, which governed my intervention design process.

The structure of my theoretical model and all related research mechanisms resembles a tree. The main theoretical framework progresses linearly upward with an orderly hierarchy, resembling a tree trunk. All interrelated components, such as the researcher’s reflections and participants’ feedback, mimic leaves and branches that help receive nutrients and nurture the tree, contributing to the tree’s health. In my case, all these factors assisted in answering my research questions. My theoretical framework is shown in Figure 6 below.

Figure 6

Theoretical Framework



Note. Illustration of my theoretical framework. The arrow direction indicates the direction in which the data are conveyed.

Summary of Chapter 3

In Chapter 3, I first introduced my ontology and epistemology. The discussion of my ontology and epistemology grounds my choice of pragmatism as my research paradigm. The exploration of pragmatism steered me in the direction of adopting the design-based research approach in designing and assessing the intervention that I used in my study. I finally proposed my theoretical framework after discussing all the background information in this chapter.

In Chapter 4, I focus on introducing the methodology that I employed in my research. Topics in the next chapter cover how my research questions emerged, how these research questions were framed, the research design process, and the factors to be considered.

Chapter 4. Methodology

Introduction

Design-based research resembles action research since both have participant-oriented and iterative natures (Cohen et al., 2018; McNiff, 2016). Following Morris's (2020) framework, I present the intervention I designed and explain the intervention and specific technologies applied in this research. To better contextualize my research design and provide the project rationale, I reflect on the innovation-specific project I conducted in 2021 (Lu, 2022b) and the original intervention I implemented in the 2023 Fall semester. Together, these two sets of data, along with data obtained from the pre-intervention questionnaire, establish the baseline of my research.

The Research

In this research, I designed and tested an intervention to investigate whether it could help develop hands-on skills at a distance and how effective it was in teaching and learning hands-on skills remotely. Based on my literature review, adopting VR offers potential pedagogical solutions in AEC higher education. For instance, Wu et al. (2019) created a VR environment to help beginners comprehend new construction knowledge. Still, I found no published studies to date on employing VR to learn hands-on model-making skills remotely (Lu, 2021b). Analogously, although Francke and Alexander (2018) suggested that AR provides an educational experience through "hands-on learning and collaboration" (p. 99), enabling learners to solve real-world problems, I found no projects experimenting with using AR to study hands-on skills remotely. Additionally, since AR is projected to be "as ubiquitous as mobile devices" by 2025 (Perkins Coie LLP & XR Association, 2019, p. 2), researchers must consider the potential benefits of using AR mobile apps in educational settings. I integrated only AR into my intervention.

I investigated the affordances of selected AR technology or technologies currently available through the lenses of the SECTIONS (Students, Ease of Use, Costs, Teaching Functions, Interaction, Organizational Issues, Networking, Security and Privacy) model and TAM (Technology Acceptance Model). I also explored the best currently available AR technology to develop the proposed hands-on skills remotely. Specifically, I learned about users' experiences related to various aspects of the chosen AR technology through TAM, which has been experimented with by researchers in the AEC field (Chandrasekera, 2014; Lee et al., 2019; Manis & Choi, 2019; Sagnier et al., 2020; Suh & Prophet, 2018) and in other educational settings (Harrati et al., 2017).

Research Questions Restated

Cohen et al. (2018) introduced that educators are concerned "not only for 'what works' but 'why,' 'how,' 'for whom' and 'under what conditions and circumstances'" (p. 87). Cohen et al. (2018) further specified that "research questions stem from the aims, purposes and objectives of the research" (p. 165). Researchers must create research questions that purposefully target specific aims and objectives. The research questions can generate valuable and reliable data to answer the proposed goals and enable researchers to establish conclusions (Cohen et al., 2018).

Cohen et al. (2018) suggested that researchers create "very specific, concrete and practicable" questions that are answerable (pp. 170, 185). For instance, questions that seek "to examine the effects of an intervention" or "to examine perceptions of what is happening" (pp. 169, 185) allow the researcher to operate the research project and achieve the goals.

Research Question Framing Techniques

The framing techniques for my research questions follow the third-order typology refined by Dillon in 1984 (Cohen et al., 2018). Cohen et al. (2018) stated that Dillon's third-order method of framing research questions concerns correlations, conditionality, and causality. Another technique incorporated into crafting the research questions suggested by Creswell and Creswell (2018) is to "begin the research questions with the words what or how to convey an open and emerging design" (p. 134). Creswell and Creswell (2018) also suggested that the directional hypothesis is about the researcher making a "prediction about the expected outcome, basing this prediction on prior literature and studies on the topic that suggest a potential outcome" (p. 138). In addition, the framing techniques for my research questions are based on the principle described by Creswell (2018): "asking what the participants experienced and the contexts or situations in which they experienced it" (p. 134). Moreover, Cohen et al. (2018) described one of the techniques that make the research question answerable thus: "compare the effects of an intervention in different contexts" (p. 169).

Research Design

Morris's Experiential Learning Cycle

I designed each iteration of the study using Morris's experiential learning cycle principles. Morris (2020) proposed to add a modifier of "contextually rich" (p. 1070) to concrete experience. Morris suggested that experience must be created in a context, and an experiment must align with and be situated in the actual and contextual environment. This research project explored how to help learners in this architectural program develop the hands-on skills needed in the course and future workplaces; thus, a genuine and hands-on concrete experience was enabled (Morris, 2020). Morris (2020) also used "critical" (p. 1070) to modify reflective observation to emphasize the importance of critical thinking in observation and self-reflection. I asked each participant to reflect on the project process and the interactions among peers and provide crucial feedback that may assist in improving the intervention design and student learning. Participating volunteers must employ an "investigator-like manner" to assess all details they observe and critically reflect on their observations (Morris, 2020, p. 1071).

Moreover, Morris (2020) specified that the abstract conceptualization must be "contextual-specific" (p. 1070) because new concepts must be generated through and within the project context. In my designed project, the intervention aimed to assist in developing hands-on model-making skills remotely; thus, new learning must be constructed and related to this specific area of knowledge. As participants gained more knowledge from the first iteration, their learning about the intervention and reflections on the process in the second iteration would differ from those obtained from the first iteration. Furthermore, Morris (2020) suggested that active experimentation is "pragmatic" (p. 1070). Participants performed each task according to what they had obtained from prior experience, and the process involved examining whether the new knowledge learned aligned with new concrete experiences.

Research Project Process

This section outlines the whole process. Before commencing the study, I obtained REB (Research Ethics Board) approvals from Athabasca University (AU) and the project site, Centennial College (CC). I then started the recruiting stage. In the pre-session period, I connected with each research participant to ensure they had the needed equipment and learned about any outstanding items that could impact the research process. At this time, I deployed the pre-intervention questionnaire. With information obtained through my previous research and teaching experience, the data set obtained from the pre-intervention questionnaire formed the baseline of my current project.

In the first iteration, recruited research participants studied a 3D wood frame wall panel model through a set of 2D drawings such as top view and section view. Subsequently, participants imported a market-available 3D model into one common AR platform, 3D Warehouse®, to generate the AR experience. Participants completed the first post-intervention questionnaire asynchronously online at the end of the first iteration. Throughout the second iteration, all project participants repeated the documenting procedures in the first iteration and uploaded another 3D wood frame house model to an architectural-oriented AR tool, ARki®, to experiment with the AR. Finally, participants constructed a physical 3D wood frame structure based on the 2D drawing set listed in the first iteration. Participants completed the second post-intervention questionnaire asynchronously online at the end of the second iteration. The questions in the second AR questionnaire differed slightly from those in the first AR questionnaire to better understand participants' learning experiences with modified AR and/or intervention strategies.

Interventions

In the course described in Chapter 1, the conventional pedagogical strategy for explaining the targeted hands-on model-making assignment consists of a group of 2D learning materials, such as content-related textbooks, lecture slides, or photographs. The standard learning sequence starts with studying 2D learning materials, reading assignment requirements, purchasing model materials, and constructing the physical wood frame structure model manually.

Stemming from the conventional teaching strategy, I developed the intervention in this study using Morris's experiential learning cycle and data from my prior teaching practice. Technically, the intervention consisted of a combination of various technologies. The intervention included a set of 2D drawings such as plans and sections, topic-related reading materials, a simplified 3D wood frame residential model created in the Revit® or SketchUp®

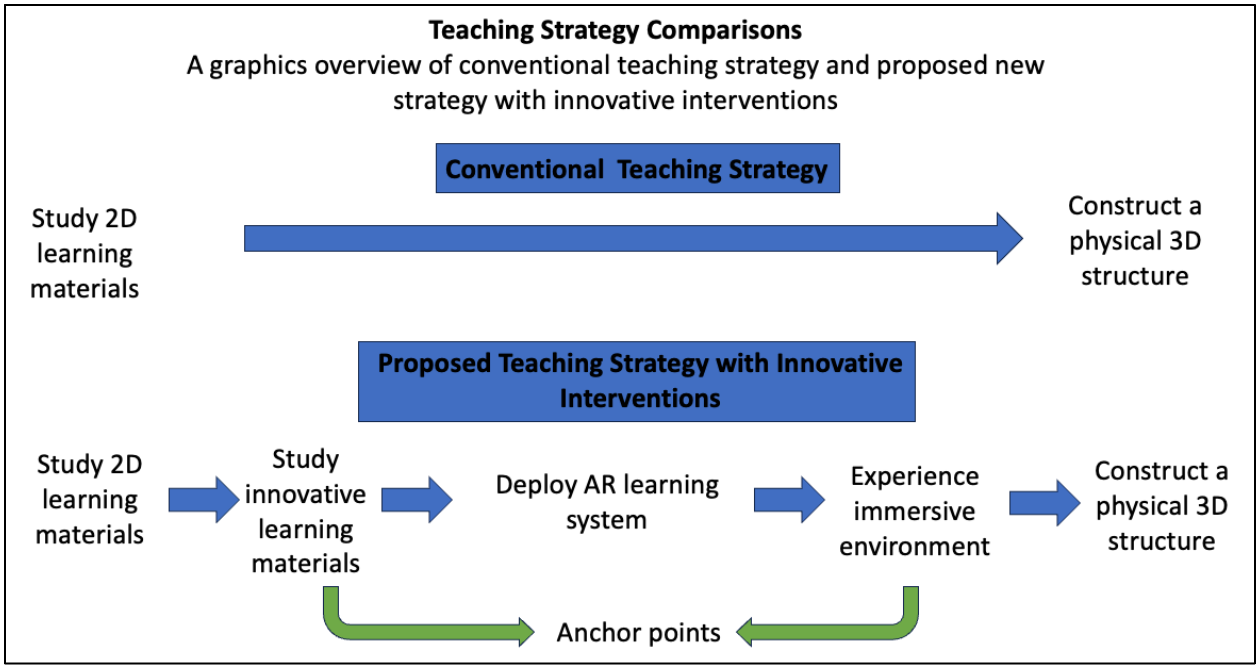
platform, an AR deploying software (3D Warehouse®) and/or other AR tools such as ARki®, and a physical 3D house model built with balsa wood pieces or other materials and constructed by participants. Procedurally, the intervention involved steps that must be followed in sequence. For instance, learning about the task through a set of 2D drawings must be deployed before asking project participants to construct a 3D physical model. The sequences were as follows:

1. Read topic-related materials from different sources.
2. Read a set of 2D drawings that includes plans, elevations, sections, and isometric perspectives of the given object.
3. Prepare technical drafting skills.
4. Manipulate the model created in professional software on desktop or laptop computers using the design drawing of the given object.
5. Install AR-deploying software on personal smartphones in different iterations.
6. Import the virtual model to AR-deploying software.
7. Review the AR model imposed in a real-world environment through an individual participant's smartphone.
8. Analyze the AR model and its wood frame construction details in the real-world environment.
9. Experience the virtual model through various formats, such as walking through (going up and down and going in and out) the model in a real-life setting.
10. Construct a 3D physical building model based on the 2D design drawings.

A graphic illustration that compares the conventional teaching strategy and the new strategy with intervention is shown in Figure 7 below.

Figure 7

Illustration of Two Teaching Strategies



Note. The blue arrow direction indicates the workflow direction. Three anchor points enclosed within two green arrows refer to the AR-enhanced teaching/ learning approach.

Mixed Methods

Cohen et al. (2018) explained that mixed methods research empowers researchers to examine the world from different angles and to discuss facts or phenomena via various quantitative and qualitative methods. Most importantly, mixed methods research applies to "different paradigms, axiologies, stakeholders, levels of analysis (micro, meso, macro) and research cultures and practices" (Cohen et al., 2018, p. 33).

Besides, Cohen et al. (2018) discussed that mixed methods research could be applied to all "stages and areas of research" (p. 33), from creating research questions to examining research validity. Cohen et al. (2018) also proposed that an embedded mixed methods research design combines qualitative and quantitative data analysis to answer research questions. While qualitative and quantitative data can be collected separately and independently, qualitative information can be converted into numbers; comparatively, quantitative figures can also be converted into narrative facts (Cohen et al., 2018). Converting and triangulating data improves data analysis quality and supports a comprehensive understanding of a phenomenon (Patton, 1999). As explained by Patton (1999), data triangulation can reveal data inconsistency and offer "opportunities for deeper insight into the relationship between inquiry approach and the phenomenon under study" (p. 1193).

Data Collection

The data included qualitative and quantitative information collected from the research process and was sufficient to answer my research questions. As appropriate, specific collected qualitative data were transferred into a quantitative format for data triangulation. Manual coding techniques combined with computer software for data analysis ensured that the prediction or description of reality was constructed based on reality (Eastman, 2022).

Qualitative Data. Qualitative data consisted of three parts. The first part came from me. Cohen et al. (2018) suggested that writing memos is one of the strategies for collecting qualitative data; it covers the researcher's diary, reflective and reflexive concepts, emerging ideas, and coding processes or operational notes. The qualitative data comprised various notes I took during the intervention sessions. For instance, my teaching reflection during the intervention design phases, observations on experiment dynamics, records of students' verbal cues or physical gestures, or messages posted in the assignment chat boxes. The second part of the qualitative data came from participants. Participants documented their project progress and reflection during the research period. The third part of qualitative data came from one pre-intervention and two post-intervention questionnaires. Manual coding techniques were used to discover themes and research questions.

Quantitative Data. Data obtained from the pre-intervention activity before the start of the first iteration formed a quantitative base of learners' demographics. In addition, questions asked in the questionnaires generated quantitative data. For example, some questions were designed with a Likert Scale to seek participants' opinions. Selected qualitative data were transformed quantitatively to triangulate the qualitative data. Manual coding skills combined with SPSS® were used for statistical analysis.

Project Baseline Data. The project baseline data consisted of information I obtained from several surveys conducted through my prior teaching practice and the pre-intervention questionnaires answered by volunteer participants.

Data Collection Methods

The data collection methods consisted of questionnaires and/or email interviews answered by project volunteers, as well as field notes and reflection journals written by participants and myself.

Questionnaires. Questionnaires were created and deployed through CC's MS Forms function, as every student in the college had the same access to all functions under the MS 365 Suite. As the sample size was small (Cohen et al., 2018, p. 474), the questionnaire used a "more open and word-based" format to enable participants to respond in their own words.

Email Interview. Foster (1994) concluded that email not only "can be a useful supplement to other forms of research data collection" (p. 95) but also has "significant potential advantages of cost, time, convenience and form" (p. 95). Meho (2006) echoed that when collecting data, researchers can use the email interview as an efficient, time-saving, and cost-effective method that is not geographically constrained, and it can be “a viable alternative to the face-to-face and telephone interviews” (p. 1293). Several researchers (Amri et al., 2021; Hershberger & Kavanaugh, 2017; Shields, 2022) have employed the email interview strategy in their studies. Reminding researchers to pay attention to sensitive topics such as health or private information, Hershberger and Kavanaugh (2017) suggested that “ in-depth, asynchronous email interviews were appropriate and garnered rich, insightful data” (p. 50). Moreover, Hershberger and Kavanaugh (2017) discovered that one extra practical benefit of employing email interviews is “the avoidance of transcription” (p. 53). Similarly, Amri et al. (2021) uncovered several new essential benefits of asynchronous email interviews, which included “anonymity,” “sampling and inclusion of diverse participants,” and “overcoming language barriers for participants” (p. 1). Shields (2022) adopted email interviews to make it more convenient for busy working educational professionals to answer interview questions. In my study, the email interview method was used to inquire about the buffer faculty’s feedback on the recruiting process and the faculty participant’s perspectives on the AR tools. Using the email interview method to gather research participants’ views on this research was inappropriate because the CC’s secure MS email channel inadvertently revealed the sender’s identity.

Field Notes. After reviewing more than 40 journal articles, Phillippi and Lauderdale (2018) concluded that combining field notes in data discussion enables “transmission of the full depth of the study context” (p. 382). Phillippi and Lauderdale (2018) encouraged researchers to “include field notes detailing the overall setting to provide a rich context of the study itself” (p. 381), even though they realized “literature provides little concrete guidance on the content of field notes” (p. 382). In this research, each individual participant and I used independent MS

Teams sessions to record thoughts that arose during the research process. The note format included text paragraphs, briefing notes, graphic illustrations, or screenshots from professional software based on the visual aspect of communication in the architectural industry.

Internet-Based Interventions

Within the different experiments discussed by Cohen et al. (2018), Internet-based interventions fit my research design practically and theoretically. Cohen et al. (2018) explained that Internet-based experiments have numerous features. For instance, they can reach diverse and large learning populations, the investigation can be realized from a distance, participants can access the experiment without space and time restrictions, it is free from the potential influence the researcher creates, and it is cost-effective. This research was designed to be managed and delivered entirely online through the Internet, synchronously and asynchronously. Thus, technically, this project could reach all participants without time and location constraints.

Participants

General Requirements. Creswell and Creswell (2018) pointed out that the researcher should be "sensitive to the needs of vulnerable populations" (p. 89). My project utilized a specific emerging technology to test whether it could realize hands-on remote teaching and evaluate how participants perceive this innovative tool in this new learning environment. Therefore, a series of conditions were applied when considering project participants. First, this project focuses on a specific area of knowledge—the manual building model-making skills required by many architectural programs worldwide. Second, the participants should possess fundamental building knowledge before participating in this project, such as basic North American residential building knowledge and specific architectural terminologies. Third, the foundational knowledge of building construction is discussed in the architectural or construction programs of vocational colleges in Ontario (Ontariocolleges.ca, n.d.). As a result, students registering in these research topic-related programs are the primary source of consideration. Fourth, this experiment used innovations, so participants must have basic digital skills, such as knowing how to use computers or keyboards to search the Internet for information. Accordingly, project participants should be drawn from learners studying at architectural or construction programs at vocational colleges in Ontario who have fundamental digital literacy skills and are comfortable using digital devices.

Project participants. Student research participants were volunteers recruited from the architectural program where I teach. One particular reason for recruiting volunteers from this program was that students generally had studied the wood frame structure and the construction details of constructing a wood frame residence. Besides, students have learned several architectural professional software applications, such as AutoCAD®. Knowing how to operate professional applications was essential, as the intervention I designed adopted several existing technologies and innovative tools linked with these applications. Additionally, it was crucial to learn about the perspectives of architectural professionals; thus, views from my faculty team about the effectiveness and affordance of the intervention contributed to forming a whole picture.

Sampling

Cohen et al. (2018) explained that researchers in mixed methods research could adopt both probability and non-probability sampling techniques in one study and use samples with "different sizes, scope and types" (p. 44), and the utilization of approaches depends on the "fitness for purpose research questions and research design" (Cohen et al., 2018, p. 44). Cohen et al. (2018) also stated that each sample should enable generations of adequate qualitative and quantitative data to answer the research questions and the logical inferences from both data types.

Probability Sampling. The simple random sampling of probability sampling techniques can create a representative group of samples (Neuman, 2014). According to Neuman (2014), random samples “yield samples most likely to truly represent the entire population” (p. 255). Project participants in the intervention’s experimental stages were volunteers, and they came randomly from the entire group of students studying in the architectural program in one academic semester when this project was conducted; thus, the samples were randomly allocated from various classes across all populations in this architectural program.

Sampling Boundaries. Neuman (2014) suggested that the sampling should have several boundaries. I set up two sampling boundaries in my research. First, the sampling process excluded anyone who did not know or was not familiar with basic architectural terminologies to facilitate communication during the process. Participants must be students registered in the architectural program with specific architectural knowledge, such as understanding a house floor plan and a building elevation in 2D drawings. Second, the sampling process excluded anyone who did not know or was not familiar with architectural drafting software such as AutoCAD® because knowing basic drafting skills was vital in joining this project. The results were generalized from these samples since the target population was very specific (Neuman, 2014).

Sample Size Considerations. The population in my study referred to students from the same architectural program at my teaching institution. Though “the larger the sample, the better” (Cohen et al., 2018, p. 203), if the population is homogenous, a smaller sample can represent the population involved (Cohen et al., 2018). Also, to conduct thorough research, a researcher may have only four to five project participants if the interactions between researcher and participant are in-depth (A. Qayyum, personal communication, online MS Teams meeting, December 5, 2023; P. Walsh, personal communication, online research seminar for cohort 14, October 30, 2023). Therefore, getting four to five volunteer participants in the experimental stage is sufficient. In addition, all volunteers were recruited from the entire architectural program; thus, the samples represented the whole student population in the targeted architectural program.

Ethical Considerations

Cohen et al. (2018) emphasized that researchers must make "informed decisions on a case-by-case basis" (p. 111) and take responsibility not only for their decisions related to ethical matters but also for their actions related to the decisions. Additionally, Simon and Usher (2000) proposed that "ethics is local and specific to particular practices" (p. 2), and each educational research study has "its own set of ethical issues" (p. 2). More importantly, Creswell and Creswell (2018) explained ethical issues that occur in the process of conducting research, which covers five stages over the lifecycle of research: before conducting the study, beginning of the study, collecting data, analyzing data and reporting, sharing, and storing data. The next subsection discusses four aspects of ethics related to my specific research project.

Relationships Between the Researcher and Participants

In reflecting on the relationship between myself and the volunteer participants, I consulted key gatekeepers by going through the REB approval process from my doctoral program's home institution, AU, and the project site, CC, in Ontario. When discussing the cost and benefit ratio concept, Cohen et al. (2018) introduced one cost that related to participants, which is "loss of autonomy and self-determination and lower self-esteem" (p. 113). Also, Cohen et al. (2018) indicated that the researchers must build trust between themselves and project participants and reduce power imbalances by enabling participants to make decisions in the research. Further, Cohen et al. (2018) indicated that researchers must be "emotionally detached yet friendly and positive" (p. 137).

Power Dynamics. Project participants were students recruited from the architectural program at the project site. Joining this project was voluntary, and research participants were screened and selected by a buffer faculty. Also, I was not teaching any of these student participants. The research design ensured no academic grade benefits were associated with participation. In addition, participants' suggestions were considered and counted towards the intervention design. Moreover, volunteers could withdraw from the project process at any time or withhold thoughts during the research without penalty (Kivunja & Kuyini, 2017). Furthermore, the results were anonymous and presented as aggregated data without any personally identifiable information. Thus, this research design mitigated any existing power imbalances between the researcher and student participants.

Recruitment Process

Cohen et al. (2018) stated that researchers have a great responsibility to adhere to the ethical principles of educational research and "design how to address and apply ethical principles in coming to a decision on how to act in the specific research in question" (p. 143). Recruitment started only after obtaining the approval of both institutions' research ethics boards.

Invitation and Recruitment Letters. To ensure that participants could make an informed decision, I stated the purpose of this project in the recruitment letter, explained the project's whole process, introduced the tools used in this project, specified the technical information (both construction knowledge-related and computer knowledge-related) associated with this research, clarified the reciprocity considerations, reassured them the voluntary nature of the participation, and described the method of dissemination (Cohen et al., 2018). I also deliberated on ethical concerns such as privacy and anonymity in the invitation letter.

Research Process

Before conducting the research, I emailed each research participant critical research-related topics. During the research, I set up one-on-one individual online synchronous MS Teams meetups to ensure no potential harm happened when participants used the AR tool, whether the impact was physical or psychological (Kivunja & Kuyini, 2017). After completing the research, I sent each participant a personal thank-you email to express my gratitude for their participation (Cohen et al., 2018). Additionally, Creswell and Creswell (2018) proposed to provide “rewards for participating” (p. 89), and Kivunja and Kuyini (2017) suggested a “just and fair price for the exchange of data” (p. 29); thus, I compensated each participant for the time they spent on this project. In fact, I discussed the appropriate incentive with the project site’s REB team (S. Kishore, personal communication, November 6, 2023) long before the commencement of this project. The incentive amount was approved by AU’s and CC’s REB in August and September 2024, respectively.

Considerations Around Ethical Practices

I prepared documents detailing a series of items about this research to achieve comprehensive reviews and approvals from the research ethics boards mentioned above.

Competency. Cohen et al. (2018) stated that it is unethical if the researcher is incompetent in their job, and the researcher must ensure the research project is well designed, conducted, analyzed, and reported. Glen (2000) specified that “integrity entails being true to the person so identified, acting in accordance with that core set of principles to commitments that make us who we are” (p. 12). From a professional perspective, both architecturally and educationally, I am a seasoned architectural professional and have taught in the architectural program at CC for over twelve years. From a research perspective, I have won two research awards of $1,500 and $30,000 Canadian dollars, respectively, and the paper (Lu, 2022b) from one of my research projects was published by *The Canadian Journal of Learning and Technology* in November 2022.

Privacy. Research participants were students in the architectural technician and/or technology programs who were voluntarily willing to participate in this research project. The data collected through questionnaires were strictly related to the research topic and were anonymous. Specifically, the demographic questions in the pre-intervention questionnaire concerned their knowledge of wood frame architectural structure, which was tied to the research topic. Each participant's field notes and reflections were recorded under each MS Teams session and could not be shared interchangeably among all participants.

Accessibility. To reach research participants from various geographic locations, I conducted this research entirely online through the Internet. Hence, I adhered to the ethical codes of Internet research detailed by Cohen et al. (2018) and ensured the security of data transmission and storage. All questionnaires were conducted through the college's MS Forms secure channel. Data were stored in the institution's online MS Forms platform with password protection and two-step authentication. I am the only person with access to the questionnaire data through my personal computer or the college's computers with a password stored securely. Participants were well-informed on how the collected data were transmitted and protected.

Property. I will delete all data stored on the college's MS 365 Suite platform five years after completing the research. I created one MS Teams platform for each project participant on the college's secure online channel so that each participant could upload their progress journals to their own MS Teams platform. Each specific platform owner and I had access to the journals. In addition, I acknowledged the institution and program from which I obtained data to form the baseline data set.

Reliability and Validity

Creswell and Creswell (2018) described that researchers should develop statements that can “explain the situation of concern or that describe the causal relationships of interest” (p. 7). Creswell and Creswell (2018) also discussed that constructivist research “rel[ies] as much as possible on the participants’ views of the situation being studied” (p. 8). Thus, choosing the appropriate group of participants could potentially impact study outcomes. The three foremost factors were measured and are discussed in this subsection.

Design of the Research

This project adopted the “test-retest” (Golafshani, 2015, p. 599) approach to iteratively examine the intervention twice to increase the degree of reliability of the research results and ensure the use of AR in developing hands-on model-making skills could be replicated in comparable architectural learning contents. Moreover, according to Cohen et al. (2018), sampling should comply with “ethical principles and be practicable and efficient” (p. 45). However, some potential aspects may affect the responses, for example diverse participants may encounter different technical issues in their experiments (Cohen et al., 2018).

As for the measurements, this study applied TAM (Davis, 1980) and SECTIONS (Bates, 2019) frameworks in determining the validity of the means of measurement, the best intervention designed for the current research purpose, and whether it measured what this tool was intended to measure (Golafshani, 2015). Questions used by published research studies that adopted TAM or other established instruments in their inquiries have been analyzed, evaluated, and modified, and I created the questions asked in the questionnaires or email interviews for my project.

Three types of data collected provided adequate information and evidence about various aspects of this study, enabling readers to evaluate whether the findings in this study could be transferred to their own situations (Merriam & Grenier, 2019).

The methods used to conduct this research were tailored to the field's research questions (National Research Council, 2002). Additionally, obtaining research ethics board approval ensured that I "avoid misuse of procedures at all stages" (Cohen et al., 2018, p. 142) and reconfirmed that the research techniques adopted in this research only benefit the participants and research community.

Research Outcomes

The whole intervention design ensured that causality between the intervention and the findings could be established to guarantee the research findings' accuracy (Cohen et al., 2018). Both the practicality of the intervention used in this research and the authenticity of no harm to participants complied with one of the ethical principles, created a safe environment for participants, and benefitted participants' learning (Cohen et al., 2018).

Processing of Data

Before the research began, all involved stakeholders were consulted. During questionnaire data collection, I ensured that all collected data was anonymous, confidential, and non-traceable (Cohen et al., 2018) by enabling the anonymity function in MS Forms. The Forms channel is password protected and is located within the secure online MS 365 system. Meanwhile, Golafshani (2005) discussed increasing the dependability of a study by examining the design process and the project's outcome to ensure the trustworthiness of the research. However, cyber incidents may occur since every piece of data is stored online. Kanuka and Anderson (2007) were concerned with resolving the issue of storing data online to guarantee its complete safety, and certain Canadian government agencies offered several strategies for organizations to ensure information technology security (Canadian Centre for Cyber Security, 2021).

Summary of Chapter 4

In Chapter 4, I presented the methodology I would apply to conduct my research. I first explained how my research questions were formed. I subsequently introduced my research design, which included the research process, intervention design, what types of data would be collected and how to collect and analyze them, and the targeted audience. I further explained several ethical considerations for this research project. In addition, to consolidate the reliability and validity of my research, I presented rationales for three foremost factors and illustrated how these are measured.

In the next chapter, I report my research findings.

Chapter 5. Findings

Introduction

The findings in this chapter are divided into two parts: a description of the research process and the discoveries from the research process. Firstly, I describe the interactions with the project site's REB officials. I then explain why I took extra measures and revised my recruitment plans. I also illustrate the additional procedures I made to improve the clarity of my research intervention. Secondly, I decode data obtained from progress reports and quantitative and qualitative data acquired from three questionnaires through three stages. I also present the findings from my interactions with the buffer faculty. Throughout this chapter, I explain all data through various formats, such as screenshots displaying complex data sets, photographs captured by research participants, and text excerpts from written reports and questionnaires. I also create different tables to lay out various data sets.

Research Timeline

I obtained AU REB approval on August 08, 2024. Based on my proposed research timeline, I would start the project in late August or early September 2024 after obtaining REB approvals from AU and the project site, CC. However, obtaining approval from CC REB took longer than I had planned, and the launch of my research was postponed until September 26, 2024. CC REB requested that I provide extra information based on the nature of my study and set up a buffer between myself and research applicants during the recruiting process. Also, my study needed approvals from the department where the study took place, in addition to CC REB.

The following sections illustrate my interaction with personnel on the project site.

Obtaining Assistance from the Project Site

CC REB was concerned that some of the project participants recruited might come from my current classes and might know each other, which could pose academic or social risks. Therefore, I took extra measures to alleviate potential bias and risks. One practical measure was to have a buffer between me and the potential research participants.

Finding a Buffer Person

Searching for a Buffer Person. I had a constructive dialogue with the CC REB regarding the need for a research assistant (RA) to represent me in the recruiting process, specifically to screen and recruit project participants (S. Kishore, personal communication, September 19, 2024).

Several questions about the buffer topic stirred my mind constantly for several days. Various questions, such as where I could find an RA, who would be the best RA candidate, how much I should pay for this RA, and how long this RA would need, filled up my brain. Trying to figure out answers to these questions also made me anxious about my research progress. My biggest concern was how I would meet my planned research timeline and when I could start and complete this research. According to my initial research timeline, I should have started the study in late August. However, I was still in the middle of the REB process in late September.

When considering the candidate to act as an RA, I suddenly wondered whether I could use help from faculty members. I immediately thought of one faculty member of our architectural team. I have known this person for over ten years. Through my experience working with him, I have learned that he always upholds high standards with an unparalleled commitment to integrity and professionalism in the educational and professional sectors. So, I called this person after consulting with CC REB. During our initial conversation, I explained that CC REB suggested I find someone to help me recruit research participants to ensure no bias was made in the recruiting process and no pressure was loaded on possible project participants. This faculty member accepted this role as a buffer faculty.

Adding Extra Information. I subsequently discussed who the buffer faculty might be with the CC REB team, and the conversation flowed smoothly. With CC REB's suggestion and approval, I specified several extra contents in my "Invitation to Participate" (see Appendix A) and "Informed Consent Form" (see Appendix B). One of the contents I added was "Students who are interested in becoming research participants must email /register with ABC@my.centennialcollege.ca (this is the email address of the buffer faculty named ABC), and the screening will be conducted by Professor ABC (full name of the buffer faculty ABC)."

Interacting with the Buffer Faculty

Initial Communication with the Buffer Faculty. On Thursday, September 26, 2024, two hours after the architectural department assistant sent the invitation email to all students enrolled in the Fall 2024 semester, the buffer faculty received several inquiries, and we arranged a phone call on the following weekend to discuss the role of the buffer faculty in this research.

Selection Criteria for Research Participants. When I discussed the buffer faculty's role in selecting project participants, the buffer faculty asked me several thought-provoking questions. For example, the moment when the buffer faculty asked the following two questions, "Do you have a set of 'criteria' that I should use to select the participants?" and "Or do you have a set of questions I should ask them?" (F. Lapointe, personal communications, September 26, 2024), I doubted the necessity of selecting participants, wondering whether a first-come, first-served approach would be a straightforward and unbiased option. In addition, I was uncertain how to evaluate and select participants and questioned whether I had criteria. The buffer faculty further probed, "Should I choose students who are only in Semester 1, only with good grades so far, etc.?" and "Only students that I know personally (in my classes)?" (F. Lapointe, personal communications, September 26, 2024). These additional insightful questions not only stimulated me to revisit my research design and research proposal on who the most appropriate research participants would be and to investigate which criterion could produce a fair and functional selection, but also challenged me to deliberate the potential selection criteria on what I should include or exclude; and subsequently prompted me to conduct a literature review on topics related to research participant selection and to scaffold the series of selection criteria finally.

More Conversations with the Buffer Faculty. I discussed various topics with the buffer faculty on different occasions. For example, in one conversation, I shared my research methodology and the type of data I planned to collect with the buffer faculty. When exchanging ideas about the qualities a research participant should possess, I told the buffer faculty that research participants' in-depth reflections in each step of the experiment would be the most helpful data as my research was primarily qualitative. The buffer faculty also agreed that research participants who could provide constructive feedback would be most beneficial to my study. This discussion helped me funnel down to one essential quality that I hoped project participants possessed: responsibility. Unsurprisingly, we both concurred that the recruited research participants should be someone an employer would like to hire in the office. Coupling with all the efforts I described above, I created the "General Notes for Screening Research Participants" (see Appendix G), in which I itemized 14 selection criteria. I also described in Appendix G several aspects the buffer faculty should be mindful of in the screening process.

Compensating Research Participants. I initially proposed using CC's bookstore gift card as compensation because the research participants were students from our architectural program. Any CC student could use the bookstore gift card to purchase items offered by bookstores on various campuses across the Greater Toronto Area (GTA). REB also suggested I consider other types of gift cards, such as Tim Hortons (https://www.timhortons.ca/?lang=en), which I agreed to. The buffer faculty and I discussed the payment method on November 5th, 2024. The buffer faculty first suggested finding out if research participants were taking the in-person program route or the asynchronous online program route. Depending on the learning format, gift cards could be picked up at the department's reception desk or mailed to off-campus research participants. We agreed that paying through prepaid cards would be the best option, considering that some research participants might reside outside the GTA and were enrolled in the asynchronous online architectural program. In this case, compensating research participants with CC's bookstore gift cards would be impractical as they could not cash out these gift cards. Also, if these research participants were residing outside of Canada, gift cards, such as those from Tim Hortons, would be impractical for them to redeem. In contrast, from the research participants' point of view, getting an e-transfer to their bank account was the easiest way. Since newer generations are prone to digital life, getting money through e-transfer is common.

On November 17, 2024, the buffer faculty started exploring through email what payment method each research participant preferred. Not surprisingly, five research participants preferred the e-transfer method. In a subsequent discussion on November 20, 2024, the buffer faculty revealed that he offered three options: e-transfer, gift card and cheque, but all students responded that they preferred e-transfer. Additionally, other factors influenced the decision on which method of payment was more appropriate. Canada Post workers across the nation entered a strike starting in mid-November 2024 (https://www.bbc.com/news/articles/c1542q49wzgo), so it would be difficult to mail the card or cheque. On the other hand, since most students were off campus, it would take a lot of work for them to pick up a gift card at the front desk of our department. Besides, although the buffer faculty was cautious about e-transferring money directly to students in our previous discussion, he indicated that he had used e-transfer a lot in his architectural practice, so he was comfortable using it. Lastly, the buffer faculty suggested another option: asking CC to provide an account credit to each research participant. I hesitated to choose this option because I was worried that this method would involve the accounting department of CC. What was I supposed to explain to the accounting department, and how could I provide money to this department? After consulting with my co-supervisors on November 21, 2024, I opted to use the e-transfer method. I e-transferred the total amount to the buffer faculty, and then he e-transferred the compensation to each research participant. The email receipt from the bank showing the buffer faculty receiving my money transfer was satisfactory to the AU GSRF (Graduate Student Research Fund) reimbursement requirement. Additionally, the buffer faculty emailed me the records of five research participants receiving money from the buffer faculty.

Obtaining Assistance from the Administrative Team

To avoid interacting directly with research applicants and biasing the recruitment process, CC REB suggested that I seek assistance from the architectural program's administrative team in broadcasting my research and sending out invitation letters. Before contacting the administrative team in my department, I believed that I would need additional institutional approval for my research as CC implements an institution-wide policy that requires all research projects conducted on-site to obtain institutional approval. Surprisingly, since the research population in my study did not extend beyond and to other areas of CC and my recruitment was limited to the architectural program in my current department, REB advised me that I could simply contact the administration via the Associate Dean in SETAS (School of Engineering Technology and

Applied Science). However, the Associate Dean informed me that my research still needed approval from the SETAS. I contacted the administrative staff in our program after obtaining the green light from the management team. On September 26, 2024, the administrative staff emailed the "Invitation to Participate" letter to all students who enrolled in the Fall 2024 semester.

Receiving a Research Grant

AU's GSRF awarded a grant on November 7 for my study to cover the research-related expenses when I was in the research data collection period. The GSRF funding challenged the financial arrangement between the buffer faculty and me regarding how to compensate research participants. I initially thought of paying all expenses out of my pocket and e-transferring all paid fees to the buffer faculty. Thus, I inquired with GSRF about their preferred way to pay out and to whom they wanted to pay directly.

I then submitted to CC REB on November 8 a copy of the grant award letter as an amendment to note changes in funding source. REB suggested informing research participants through the buffer faculty of the new funding information. REB also inquired whether this grant would impact the study incentive, whether the compensation would stay the same, and whether the buffer faculty would be compensated. Recalling the question prompted by co-supervisor Dr. Ives on October 1st about whether the buffer faculty would be compensated, REB's inquiry awakened me to promptly ask GSRF whether the buffer faculty should be and could be compensated. GSRF replied on November 13 that I might submit a budget modification to include an honorarium for the buffer faculty. Meanwhile, I sought clarification from REB about whether buffer faculty should be compensated. REB advised that the buffer faculty was considered as part of my research team. As the principal investigator, I could not typically compensate a co-investigator; thus, whether to compensate the buffer faculty was "up to the department or institution that allocates funds" (S. Kishore, personal communication, November 14, 2024). I then sought advice from my co-supervisors on faculty compensation issues. My co-supervisors confirmed that compensating the buffer faculty might be ethically inappropriate since my research had already started, and determining the appropriate amount of compensation was also challenging. Also, faculty participants would be considered volunteer participants; thus, compensation would be inappropriate. However, I could invite faculty members for dinners to show my gratitude.

Recruiting Participants

Recruiting Research Participants from Students

In contrast to the recruiting plan in my proposal, I neither sent mass invitation emails to students nor had a chance to answer questions from research applicants. Instead, the administrative staff emailed the invitation letter, and the buffer faculty responded to the applicants' questions. Also, students had five business days after receiving the mass email to consider whether they would like to contact the buffer faculty to ask questions or express their interest in participating in this research. The buffer faculty reviewed applications as soon as he received them. The buffer faculty received eight applications on time and one late submission. I sent the "Informed Consent Form" to the buffer faculty after he selected five research participants, and he waited for another five business days so potential research participants could have enough time to read, understand, and sign the form. Then, the buffer faculty emailed me all the signed forms to review. After signing all the forms, I emailed them back to the buffer faculty, who then emailed them to each research participant as a record. Finally, the buffer faculty emailed me the list of recruited research participants, including each participant's first name, the initial of their last name, and their official CC email addresses.

One participant dropped out of the research before the first iteration began and did not notify the buffer faculty or me for two weeks. I asked REB whether I should find a replacement. REB suggested that the buffer faculty contact the student and that I should wait longer. After the buffer faculty received the student's reply, I asked the buffer faculty to select one more research participant. The sixth research participant came on board on November 15, 2024, after a one-week-long miscommunication about the consent form between the buffer faculty and me. Therefore, there were a total of five research participants in this study.

Recruiting Faculty Participants from the Architectural Faculty Team

I did not initially think of recruiting study participants from the faculty team. From my teaching experience, I knew different faculty members had individual situations with various obligations. For example, some faculty members might have other commitments with other employers, or they might have their own professional practices. In addition, all faculty members in the Fall 2024 semester were occupied with a significant change in CC's learning management system (LMS). CC had decided to migrate the existing LMS to a new platform this semester; thus, all faculty members must learn how to use this new LMS, which was set to be deployed in January 2025, and some faculty members were assigned to assist in the transition of course content.

On one hand, one faculty member always showed interest in learning about my research topic. This individual expressed the desire to experiment with the AR tools and offered me feedback from an educator's perspective. On the other hand, the buffer faculty showed interest during our conversations about my research. So, I asked the buffer faculty whether he had time to experiment with the two AR tools and share his viewpoints.

Preparation

Constructing a Research Padlet to Present the Intervention

Selecting an Online Platform. My intervention was described in a specific sequence of ten steps in a plain text format. However, when I discussed screening criteria and the qualities research participants should possess with the buffer faculty, I gradually realized that my intervention was itemized in a pure text form, which might be too abstract for some research participants to grasp, especially if they were semester-one students who had only started to study in our program in September 2024 and, thus, they might be overwhelmed by certain specific terminologies I used such as 3D model, or might find some language was vague such as 2D drawings. I then thought of how to provide multiple expressions to convey my intervention in a self-explanatory format while adhering to the Universal Design for Learning guidelines (https://udlguidelines.cast.org/). Consequently, I spent several days investigating how to present graphically appealing content while making it easily comprehended by the audience.

Three Options. I was well-acquainted from prior experience with three commercially available online platforms that could present different content in various ways. These platforms were Notion (https://www.notion.so/), Padlet (https://padlet.com/) and Coggle (https://coggle.it/). In order to find the best solution to present my intervention, I explored additional details of these web applications and compared their characteristics with the functions my presentation would need. I first thought of Coggle, which produces a hierarchical structure with branches that itemize complex information into orderly categories, but Coggle still presents all information in plain text. Alternatively, Notion is versatile and can house diverse file types, such as Word, PowerPoint (PPT), video or photo. However, the abundance of features this tool offers could overwhelm and confuse first-time users. In addition, my intervention consisted of a variety of document formats, such as photographs and web links, and all information should be presented in an orderly and logical format so that research participants could follow the procedure straightforwardly. After the comparison, I was confident that I should use Padlet.

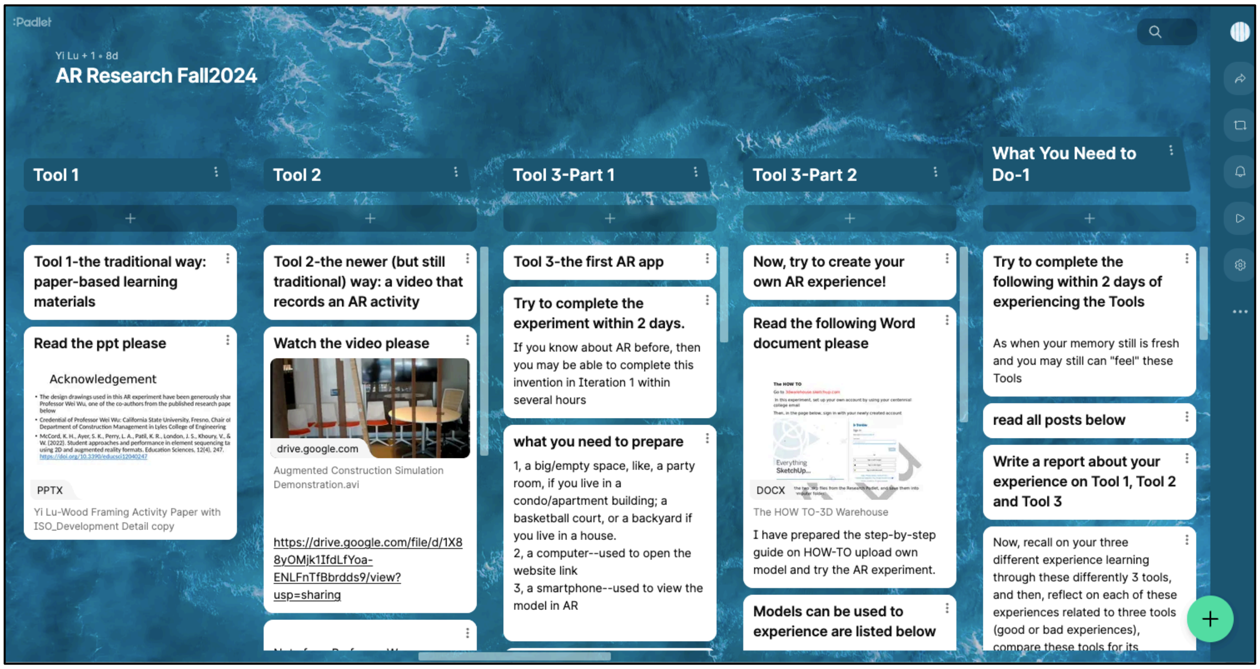
Research Padlet. I created a new website using Padlet to organize materials related to the intervention. The Padlet platform provides six layouts, such as Wall, Grid, and Map. Users can choose one of the formats to display various posts according to their preferences. After comparing all the layouts, I finalized that the Wall function best fits my needs.

The entire wall in my Research Padlet consisted of numerous vertical columns, each representing a specific theme with a label displayed at the top of the column. Each column consisted of several posts, which were presented in a specific order, explaining such a topic from top to bottom, all contributing to the column's formation. For instance, in column Tool 3-Part 2, I first posted a note signalling to participants what this column was about; I then posted a step-by-step guide explaining how to create a unique AR experiment with the first AR tool using a self-made 3D model. I further posted two 3D models with different file formats. Subsequently, I grouped columns based on the contents and formed sections. There were four sections: Section A-Overview, Section B-Iteration 1, Section C-Iteration 2, and Section D-Thank You. Each section signposted a stage in the intervention. For example, Tool 1 and Tool 2 columns were organized within the Section B-Iteration 1 area, and Tool 4-Part 1 to Tool 4-Part 3 were arranged within the Section C-Iteration 2 area. Finally, I sequenced the sections based on the order of the research design. For example, Section A-Overview was set before Section B-Iteration 1.

This Research Padlet can be browsed using the link below: https://padlet.com/ylu65/ar-research-fall2024-pzxyb3nvjruorehn. Figure 8 below shows a screenshot of my Research Padlet presenting a standardized Wall format.

Figure 8

A Screenshot of the Research Padlet



Note. This illustration shows a partial Wall view of the Research Padlet, with five columns (themes): Tool 1, Tool 2, Tool 3-Part 1, Tool 3-Part 2, and What You Need to Do-1. Each column has several posts. For example, only two posts explain the column of Tool 1, while more than two are under Tool 2. Users with this link can click the green plus "+" sign on the lower right-hand side to add a new post or column to the Wall.

Explaining the Research Padlet

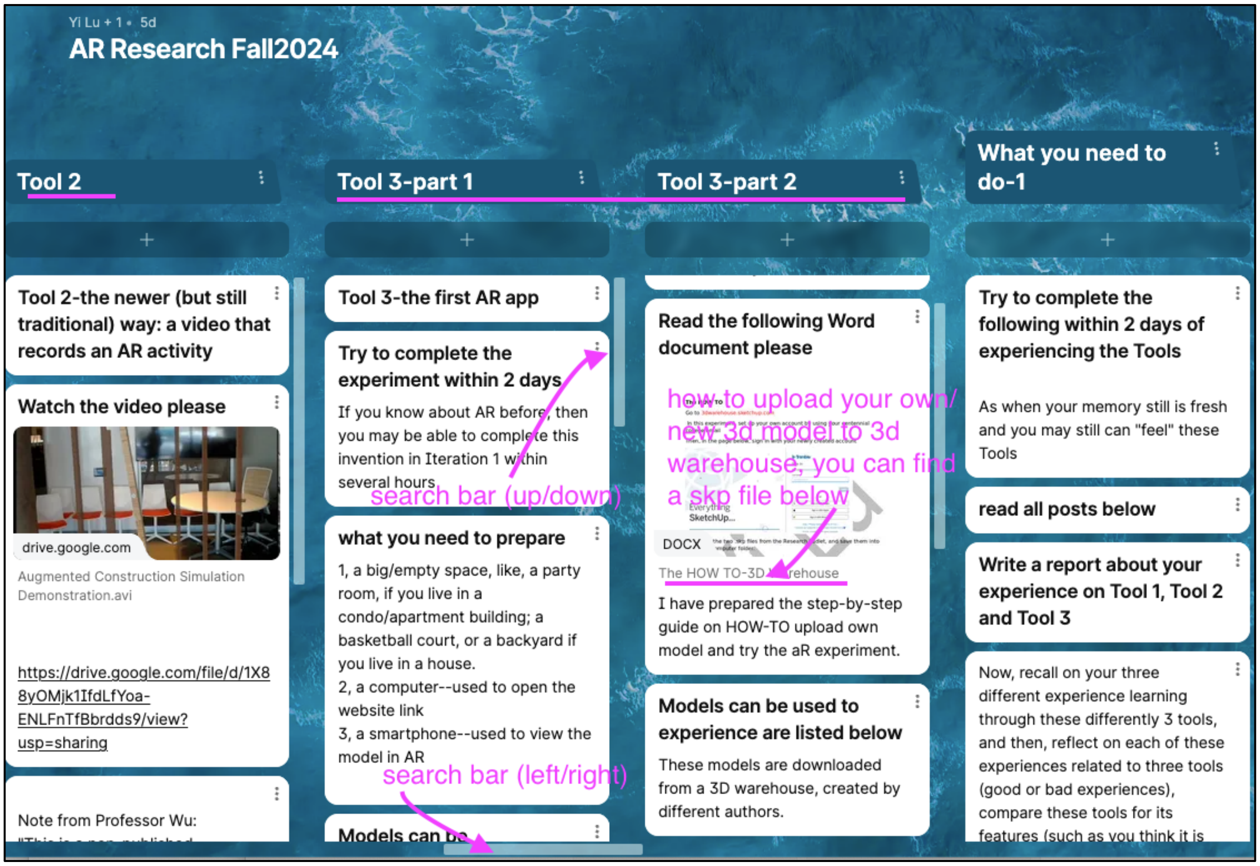
Research Participants. I repeated my discussion for each research participant in each one-on-one MS Teams meeting (see page 101 for details).

Faculty Participant. Since I posted all experiment-related content in the Research Padlet and only I on the faculty team used Padlet in teaching practice, I was unsure whether potential faculty participants were familiar with the platform's functions. To explain how to use the

Research Padlet, I screenshotted a portion of it and added annotations, such as notes and arrows, to the screen capture.

Figure 9

A Screenshot with Annotation of the Research Padlet



Note. This illustration shows several annotations explaining a partial Padlet.

Pre-Session

Connecting with Research Participants

Group Email. I started my first connection with all research participants by sending out a group email. To protect each participant's privacy, I used BCC (blind carbon copy) to hide the list of recipients. I sent group emails with distinctive subjects. For example, I welcomed all research participants in my first email, and I invited each participant in my second group email to vote for the best time to start the experiment, as it was before the midterm week at CC.

Individual Email. To facilitate individual discussion, I personalized emails to each research participant. To further protect their identity, I assigned each participant a username, which was used in all subsequent communication. Usernames were formed using the first initial and a numeric identifier based on the second or third letter of the first name. For example, research participants Joan W. and John S. were assigned usernames J1 and J2, respectively. Before the intervention began, I emailed each participant to schedule the first one-on-one online MS Teams meeting.

Only one participant emailed me during the entire research process to explain what obstacles had occurred, and another apologized for being too busy to start the research at the time we both agreed on. After completing this research, I emailed each participant a personal thank-you message and expressed my appreciation for their contributions.

Connecting with the Faculty Participant

I first emailed the faculty participant explaining how to use the Research Padlet and my data collection timeline. We then used cell phones for all subsequent communications. For instance, we verbally discussed the possible scheduling conflict between my research deadline and the CC LMS transition timeline, as we needed to help migrate several courses.

Setting Up One-on-One MS Teams Meeting

I made one MS Teams account for each research participant, linking with their CC's MS email address. Once the MS Teams environment was set up, it notified each participant automatically. I also created three folders in each Teams account using MS Teams' Files function: one for each intervention reflection and one for the physical model-making reflection.

This allowed each participant to upload their periodic reports. I posted a scheduling message for each participant using MS Teams' Post function and addressed them using their usernames. However, the Teams still displayed the participant's full name in the Post section. Changing the displayed name was impossible because editing such details could require approval from CC's IT or human resource department (One research participant, personal communication, October 16, 2024).

The MS Teams Meeting

First, I emailed each participant to arrange an MS Teams meeting at a time that best fitted their schedules. The meeting lasted about 60 minutes. At the beginning of each meeting, I welcomed the participant and asked whether he or she agreed to video or audio recording. I reminded each participant that they could change their minds even though they had signed the consent form agreeing to record it. Three participants opened the camera, and each restated that they agreed their faces or voices could be recorded.

During each individual meeting, I described to each research participant how to use the Research Padlet, and I used the Padlet as a guide to explain what needed to be done. I explained the contents posted in each column and answered their questions. I focused on detailing the procedure for conducting AR experiments using two AR tools. I reminded everyone to use open and safe spaces, such as an urban park area, for all AR experiments. In support of this, I used the screen share function on MS Teams so each participant could watch content on my screen while I explained.

Explaining Two Iterations

Explaining the First Iteration. I first explained how the Padlet worked and how its contents were laid out. Then, I reminded each participant to complete the pre-intervention questionnaire before watching the two YouTube AR warming-up videos, which were designed as the first step in the intervention. Finally, I explained all the Tools used in each iteration.

Tool 1. Tool 1 referred to the traditional pedagogical method, introducing a concept through 2D lecture slides, with plain text accompanying graphic illustrations. I obtained the 2D drawings and PPT explanation file from Professor Wu from one of the projects he conducted with other researchers (McCord et al., 2022). I then added the acknowledgement page to the PPT file. When explaining Tool 1 to each research participant, I opened the PPT file to explain the 2D drawings under the theme of Tool 1 in the Padlet, and I ensured each participant understood what this set of 2D drawings referred to by explaining what a building section or building elevation meant. I emphasized that participants were required to construct a wood frame wall panel model based on this set of 2D drawings after completing the Tool 4 activities.

Tool 2. Tool 2 referred to a modern multimedia teaching approach, using a video to explain an activity. I obtained the file from Professor Wu, who conducted a project with other researchers (McCord et al., 2022). When explaining Tool 2, I reminded each participant to pay attention to the activity demonstrated in the recording while reflecting on how they felt about using the video demonstration to learn how to construct a wood frame structure. I explained to each research participant that the Tool 2 video recorded an AR experiment on studying the construction sequence of a wood frame structure, coded specifically for and deployed only via MS Hololens® (W. Wu, personal communication, June 22, 2022). Unfortunately, research participants could not experiment with this AR activity since CC libraries do not carry a Hololens® headset (M. Ogunleye, personal communication, November 10, 2023).

Tool 3. Tool 3 referred to the first AR tool-3D Warehouse® (https://3dwarehouse.sketchup.com/). I categorized Tool 3 into two parts, with Part 1 explaining the basic functions of the 3D Warehouse® application and Part 2 focusing on more advanced functions. One testing file was authored by SketchUp (https://3dwarehouse.sketchup.com/model/u23c11c43-2137-400f-bc2e-31d5224875d7/Framed-Wall-12ft-Long-with-Window-Opening-2x6-Detailed), and another testing file was published on 3D Warehouse® by Jabhnko R. (https://3dwarehouse.sketchup.com/model/375169a1-544e-414c-b847-f1a124171deb/Wood-Framed-Wall). When explaining to each research participant, I visited the 3D Warehouse® website and demonstrated how to experiment with the AR tool using a preset AR activity with a prefabricated 3D wood frame model. I clarified several factors that might impact the experiment, such as participants needing to stay close to their computer, which showed the QR (quick response) code while trying the AR on their smartphone. I then discussed the step-by-step guide I created, describing how to create a unique personal AR experience using one's own 3D model. When explaining what constituted an effective report, I exemplified one report sample describing one research experience from a previous project (Lu, 2022b) and two screenshots showing one AR experiment that I tried before. I reminded participants to take the first AR questionnaire after submitting the first report.

Explaining the Second Iteration and Tool 4. I first briefly reminded each participant to review the experience when conducting the activities listed in the first iteration. I then showcased Tool 4-the second AR tool-ARki® (https://www.darfdesign.com/subscription.html) and explained how to download it from the App Store (https://apps.apple.com/gb/app/arki-room-planner/id700695106) instead of its website. For the second AR experiment, I suggested participants use two 3D model files that Professor Wu (W. Wu, personal communication, July 14, 2023) shared with me from one of the projects he published with other professors (McCord et al., 2022). These two files were: one 3D model was in FBX (a 3D file format for exchanging assets between digital content creation applications) file format, and the other was in RVT (a file extension assigned to Autodesk Revit project files) file format. In addition, I explained that the outcome of experimenting with the second AR tool would be similar to that of the first AR tool: Each participant was required to submit a progress report after trying the second AR. However, before completing the second AR questionnaire, participants also needed to construct a 3D physical wood panel model using the set of 2D drawings illustrated under Tool 1 and prepare a written report of the model-making process. For all progress reports, I also invited participants to write about their feelings and thoughts (Aguas, 2022).

The Iterations

When reporting the research process in this report, I created a pseudonym for each research participant to conceal their identity further. The assumed name was assigned in alphabetical order, implying the sequence of the individual MS Teams account creation. For example, the MS Teams for research participant Joan W. was created before John S., and the pseudonyms for Joan W. and John S. were A and B, respectively.

The First Experiment

All research participants successfully experimented with the first AR tool. Users imported the pre-made 3D wood frame panel model into the 3D Warehouse® (https://3dwarehouse.sketchup.com/) platform via its AR function. Then, they viewed the virtual wall panel model superimposed on various real physical settings through their smartphones. Users could walk around the virtual 3D model and perceive its dimensions, such as the actual height and width of the wood members. Additionally, they could analyze the construction details of the virtual panel, such as how the window jambs on both sides of the window opening support the double headers above the window opening, which played a vital role when constructing a physical 3D wood panel model. Figure 10 below displays four screenshots of the successful 3D Warehouse® experiment.

Figure 10

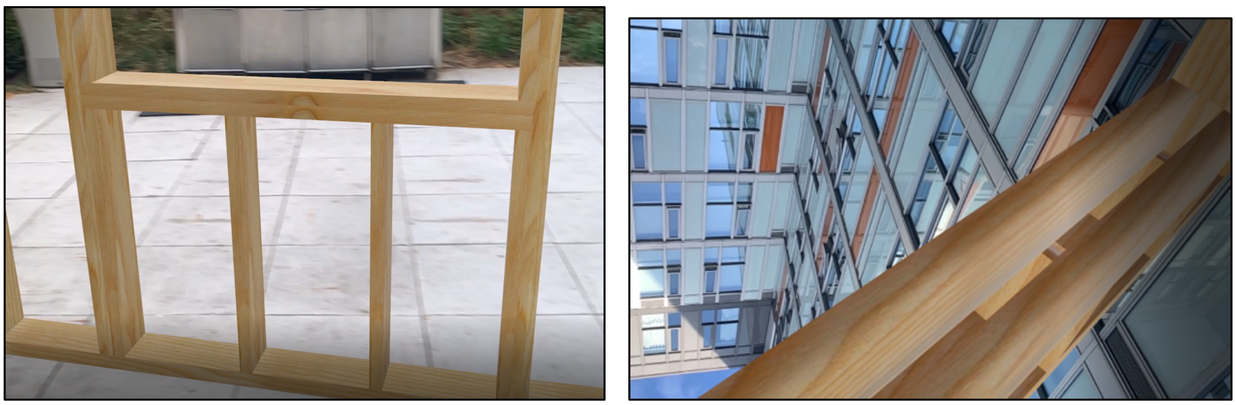
Sample Scenes of the 3D Warehouse® Experiment

Note. Four research participants provided these four screen captures. The top-left picture shows a partial 3D wood frame panel model viewed from an outdoor courtyard; the top-right picture shows a partial 3D wood frame panel model viewed from an urban park space; the lower-left picture shows a partial 3D wood frame panel model viewed from an indoor common space; the lower-right picture shows a partial 3D wood frame panel model viewed from a building's balcony with a partial of the model extended beyond the balcony floor. The link to larger JPG (Joint Photographic Experts Group) versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-12-180408515282809ea24ae70a95cec870.

Students could also view the virtual model in detail from different angles when angling their smartphones to identify the arrangement of all wood members. Figure 11 below shows two screenshots displaying details from the 3D Warehouse® experiment.

Figure 11

Sample Scenes Showing Details Through the 3D Warehouse® Experiment



Note. Research participant D provided these two screen captures. The left picture shows the model rendered with wood grain textures, making it easier to identify how various wood members were connected and constructed. The picture on the right shows the arrangement of wood lintels in the opening and how other wood studs supported the top plates. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-13-18040851528280e48fc7e327370a3eb1.

The Second Experiment

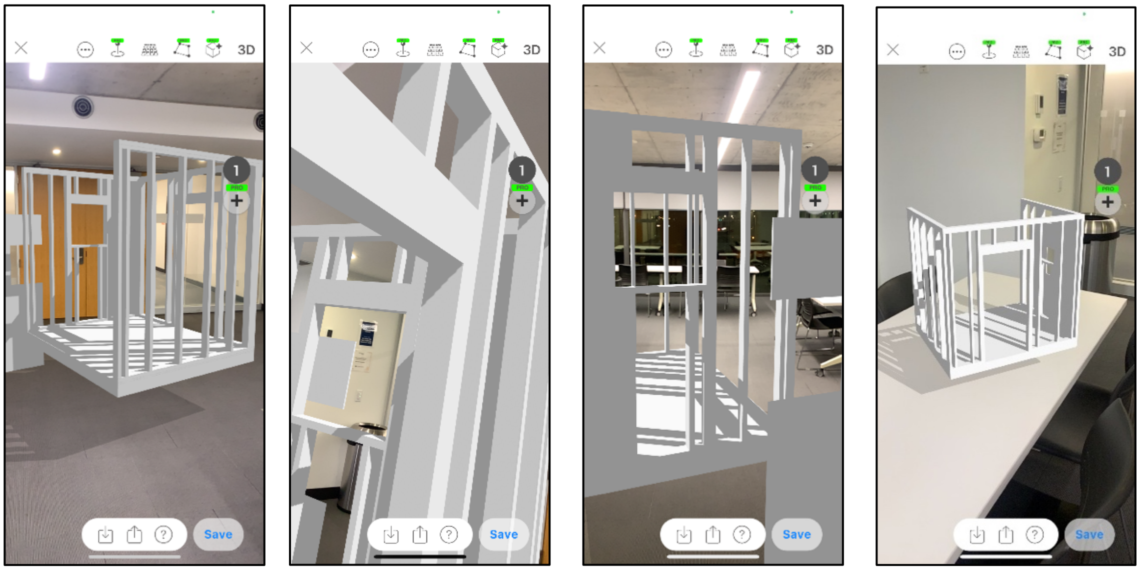
Using the Second AR Tool. 3D Warehouse® (https://3dwarehouse.sketchup.com/) is an online resource for anyone who creates or uses pre-made 3D models based on their individual interests; thus, this application can be used by anyone with various backgrounds. Comparatively, ARki® (https://www.darfdesign.com/) was created by an architect and designed specifically for the architectural industry. It provides real-time visualization of various design ideas. Thus, after investigating an ordinary AR tool that is designed to benefit everyone in society, experimenting with an architecture-focused AR tool becomes a rational choice.

Research Participants. An unexpected event occurred when research participants tried the second AR application. Initiating activities at times that were convenient to their own schedules, each participant reached various stages differently. Research participant D was the first person to try the second AR. D discovered that ARki® required users to subscribe to a plan and link a payment method. I promptly informed other research participants not to conduct their experiments until I contacted the developer and site owner. It turned out that the seven-day free trial could be unlocked via the app, but students would need to pay a monthly subscription if they had used the free trial; they could also cancel anytime via the app (ARki® App, personal communication, October 29, 2024). However, to obtain the free trial, users were still required to input their financial information anyway. After confirming this condition, I swiftly informed each participant through the MS Teams Post section not to continue with this app, and I also created a new theme on the Research Padlet to explain the newly emerged situation.

However, research participant D still could trial partial functions on ARki® without signing up for the subscription plan and D did not know why. When attempting to upload the FBX and RVT files, D experienced that the application only supported FBX but not the RVT format. D also noticed that ARki® supported file uploading through a personal Google Drive account but not MS SharePoint. Additionally, D could view the AR structure at different scales. D walked around and walked through the model and inspected it from different angles; however, D was unable to identify different wood pieces of this model because all wood pieces blended and exhibited the same solid shade. In addition, D exhausted what a user was allowed to do with the free version. Four images showing ARki® experiment are shown in Figure 12 below.

Figure 12

Sample Scenes of ARki® from Research Participant D



Note. Research participant D provided these four screen captures. From left to right, the first picture shows a whole 3D wood frame model viewed from one indoor space; the second picture shows the model was zoomed in to get a closer look at details of different wood elements; the third one shows the model's rear view; and the fourth one is presented at a smaller scale. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-14-18040851528280329a76dfc9e2837abb.

Research participants A, B, and C's experiences differed. Participant A could upload and navigate the 3D wood frame model as D but could not access advanced features. For example, A could not test Reality Mode, which was accessible only through a subscription plan, but D could. Participant B had an Android phone, but ARki® only functioned on Apple devices. B then borrowed an outdated and unused iPhone from a roommate. B attempted multiple times but ultimately gave up because of failing to create a new Apple ID. C could only interact with ARki®'s pre-stored illustrative models and failed to upload the required wood frame model.

Faculty Participant. On one occasion, the faculty participant called me and discussed concerns about the second AR tool, which required users to input their financial information before access to advanced features was granted. We agreed that students should not be required to reveal their financial information to gain access to any application.

Period Between the First Iteration and the Second Iteration

While it provides an AR function, 3D Warehouse® is indeed an online community for displaying and storing all kinds of pre-made 3D models that work with SketchUp® and are created by various model-makers from different disciplines. For instance, a 3D model maker could create and upload a circuit board or a car wheel model. On the other hand, ARki® is an architecture-specific AR product that enables AR experiments. Thus, I expected ARki® to be functionally more suitable for the architecture industry. I was supposed to use the interval between the two iterations to inspect and alter the intervention to improve project participants' learning experiences (Kulhanek et al., 2021). Since every research participant started the project at various times, analyzing all reports simultaneously and getting one comprehensive analysis was impossible.

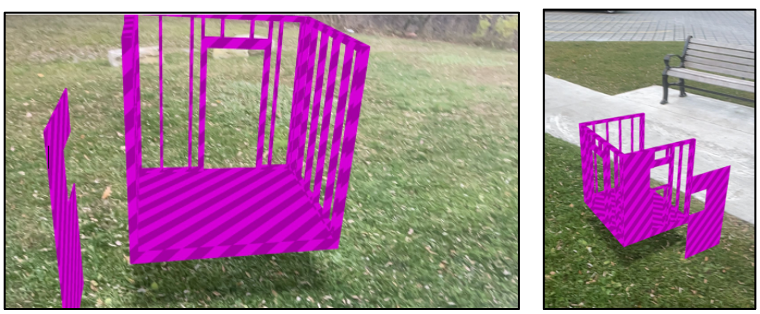
The Third Experiment

I did not plan to conduct the third experiment. However, the fact that every research participant started the research at different times and that their time spent conducting various activities differed allowed me to examine the progress reports gradually and improve the process periodically. Indeed, I got four inspirations when evaluating participants' progress reports, resulting in additional modifications which not only greatly helped users explore more functionalities of ARs and improve their experiences but also made the research process more iterative and my interpretation of the research findings more trustworthy.

The First Inspiration. The first inspiration came from research participant A's first iteration report, in which A commented that 3D Warehouse® enabled users to view and analyze the entire structure, inside and out, in a real-world setting. I wondered whether inserting the 3D wood frame models intended for ARki® into 3D Warehouse® would advance the AR experiment. I then asked A if A could upload the structural models to 3D Warehouse® and evaluate what might happen. A's result showed a surprise magenta colour because the colour of the same 3D model shown in participant D's AR experiment was solid grey (refer to Figure 14 for screenshots shared by participant D). A's scenes are shown in Figure 13 below.

Figure 13

Surprise Scenes of 3D Warehouse®



Note. Research participant A provided these two screen captures. They show the 3D model with the original solid grey colour changed to magenta when experimenting in 3D Warehouse® for unknown reasons. The actual bench in the second photograph served as a comparison scale for the model size. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-15-180408515282800dbe64f31f2c58dc56.

The Second inspiration. The second inspiration came from research participant A's first iteration report, in which A mentioned using a 5G (the fifth generation of cellular network technology) network from a commercial carrier with an iPhone 12mini when experimenting with the AR. A's report prompted me to ask what types of equipment every participant was using when conducting their AR experiments. So, I opened each research participant's Posts section in MS Teams the next day and posted two questions. Question 1 was, "Can you tell me what type of phone and its version you used for experimenting with the first AR and the second AR tools? For example, the answer can be that you use an Android Samsung XYZ version." Question 2 was, "Can you tell me which Wi-Fi or internet connection you used? For instance, the answer could be that your phone has a 5G plan or other plans, or you used the school's Wi-Fi network or the public library's Wi-Fi." All research participants replied at various times. Obtaining this new data contributed to refining my analysis of the Cost section in Bates' SECTIONS framework.

The Third Inspiration. Research participant D's first report inspired the third exploration. In the first report, D stated that users could measure 3D Warehouse® models in SketchUp® using the Tape Measure tool. The measuring tool is shown in Figure 14 below.

Figure 14

Screenshot Showing the Measuring Tool in SketchUp®

Note. Research participant D provided this screen capture. It shows that the measuring tool in SketchUp® measures the width of the window opening of a 3D model. The link to a larger JPG version is: https://www.notion.so/Dissertation-Yi-Lu-Figure-16-181408515282809e965ffbf58d652e36.

In AEC education, using a physical handheld tape measure to measure a real-world object, such as a 2” x 4” wood stud or a real-world setting like an exit stair, allows learners to engage physically with the learning materials and grasp their true 3D dimensions firsthand rather than abstractly imagining their dimensions as explained in a 2D format. Using a tape measure properly to measure an object accurately is also an important skill when working at job sites. I asked four research participants to use a physical tape measure to measure the dimensions of the wood panel model in 3D Warehouse®. Only participant C conducted the measurement using a tape measure. Figure 15 below shows two images of the process.

Figure 15

Scenes of a Wood Panel Model in 3D Warehouse® with a Physical Tape Measure

Note. Research participant C provided these two photographs. They show a physical tape measure measuring the dimensions of a scaled virtual 3D wood panel model projected to an interior space by 3D Warehouse®. The left picture shows the tape measure measuring the overall height of the virtual wood stud wall model, and the right picture shows the tape measure measuring the width of the window opening. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-17-1814085152828045be8ef2c05977080a

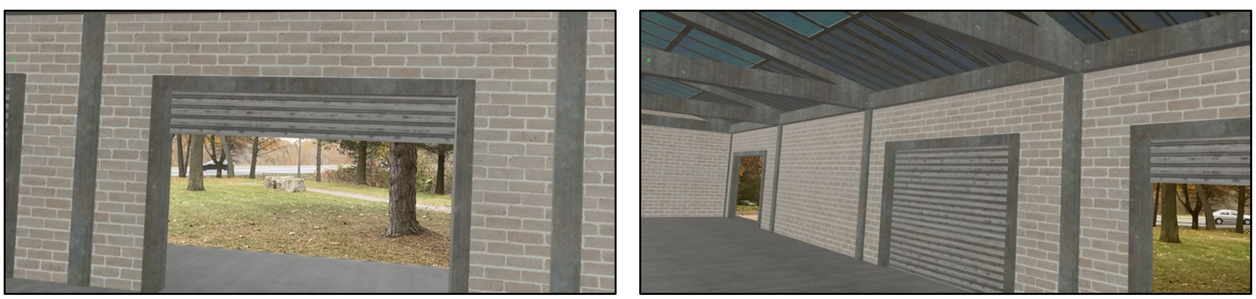
The Fourth Inspiration. The fourth inspiration came from research participant A’s first report, where A experimented with two additional building models in 3D warehouse®. Using this AR in a large park area, A remarked that “the learning experience feels realistic and interactive." A described, "I can freely walk around the virtual model to explore it from different sides, making it much easier to understand the structure compared to looking at a flat drawing or video." A continued, "The AR tool's zoom function adds to the hands-on feel, as I can focus on specific details or step back to see the model's full scale." A finally commented,

> By scaling the model up, you can "enter" and move around inside, just like in a real building. This change in size is key for making the AR experience more immersive and helpful, especially in spaces like warehouses where you need to feel the scale of everything.

The following figure fully demonstrates what A described.

Figure 16

Sample Scenes of an Industrial Building Model in 3D Warehouse®

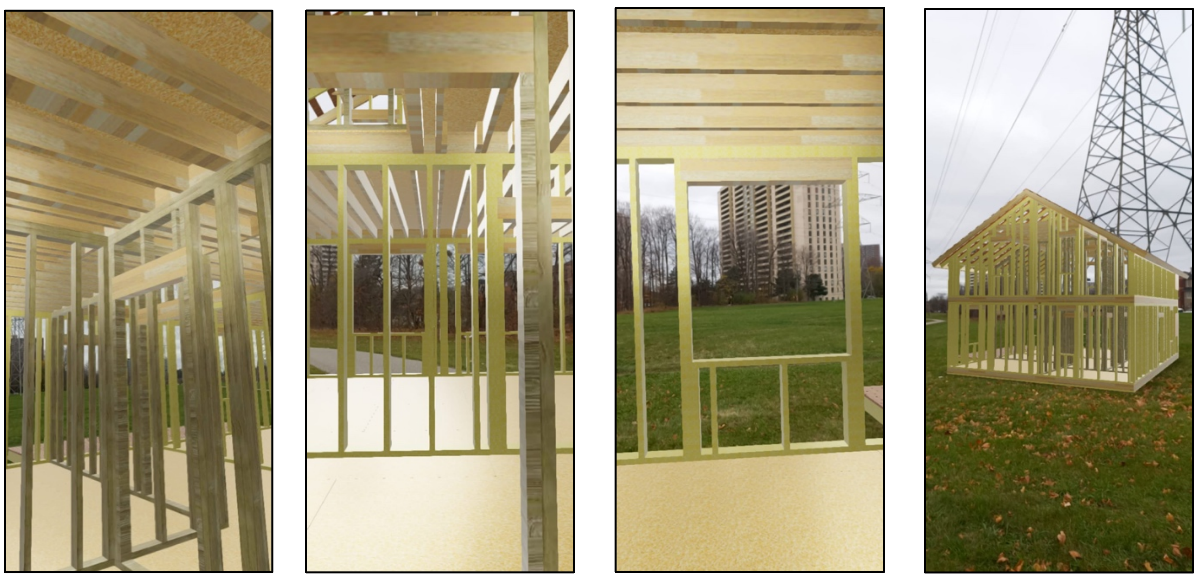


Note: Research participant A provided these two screen captures, which depict a virtual building model viewed from the interior. The left image shows the viewer observing park landscaping through the opening of an overhanging door. The right image presents the viewer standing within the building's floor slab, viewing some roof structure elements along with three overhanging doors, two of which are open, allowing the viewer to see the exterior landscape. A did not specify the designer of the building or the creator of the model. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-18-18240851528280be89c9db4f10ae23b6

Participant A's experiment inspired me to advance this research by encouraging research participants to upload their design building models from their architectural design courses and experience AR. Purposely, participant C uploaded a wood frame model created by C's colleague and experimented with it in an open park area. The following figure shows C's experience.

Figure 17

Sample Scenes of a Wood Frame House Building Model in 3D Warehouse®



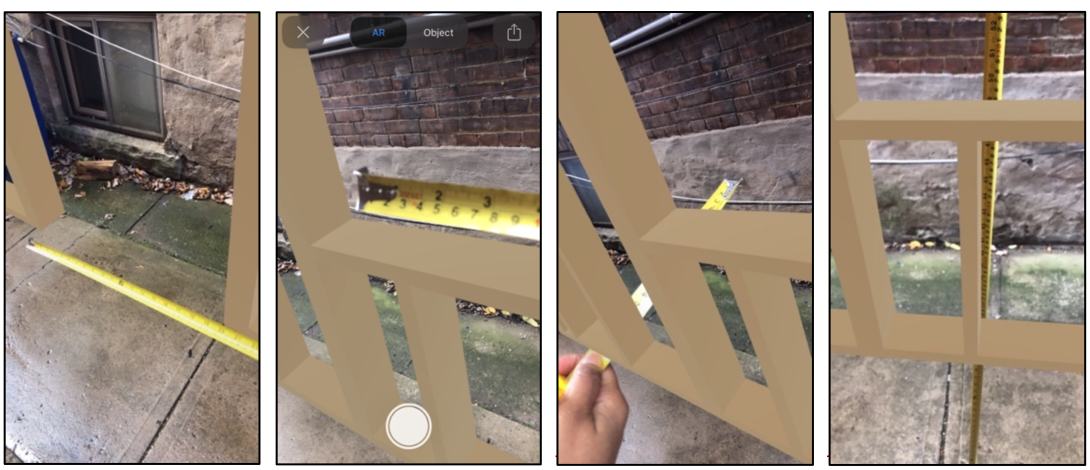
Note. Research participant C provided these four screenshots, showing a virtual wood frame structure model viewed from both inside and outside. The three pictures on the left illustrate views within the model, highlighting various wood elements. The leftmost image displays roof joists intersecting with rim boards atop two top plates, as well as studs on both sides of a door opening supporting lintels. The second image from the left offers a closer look at wood studs on one side of the door opening that support lintels, along with the stud arrangement inside a wall panel beyond the door frame. The second image from the right depicts wood studs and lintels at a window opening. The rightmost image shows the entire framing model situated in an open park area, as seen from the outside. The model's designer and creator, I. S., who has explicitly stated that they do not wish to share their full name, has granted me written permission to use this model exclusively for my dissertation research and future publication (I. S., personal communication, November 23, 2024). The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-19-182408515282802da702ee430bb34f5c

More Experiment

Participant E joined the experiment three weeks after the other participants completed the second iteration. I asked E to use a tape measure to measure the virtual models in two iterations. Participant E presented the results, which demonstrated that the first AR has other pedagogical potentials besides superimposing virtual 3D models into real-world settings. In this case, learners could integrate physical learning tools to achieve greater learning outcomes. Figure 18 below shows four images of the results.

Figure 18

Sample Scenes of a Wood Panel Model in 3D Warehouse® with a Physical Tape Measure

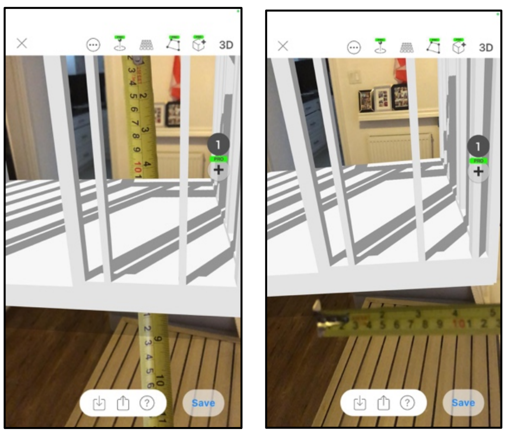


Note. Research participant E provided these four screen captures, showing a physical tape measure measuring the dimensions of a true-size virtual 3D wood panel model in 3D Warehouse®. The picture on the left shows the measurement of the door opening width. The second picture from the left shows the width of the window opening. The second picture from the right shows the depth of the wood bottom stud being measured. The picture on the right-hand side shows the tape measure measuring the height of the windowsill plate. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-20-1824085152828005b378fc170f6c9867

Participant E also used a tape measure to measure the virtual model shown on ARki®. Figure 19 below shows two images of the experiments.

Figure 19

Sample Scenes of a Wooden House Model in ARki® with a Physical Tape Measure



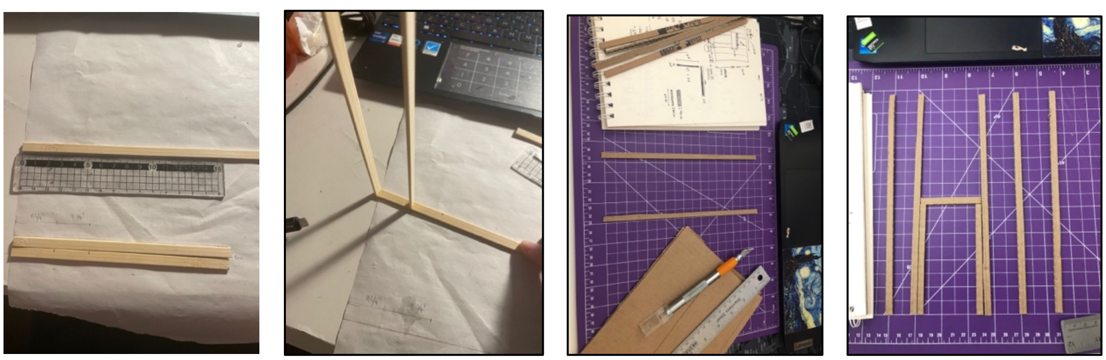
Note. Research participant E provided these two screen captures. They show a physical tape measure measuring the dimensions of a scaled virtual 3D wood structure model projected to an interior space by ARki®. The picture on the left shows the thickness of the bottom wood platform, and the picture on the right shows the width between two wood studs. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-21-1824085152828025a5f5f97872698d9b

The Physical Model-Making

Since this research study was designed for distance learning where learners might live in remote locations worldwide, shipping model-making materials to learners' sites might be infeasible and time-consuming. Thus, I suggested that research participants choose free materials that were easy to find in their household or neighbourhood and that could mimic the wood stud sizes of 2” x 4” and 2” x 6”. The model-making process went smoothly. Three research participants created wood panel models using leftover architectural model-making materials (e.g., balsa wood strips) from a previous model assignment from their Materials and Methods 1 course. One participant carved a piece of cardboard, available in the home environment, into strips based on the dimensions from the 2D drawings and then attached all strips with a craft glue gun. One participant cut an empty cardboard pizza box into strips that mimicked the balsa wood strips and glued the strips together to form the model. Four images showing the process of model-making using balsa wood and cardboard strips are shown in Figure 20 below.

Figure 20

Photos of the Model-Making Process

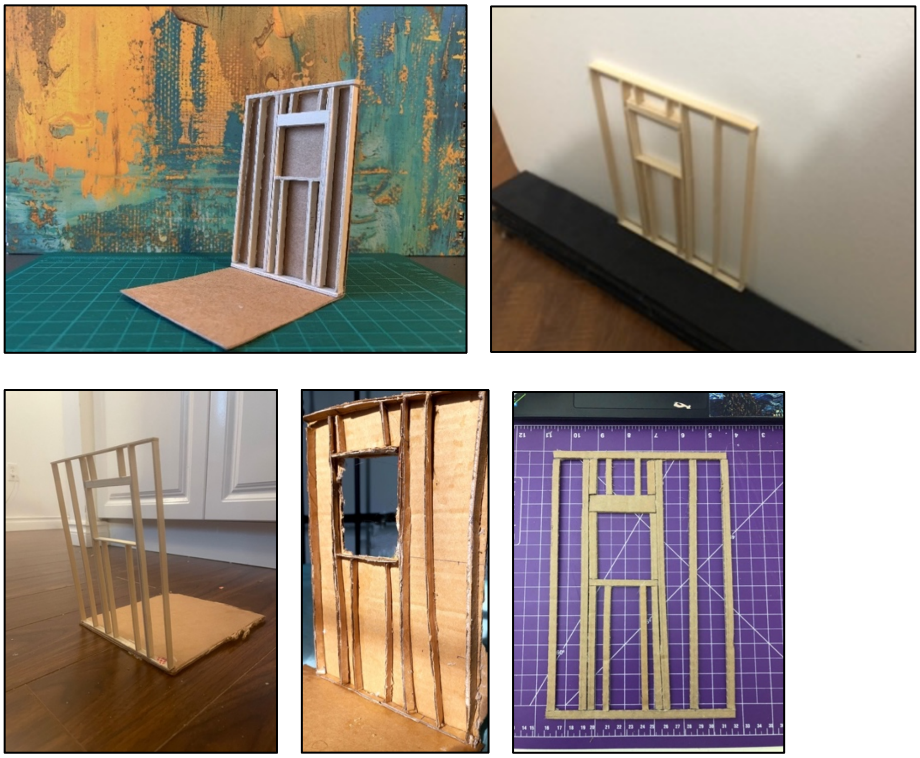


Note. Two research participants provided these four screen captures. Two pictures on the left show the physical model being constructed using balsa wood strips, and two pictures on the right show it being constructed using cardboard strips. The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-22-182408515282807fa0e1f49bf6e16bbd

The final products are shown in Figure 21 below.

Figure 21

Photos of the Physical Wood Panel Model Made by Different Materials



Note. Five research participants provided these five illustrations. All models were made from balsa wood strips, except for those shown in the lower-right and lower-middle photographs, which were made from cardboard strips. Each of the five models was built to scale (in this example, “to scale” means that a model was constructed accurately and proportionally to the dimensions of the actual object it represented, based on its 2D drawing set listed in Tool 1. For instance, if the model was built to a scale of 1:1/4” = 1’-0”, this meant that every ¼ inch on the model represented 1 inch in real-life dimension. In other words, the model was smaller than the actual object it represented). The link to larger JPG versions is: https://www.notion.so/Dissertation-Yi-Lu-Figure-23-1824085152828024ac7dd156320f8898

Since the process had multiple steps and each step required various technologies, I created an infographic, Appendix I, to display the components involved in the entire framework of the experiment. This experiment framework has a base that refers to a conventional learning method, using digital equipment such as computers or smartphones to study a set of 2D drawings or watch a 2D video. Iteration 1 is then constructed on top of the base. Participants use digital equipment to experiment with the first AR tool. Subsequently, iteration 2 is built on iteration 1. Participants use digital equipment to experiment with an architecture-focused AR tool. And more experiments are conducted based on the previous iteration 2.

Other MS Teams Functions

During the research process, I used other functions provided by MS Teams to communicate with research participants as well.

Recording. The last research participant, E, who joined in late November, was busy with academic tasks as the Fall semester was nearing its end. To remove the time constraints, I decided to make a recording for E instead of arranging an MS Teams meeting. I recorded how to follow the contents posted on the Research Padlet to conduct the experiment asynchronously.

Posts. I used MS Teams' Posts function to communicate with each research participant. In each designated Posts section, I regularly posted notes to keep each participant updated and promptly responded to their questions. I noticed that all participants responded during the evenings, and I was not surprised by how busy during the daytime students in our architectural program were from several surveys I conducted previously (Lu, 2021a, 2022a, 2023b).

Files. I set up three folders under each MS Teams' Files function for the first and second intervention journal reports and the physical model-making report. I reminded each participant to submit written text documents with graphics, such as screenshots of the experiment.

Technical Issues

Research Participant A. Participant A initially joined the first MS Teams meeting on one of the CC campuses and used the CC's Wi-Fi connection. However, the quality of our online meetup was unstable. Participant A often could not listen to me well or see me in the video, or the Teams disconnected altogether, so A had to go home. We reconnected later.

Research Participant B. Participant B has an advanced mastery of several professional architectural applications, such as Lumion, the 3D rendering software. However, B was initially unfamiliar with the function of MS Forms but could adapt to it quickly. Also, as someone who never used an Apple product before, B spent much time learning about a new operating system.

Research Participant D. Participant D encountered a situation that might be unique. D's Apple account was created years ago in the United States (US), but D currently does not have a valid US payment method linked to this account. D's account was currently linked with a gift card with a balance, but D could not switch to the Canadian store due to a remaining gift card balance that D could not figure out how to spend entirely. Thus, D had no way to pay for subscription services at all. However, this situation mysteriously allowed D to try the free version of ARki® and access advanced functions, which C could never manage.

Reports

Reports from the First Iteration

Five research participants wrote their reflection journals after conducting the experiment with 3D Warehouse® (which was referred to as Tool 3 in the Research Padlet). They then submitted the completed report and all associated graphics to the designated MS Files folder. I processed the data in each Word document using manual coding. The codes are shown in Table 1 below.

Table 1

Codes from the First Iteration

n	Sample quote	Code
7	"Tool 3 (3D Warehouse®) provided the clearest visual understanding, which was crucial for accurate model-making."	Help in understanding
10	"It was especially helpful for hands-on learning, as users could view every angle and detail, making it ideal for transitioning from digital to physical construction."	Usefulness in learning model-making
8	"3D Warehouse® is easy to use, with a simple interface and access to many 3D models."	Easy to use
7	"I found myself wanting to play with other models using the Sketchup AR tool after I had completed the research goals."	Happy/unhappy to use
3	"Rotation and zoom functions are less smooth, making it harder to interact with the model effectively."	No very helpful
17	"I would choose 3D Warehouse® for model-making… This flexibility makes it ideal for examining both exterior and interior structures in detail."	Usefulness in model-making
8	"A perspective factor played in along the technology, even though the model was sized 100%, meaning scaled 1:1 on the chosen site."	Technology issues
10	"Also, if the app worked on more devices and could be used offline, it would be easier for people to access it anywhere, even without 5G."	Inclusiveness
3	"It's free and includes a reality mode, which I found very helpful for getting a better feel of the structure."	Cost
1	"I had some major issues. One such thing is that I cannot use in my apartment as it is very small and has so many things covering the model."	Privacy
4	"It was not immediately evident how I could reposition and rotate the model, but I figured it out eventually."	Technology literacy
6	"The AR made possible the navigation of the model to clarify any doubt related to the configuration of the framing layout, as it can be walk-through and viewed at real scale."	Efficient in learning
10	"There are drawbacks such as needing an empty space, Wi-Fi issues, and the need of taking the laptop with the mobile phone just to scan the code sets some issues on this tool."	Technology limitation
11	"Sketchup AR could improve its responsiveness to make rotating and zooming smoother, enhancing the user experience for model exploration."	Suggestions

Note. In the above Table, *n* denotes the number of report excerpts discovered that are semantically related. Sample quotes are reported from different participants.

The data indicate that after experimenting with the first AR tool, five participants mentioned, 17 times across five reports, that this tool aided them in model-making.

Reports from the Second Iteration

Five research participants prepared their reflection journals after experimenting with ARki® (Tool 4 in the Research Padlet). They submitted the finished Word document and all associated graphics to the designated MS Files folder. I processed the data in each Word document using manual coding. The codes are shown in Table 2 below.

Table 2

Codes from the Second Iteration

n	Sample quote	Code
2	"Tool 4 provided the clearest and more advanced visual understanding, which was crucial for accurate model-making."	Help in understanding concepts
2	"I'm not very sure if this tool in particular would be very useful to gain hands-on experience, as it was tricky to manipulate and errors popped up regularly, refraining my learning experience from being interactive and positive."	Usefulness in learning model-making
5	"ARki® has a simple interface that lets you rotate and zoom in on 3D models, which is useful for seeing the structure of a building."	Easy to use
8	"I am very averse to this type of subscription gimmick, in part because I always forget to go back and cancel the subscription (I think they count on this)."	Happy/unhappy to use
10	"Many features, like Reality Mode, require a subscription, limiting access to the full AR experience."	No very helpful
9	"ARki® has the potential to be a really useful tool if you are willing and able to pay the subscription; but because it hides all but the most basic tools behind a paywall, its usefulness to students is severely limited."	Usefulness in model-making
18	"From this free version, I could not figure out how to bring the object back to 0.00 on the Z axis from ARki®, without the need to manipulate the file from the computer and reloading it."	Technology issues
6	"This makes ARki® not a very good choice to begin with for a learning tool as it excludes a probable majority of students from easily accessing."	Inclusiveness
5	"It was not so much a free trial, as a trick to get you to sign up for a professional account."	Cost

5	"If I can pay for the subscription without needing to use my financial information, I would like to try these features for more options."	Privacy
4	"I reboot my phone, and the app only identified the .fbx file. The file with the .rvt extension was never recognized by ARki® from my phone."	Technology literacy
1	"ARki®'s interface provided two environment settings for the objects to be placed in."	Efficient in learning
10	"The unpaid version of the app, only provided viewing of the .fbx model on the tridimensional environment."	Technology limitations
11	"However, some minor alterations to the operation are needed for better user experience."	Suggestions

Note. In the above Table, *n* indicates the number of semantically connected report excerpts found. Sample quotes are reported from different participants.

The data show that five participants projected, nine times across five reports, that they assumed the second AR tool would help them in model-making if they could experiment with it.

Reports from the Model-Making Process

Five research participants constructed the model using the 2D drawings listed on the Research Padlet, Tool 1. They also reflected on whether the 3D Warehouse® or ARki® assisted them in the process. I analyzed the data in each Word document using manual coding. The codes are shown in Table 3 below.

Table 3

Codes from the Model-Making Process

n	Sample quote	Code
1	"The AR 3D ARki® (Tool 4) and the 3D Warehouse® (Tool 3) are tools that help understand the concept of making a model and they provided me sufficient understanding and information before I started my hands-on physical model."	Help in understanding concepts (both AR tools)
4	"The 3D Warehouse® model cleared out doubts quickly when I need to confirm the collocation of the bottom and top wooden plates."	Usefulness in learning model-making (3D Warehouse®)
2	"I didn't make use of ARki® because it was stressful, it took too long, and errors popped up continuously before, so it prevented me from trying to use that tool again."	Usefulness in learning model-making (ARki®)

2	"I found 3D Warehouse® (SketchUp) to be the better tool for learning hands-on model-making skills remotely. It's easy to use, offers free access to important features, and allows for a more detailed understanding of how structures come together."	Easy to use (3D Warehouse®)
8	"The agility and clarity that it provided is unmatched if I compared it with ARki®."	Happy to use (3D Warehouse®)
2	"I didn't make use of ARki® because it was stressful, it took too long, and errors popped up continuously before, so it prevented me from trying to use that tool again."	Unhappy to use (ARki®)
2	"Perhaps ARki® could have other potentials that I didn't explore, but as of now, the 3D Warehouse® model, along the drawings gave me enough information and provided the confidence required to build the physical model."	No very helpful (ARki®)
15	"The AR 3D Warehouse® (Tool 3) was the most effective for developing model-making skills, allowing a comprehensive view of 3D designs that made constructing physical models, like wood panels, more accurate and precise."	Usefulness in model-making (3D Warehouse®)
1	"It was impossible to see the distinct (wood) members of this structure as they are all the same solid shade which blended together."	Technology issues
1	"I find SketchUp (3D Warehouse®) better suited for learning model-making. While it doesn't have the smoothest controls, it provides all the necessary features for free, allowing me to understand building layouts as though I were looking at a real structure."	Cost

Note. In the above Table, *n* indicates the discovered number of answer excerpts that are semantically related. Sample quotes are reported from different participants.

The data suggest that five participants overwhelmingly agreed, with 15 times mentioned across five reports, that 3D Warehouse® was useful in developing model-making skills.

Addressing Research Questions and Assessing Themes

Based on the TAM (Technology Acceptance Model) and a portion of the SECTIONS (Students, Ease of Use, Costs, Teaching Functions, Interaction, Organizational Issues, Networking, Security and Privacy) principles, I grouped codes into three themes to assess participants' attitudes toward the technology used: Perceived Ease of Use (PEU), Perceived

Usefulness (PU), and the Intent to Use (IU). I further categorized these codes to address four research questions (RQ). Table 4 is shown below.

Table 4

Grouping of Codes to Address Research Questions and to Assess Themes

Research question (RQ)	Code	Theme
RQ1. How does augmented reality aid in developing hands-on skills remotely?	Help in understanding concepts (both ARs)	PU, IU
	Usefulness in learning (both ARs)	PU, IU
	Not very helpful (ARki®)	PU, IU
	Usefulness in model-making (3D Warehouse®)	PU, IU
RQ2. What are the perceptions of individuals regarding using augmented reality in learning hands-on skills at a distance?	Easy to use (3D Warehouse®)	IU, PEU
	Happy to use (3D Warehouse®)	IU, PEU
	Unhappy to use (ARki®)	IU, PEU
	Not very helpful (ARki®)	IU
	Usefulness in model-making (3D Warehouse®)	PU, IU, PEU
RQ3. How feasible is it to adopt augmented reality in developing hands-on skills at a distance?	Technology issues (both ARs)	PU, IU
	Cost (both ARs)	PU, IU
	Inclusiveness (ARki®)	IU
	Privacy (ARki®)	PU, IU
	Technology literacy (both ARs)	PU, IU
RQ4. How does employing augmented reality to teach hands-on skills online affect the learning experience?	Efficient in learning (both ARs)	PU, IU
	Technology limitations (both ARs)	PU, IU, PEU
	Suggestions (both ARs)	PU, IU, PEU

Note. The column on the left lists four RQs that assisted in answering my overarching RQ, and the column on the right shows three themes of TAM used to assess research participants' attitudes toward the technology used. Codes located in the middle column are grouped together to demonstrate how these groups of codes are arranged to answer specific RQ and to address three themes.

As the above table shows, the codes discovered from 15 written reports sufficiently assess research participants' attitudes toward the technology used and answer specific RQs. An infographic that visually represents the findings is shown in Appendix J.

Questionnaires

Three questionnaires were prepared using MS Forms. Questions have three types of answer formats. One was selecting a word of Yes or No; the second one was a textual elaboration on the chosen answer; the last one was the Likert Scale format, with "5" being "Strongly agree" and "1" being "Strongly disagree," and participants were encouraged to elaborate on their chosen answer. When creating the Likert Scale answer format, I was surprised to discover that it was impossible to insert corresponding Emojis to benefit visual learners using MS Forms. Additionally, to learn about research participants' opinions on using the Padlet to display research content, I created one extra question, "Contents listed on the Research Padlet are very helpful in knowing the research process and steps," with a Likert Scale of 1–5 on the "Second AR Experience Questionnaire."

Questions prepared for the Pre-Intervention Questionnaire aimed to explore the research participants' backgrounds related to the academy and technology. I coded the answers collected from the Pre-Intervention Questionnaire as I coded participants' progress reports. Additionally, I created questions in the First and the Second AR Experience Questionnaires based on the combination of Davis's (1985) Technology Acceptance Model (TAM) and a portion of Bates's SECTIONS framework to assess research participants' attitudes toward the technologies used and the technologies themselves. Also, questions in each AR questionnaire were specifically designed to answer my research questions (RQ). Thus, in the subsections below of my report of findings, I indicate which questionnaire question was intended to answer which research RQ.

Pre-Intervention Questionnaire

Answers from the pre-intervention questionnaire, data from several surveys I conducted in the past, and first-hand information obtained through teaching formed a baseline dataset.

Six research participants answered this questionnaire. To present a convenient and accurate data exhibition, I created two Tables: Table 5 lists quantitative data, which includes questions and outcomes from each Likert scale; and Table 6 presents qualitative data, which includes question numbers and brief contents, the number of research participants who contributed, a sample quote from the associated question, and the discovered codes. To protect participants' privacy, I have intentionally omitted identifying information when presenting the excerpts. Tables 5 and 6 are shown below, respectively.

Table 5

Quantitative Data from Pre-Intervention Questionnaire

Question	**Answer**
Q2. Prior AR experience	Four participants answered Yes and two answered No
Q4. like to learn about AR technology	Six participants answered Yes
Q7. Took architectural classes before	Six participants stated Yes
Q9. Have a good architectural knowledge	Five stated Agree, one stated Strongly agree
Q10. Have a good understanding of architectural drawings	One participant stated Neutral, two stated Agree, three stated Strongly agree
Q11. Have good wood frame structure knowledge	One participant stated Disagree, three stated Agree, two stated Strongly agree
Q12. It is hard to mentally to gain wood-frame structure knowledge to reach one's level of performance	Two participants stated Disagree, two stated Neutral, one stated Agree, one stated Strongly agree
Q14. Have good knowledge of making physical wood models by hand	Four participants stated Neutral, two stated Agree
Q15. New to making physical wood models built by hand	Two participants stated Yes, and four stated No
Q16. Good at making physical wood models built by hand	Two participants stated Disagree, four stated Neutral
Q17. It is hard for me to physically construct the physical wood-frame structure	One participant stated Strongly disagree, one stated Disagree, one stated Neutral, two stated Agree, one stated Strongly agree
Q18. Prefer to get new information from a) pictures, diagrams, graphs, or maps. b) written directions or verbal information. c) Both	One participant stated Option a), five stated Option c)

Q19. Prefer to study a) in a study group. B) alone. c) Both	Three participants stated Option b), three stated Option c)

Note. Questions have been reworded to simplify the presentation. Answers are obtained through the Likert Scale.

The data suggest that no one regarded themselves as good at model-making, and three participants thought that physically constructing the physical wood-frame structure was challenging.

Table 6

Qualitative Data from Pre-Intervention Questionnaire

Question	**Sample quote**	**n**	**Code**
Q1. Experience with technology	"I have laptop, a tablet and a cellphone, and I use each for different things."	14	Surrounded by technologies
Q3. Prior AR knowledge	"I often use AR features when purchasing products online to see real life scale of an object."	2	Used AR for daily life
Q5. Why learn about AR	"I'm passionate about technologies and how they can help us achieve and deliver greater things."	13	Excited about AR's potential
Q6. Technology literacy	"I feel comfortable using different technologies in both my social and school life, as they have become an important part of how we connect, learn, and get things done today."	10	Technologies were essential to one's life
Q8. Architectural backgrounds	"I did my Bachelors in… where I was able to learn about the basics of detail drawing, plan and elevation drawings and even sections."	10	Good Architectural knowledge
Q13. Why want to learn hands-on skills	"I like learning hands-on skills because they let me work directly with the materials and use the techniques (that) I study."	5	Enjoy learning by doing

Note. Questions have been rephrased. In the above Table, *n* specifies the number of answer excerpts that are semantically linked. Sample quotes are reported from different participants.

The data show that all participants were immersed in various technologies and were extremely excited about AR's potential impacts on their lives.

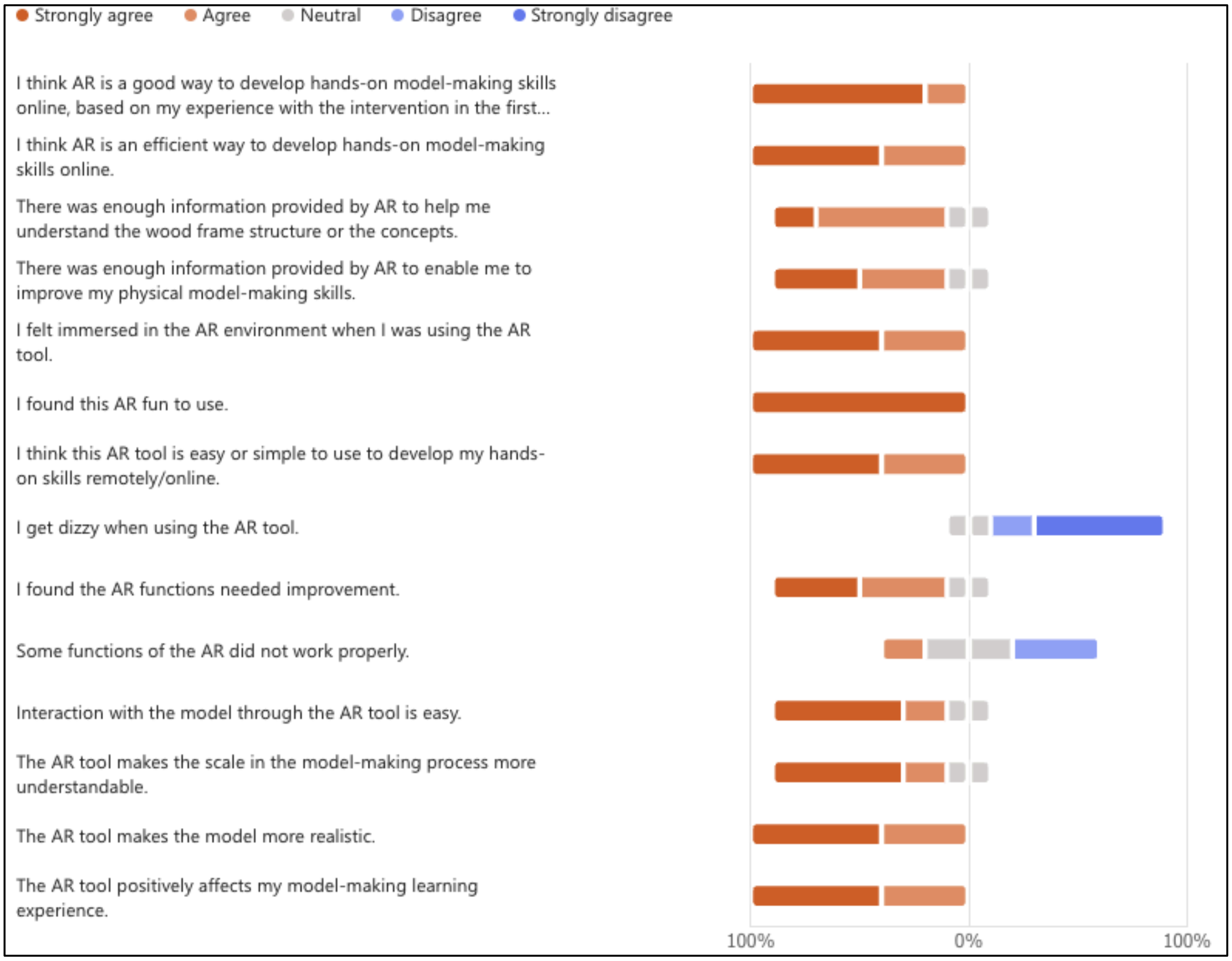
First AR Experience Questionnaire

I present all data using three formats: a Figure showing question 1 from MS Forms, one table demonstrating qualitative data, and one table demonstrating quantitative data. All questions I designed in the questionnaire were intended to answer specified RQs, which I itemized in the Tables. Five research participants contributed to this questionnaire.

Figure. Question 1, “Overall, please share what you think about the quality of AR as a way to develop hands-on skills remotely online,” has a string of sub-questions, each with a different percentage showing the participants’ selection. So, I screenshotted the original MS Forms as a Figure to show the data clearly. Figure 22, showing question 1, is shown below.

Figure 22

Quantitative Data of Question 1 from the First AR Experience Questionnaire

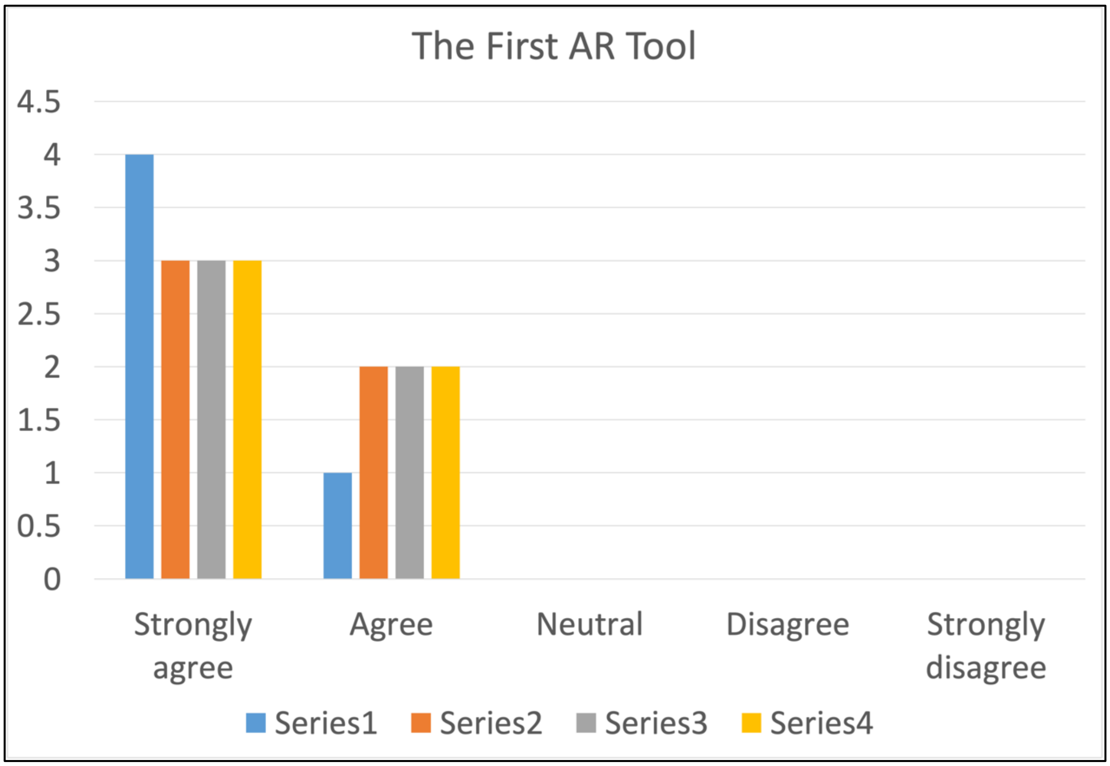


Note. Answers to Likert Scale items are obtained using MS Forms and are shown in percentage format. Sub-questions in Q1 answer four RQs. The link to a larger JPG version is: https://www.notion.so/Dissertation-Yi-Lu-Figure-24-17d408515282805aac87c8c1a3bc77cd

Responses to the first and second sub-questions show that five participants agreed that AR was a good and efficient way to develop hands-on model-making skills remotely. Users also responded to other questions regarding their experience. Four participants agreed that certain AR functions needed improvement, but interacting with the AR was easy. All participants agreed that the AR improved their understanding of model-making by showing realistic and true-scale models, and it positively affected their model-making learning experience. The following figure is a re-presentation of the number of participants' responses to four main sub-questions from Q1 in a vertical chart format.

Figure 23

Four Main Sub-Questions in Question 1 from the First AR Experience Questionnaire



Note. Answers to the Likert Scale items are collected through MS Forms and are re-formatted in MS Excel on a Macbook (https://www.apple.com/ca/macbook-air/). The horizontal axis shows five Likert Scale options, while the vertical axis shows the number of participants who selected that option. There are a total of five participants. Four series numbers refer to four main sub-questions. Series 1 refers to "This AR is a good way to develop hands-on model-making skills online." Series 2 refers to "This AR is an efficient way to develop hands-on model-making skills online." Series 3 refers to "This AR tool is easy or simple to use to develop my hands-on skills remotely/online." Series 4 refers to "This AR tool positively affects my model-making learning experience."

Tables. All questions except Q1, shown in the following quantitative and qualitative tables, have been rephrased to present a concise format. The quantitative and qualitative tables are shown below, respectively.

Table 7

Quantitative Data from the First AR Experience Questionnaire

Question	**Answer**	**RQ**
Q4. The AR tool helps develop actual hands-on skills in making the actual physical building model remotely	Two participants stated Agree, three stated Strongly agree	RQ2, RQ3
Q6. The AR tool helps improve knowledge of hands-on skills in making the building model remotely	Two participants stated Neutral, Two stated Agree, one stated Strongly agree	RQ2, RQ3
Q12. Like to use cellphone to gain new knowledge	One participant stated Agree, four stated Strongly agree	RQ4
Q14. Any technical issues encounter during the AR experiment	One participant stated Yes, four stated No	RQ3, RQ4

Note. Answers are obtained through the Likert Scale.

Table 8

Qualitative Data from the First AR Experience Questionnaire

Question	**Sample quote**	**RQ**
Q3. Other comments related to the AR tool	"It was a very interactive, fun and easy to use tool." "The tool could be better if it were easier to use and offered more ways to customize things."	RQ1, RQ2, RQ3, RQ4
Q5. Working with the AR helps develop actual hands-on skills in making the actual physical building model remotely	"It was clear, for example, when examining the lintels that if there was any space it should go in the center of the (wood) members that made up the lintel rather than to one side." "Since I've already explored the virtual version, I feel more confident and prepared. I know exactly where each piece should go because I've had the chance to 'practice' assembling it in the AR environment."	RQ1, RQ4

Q7. Working with the AR helps improve knowledge of hands-on skills remotely	"It allows me to get a better view of how to assemble a wooden panel in order." "I can see how wood studs and beams fit together, which is great for learning about wood frame construction. The AR tool also shows me the steps to build a physical model, making it easier to see how different parts connect."	RQ2, RQ3
Q8. Money spent	"Nothing. I already have internet and the tool was free."	RQ3
Q9. Other comments or questions about your AR experience	"The use of a QR code (meant) that I had to have both my phone and laptop nearby. I am not sure if Sketchup can be accessed through the phone browser on an app but an option to share a link may be useful." "The space and connection issues have a negative impact."	RQ2, RQ3
Q13. Why you like to use smartphone for studying	"Using my cellphone lowers my anxiety about learning because I can take my time and go back to review things whenever I need to. Overall, it makes learning easier and less scary."	RQ4
Q15. Technical issues during the AR experiment	"I found the consumption of battery power was higher during the experiment in comparison with the regular use I give to my phone."	RQ3, RQ4
Q16. Other comments	"I feel satisfied with what I've shared."	RQ3, RQ4
Q32. More AR-related questions	"It was a pleasure taking part in the experiment and acknowledging the importance of technology and AR in precise in providing productive and efficient tools."	RQ3, RQ4

Note. Various research participants provided answers.

The data show that all five participants agreed that the first AR tool helped them develop actual hands-on skills in making the actual physical building model remotely. Participants elaborated on how this AR tool assisted with developing model-making skills. I identified excerpts from research participants that could address certain RQs in the right column. Also, in the First AR Experience Questionnaire, I asked questions about assessing the current research design and learning preferences. I reword all questions to present a concise format, and I group them into the two tables below.

Table 9

Comments on Research Design on the First AR Experience

Question	**Answer and sample quote**

Q10a. Enough information provided	Four participants stated Agree, one stated Strongly agree
Q10b. Required extensive preparation	One participant stated Strongly disagree, two stated Disagree, one stated Neutral, one stated Strongly agree
Q10c. Good quality of facilitation/support	One participant stated Neutral, two stated Agree, two stated Strongly agree
Q11. Reasons of your selection	"The meeting we had pre-intervention was helpful in clearing up any questions I had, and I appreciated that I could continue to ask questions throughout." "I think I would do better if I had more practice before starting the experiment. The AR tool gives useful information, but without enough hands-on experience, it's hard to use that knowledge well."

Note. Quantitative answers in the above table are obtained through the Likert Scale. Qualitative data are from various participants.

The data indicate that all five participants agreed that enough information was provided; four participants thought the facilitation was efficient. As one participant commented, the AR experiment could be enhanced if more preparation practices were provided before the commencement of the AR.

Table 10

Learning Preferences Surveyed on the First AR Experience

Question	**Answer and sample quote**
Q17. Enjoy short learning sessions	One participant stated Agree, four stated Strongly agree
Q18. Reasons of your selection	"I prefer learning material that is compressed and is easy to grasp in short time. I don't like the sensation of investing long hours on something that I think could be done more efficiently.
Q19. Enjoy working without disruption	One participant stated Agree, four stated Strongly agree
Q20. Reasons of your selection	"It allows me to maintain a steady flow and stay fully immersed in the task."
Q21. Enjoy working individually	Two participants stated Agree, three stated Strongly agree
Q22. Reasons of your selection	"When I work with other people, I get distracted by trying to make sure they have everything they need to complete their work."
Q23. Enjoy working with peers.	Three participants stated Agree, two stated Strongly agree

Q24. Reasons of your selection	"Working in a group environment is more fun and challenging as well as it allows peers to exchange knowledge and skills."
Q25. Enjoy expressing oneself	Two participants stated Neutral, three stated Agree,
Q26. Reasons of your selection	"Openly sharing ideas makes group work more effective and often leads to stronger designs."
Q27. Prefer format for expressing ideas	"Written words or graphical representations make me most comfortable because I can edit what I have said to reflect exactly what I meant to say. Spoken words can be imprecise and awkward."
Q28. Being outside of one's comfort zone	One participant stated Agree, four stated Strongly agree
Q29. Reasons of your selection	"I am interested in unusual experiences as it allows me to experience new methods and tools rather than the traditional ways to gain more hands-on skills and knowledge."
Q30. Worked in a small online group	"I have taken online courses in the past and interacted with different people using a variety of platforms."

Note. Quantitative answers in the above Table are obtained through the Likert Scale. Qualitative data are from various participants.

The data suggest that all five participants preferred short and uninterrupted learning periods. While five participants agreed that they would like to work alone, they also expressed that they could work within group environments depending on various learning situations.

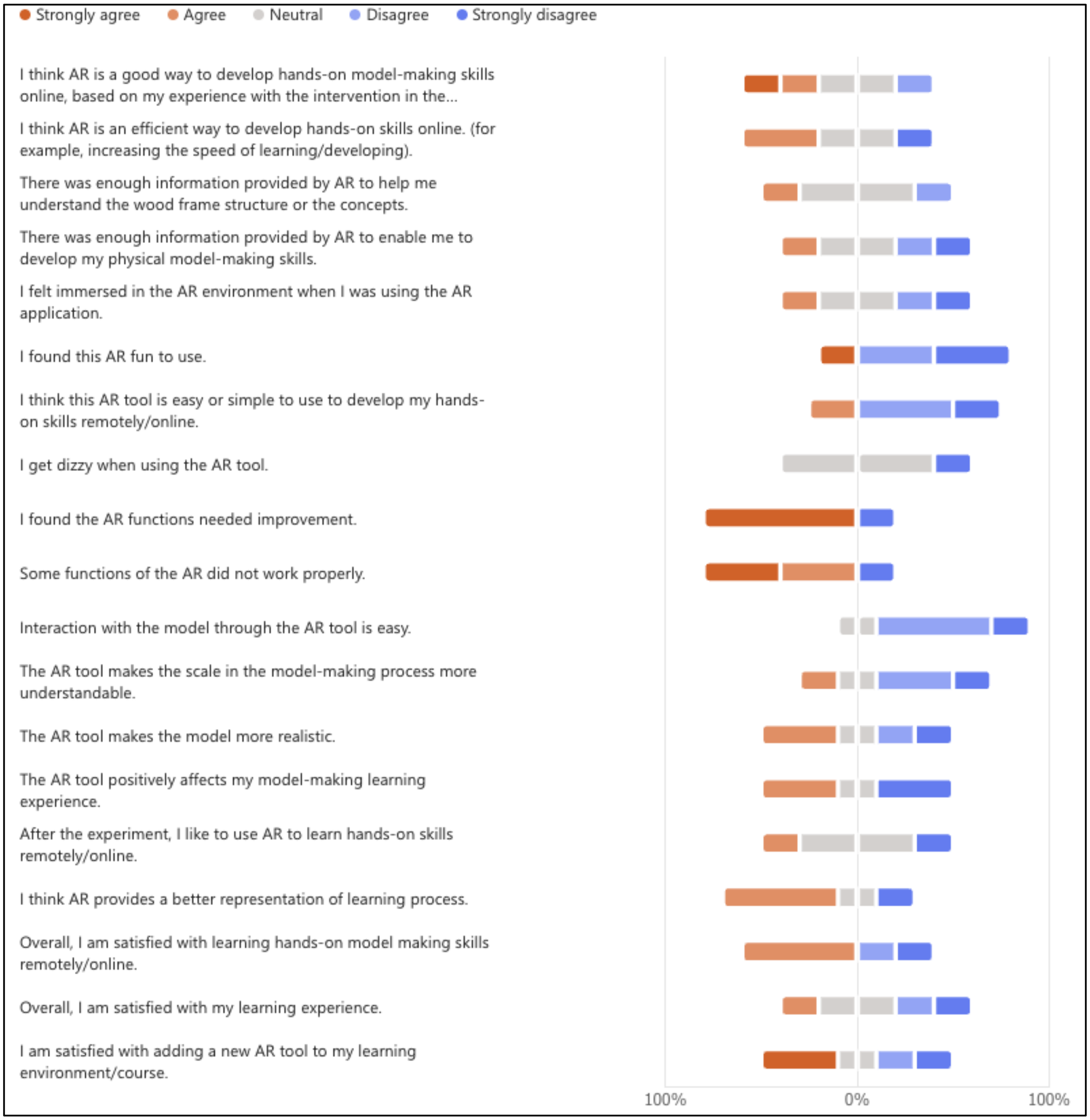
Second AR Experience Questionnaire

The questions planned for the Second AR Experience Questionnaire were similar to those asked in the First AR Experience Questionnaire. I also wanted to compare two AR tools to identify the best option. Similarly, I display data using three formats: one Figure displaying a screen capture from MS Forms, one Table showing qualitative data, and one Table showing quantitative data. Equally, the questions I designed in the Second AR Experience Questionnaire were intended to answer specified RQs, and I catalogued the questionnaire questions into research questions (RQ) in my presentation. Five research participants contributed to this questionnaire.

Figure. Question 1, "Overall, please share what you think about the quality of AR as a way to develop hands-on skills remotely online," has a thread of sub-questions, each calculating the percentage of participants' Likert Scale selection. I present Question 1 screenshotted from MS Forms as a Figure. Figure 24, highlighting question 1, is shown below.

Figure 24

Quantitative Data of Question 1 from the Second AR Experience Questionnaire



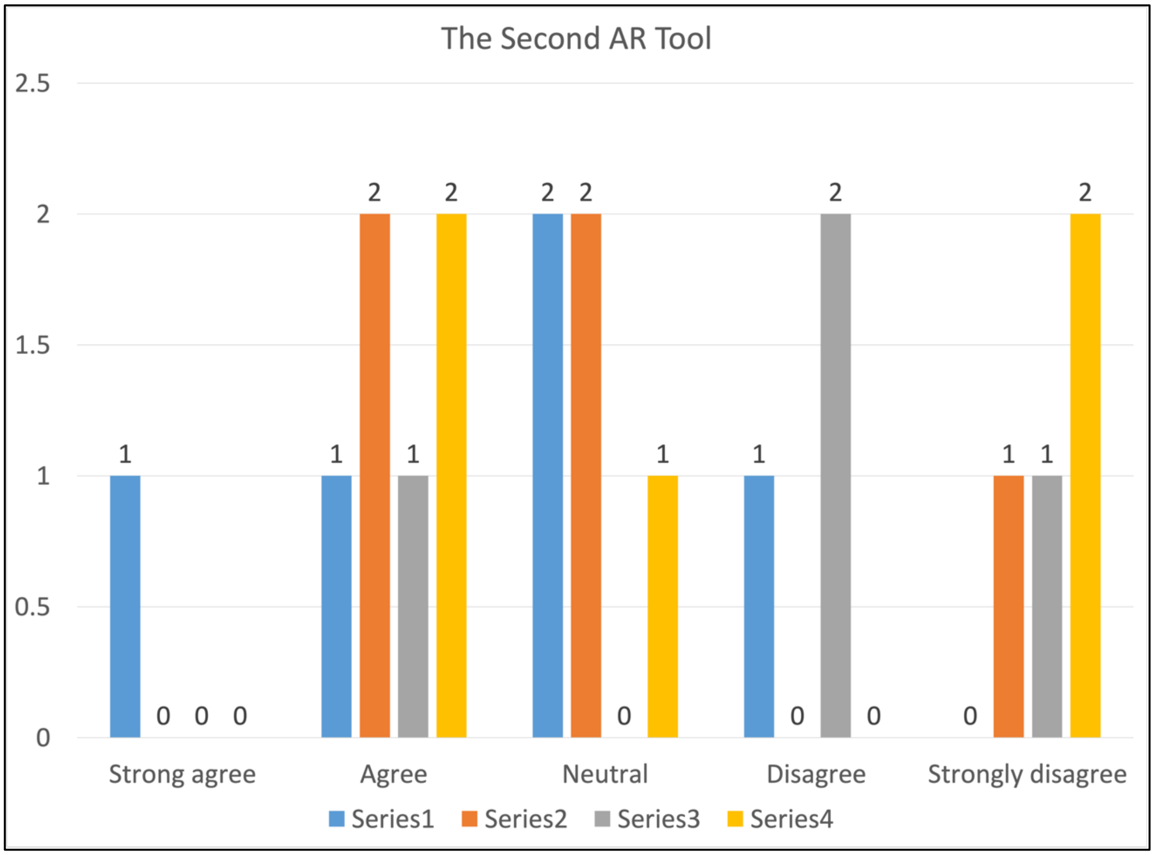
Note. Answers to Likert Scale items are collected using MS Forms and are presented in percentages. Sub-questions in Q1 answer four RQs. The link to a larger JPG version is: https://www.notion.so/Dissertation-Yi-Lu-Figure-25-17d4085152828073a538cb94c6e453db

In the first sub-question, one participant stated Strongly agree, one selected Agree, two stated Neutral, and one stated Disagree. In the second sub-question, two participants selected Agree, two answered Neutral, and one Strongly disagree. Users also answered inquiries related to their experience. Four participants strongly agreed that some AR functions needed improvement, while one strongly disagreed. Four participants further expressed that interacting with the AR was challenging. One participant strongly disagreed, and four disagreed that the AR tool improved their model-making understanding. Two participants agreed, and two strongly disagreed that the AR positively affected their model-making learning experience. The negative experience in the second AR experiment led to a mixed message represented by the last three sub-questions, where participants were asked about their overall perceptions toward AR used. The last three sub-questions asked participants' views on the two AR tools experimented with. Overall, three participants were satisfied with the AR experiment, with one unsatisfied and one strongly unsatisfied. As for their learning experience, one participant was satisfied, with two neutral, one unsatisfied and one strongly unsatisfied. When asked whether they were satisfied with adding AR into the learning environment, two participants were strongly satisfied, with one neutral, one unsatisfied and one strongly unsatisfied.

The following figure, in a vertical chart format, represents the number of participants' responses to four main sub-questions from Q2, the same as those represented in Figure 23.

Figure 25

Four Main Sub-Questions in Question 2 from the Second AR Experience Questionnaire



Note. Answers to the Likert Scale items were obtained through MS Forms and re-formatted in MS Excel on a Macbook (https://www.apple.com/ca/macbook-air/).

The horizontal axis shows five Likert Scale options, while the vertical axis shows the number of participants who selected that option. There are a total of five participants. Four series numbers refer to four main sub-questions. Series 1 refers to “This AR is a good way to develop hands-on model-making skills online.” Series 2 refers to “This AR is an efficient way to develop hands-on model-making skills online.” Series 3 refers to “This AR tool is easy or simple to use to develop my hands-on skills remotely/online.” Series 4 refers to “This AR tool positively affects my model-making learning experience.”

Tables. All questions, except Q1, are shown in the quantitative and qualitative tables below, respectively. All questions have been rephrased to present a concise format.

Table 11

Quantitative Data from the Second AR Experience Questionnaire

Question	Answer	RQ
Q3a. Would recommend this AR to other students	Two participants stated Strongly disagree, two stated Neutral, one stated Strongly agree	RQ2, RQ3, RQ4
Q3b. Would like to learn more AR tools	One participant stated Neutral, one stated Agree, three stated Strongly agree	RQ2, RQ3, RQ4
Q6. AR helps develop actual hands-on skills in making the actual building model online	One participant stated Strongly disagree, two stated Neutral, two stated Agree	RQ2, RQ3
Q8. AR tool helps improve understanding of hands-on skills in making the building model remotely	One participant stated Strongly disagree, one stated Disagree, one stated Neutral, two stated Agree	RQ2, RQ3
Q10. AR is worth spreading to the architectural academic learning environment	One participant stated Agree, four stated Strongly agree	RQ2, RQ3
Q17. Enjoy using cellphone to gain new knowledge	One participant stated Agree, four stated Strongly agree	RQ4
Q19. Any technical issues encountered	Four participants stated Yes, one stated No	RQ3, RQ4
Q37. AR is suitable for online education	Two participants stated Agree, three stated Strongly agree	RQ2, RQ4

Note. Answers are obtained through the Likert Scale.

Table 12

Qualitative Data from the Second AR Experience Questionnaire

Question	Sample quote	RQ
Q2. Enjoy learning hands-on skills remotely	"I think it is easier for everyone to get a good view of the digital model on their own screen than it would be to give everyone turns looking at a physical model in a classroom."	RQ2, RQ3, RQ4
Q4. Money spent for the experiment	"None, because I was unable to do many things on this tool at first place. Overall, I would say this was more time consuming than spending."	RQ3

Q5. Other comments about this AR tool	"The technology is fascinating though it needs more user-friendly improvement."	RQ2, RQ3
Q7. Working with the AR helps develop actual hands-on skills in making the actual physical building model remotely	"I could see the general layout of the elements, but it was all blended together and hard to distinguish where one element started and the other began. I also would have preferred to be able to interact with the model more: to take dimensions, pull it apart, change the materials, etc." "ARki® didn't really improve or worsen anything."	RQ1, RQ4
Q9. AR helps improve knowledge of hands-on skills remotely	"The free version is too limited to have added any value that I have not already experienced with the other AR tool." "No difference in my understanding of the structure after the usage of ARki®."	RQ2, RQ3
Q11. AR is a good learning tool in learning new knowledge	"With the bad experience I had with this tool I must say that not every AR tool is good to be learn to some tools are in my opinion just time consuming."	RQ2, RQ3
Q12. Money spent on building the actual model	"I did not spend any as I used empty pizza box and glue that I already had."	RQ3
Q13. Money spent to interact with the AR tool	"Zero."	RQ3
Q14. Other comments about AR experience	"I had a hard time trying to download the app because of the mobile phone used, and also the use of windows and android which do not support the app."	RQ2, RQ3
Q18. Why you like to use smartphone for studying	"My cellphone is always nearby, and it is often easier to grab and use than to pull out a tablet or laptop. Sometimes it is better to have a larger screen though."	RQ4
Q20. Technical issues during the AR experiment	"I could not open upload the original file on the application."	RQ3, RQ4
Q21. Other comments	"I have good 5G and enough space on my phone to use the AR app without problems."	RQ3, RQ4
Q36. More AR-related questions	"I'm curious if there will be more options to customize the AR tool for different types of models. Are there any new features coming that will make the tool more interactive or fun to use?"	RQ3, RQ4

Note. Answers are provided by different research participants.

The data show that perceptions about the second AR experience were mixed. Depending on whether the users' experiments were successful or not, two participants thought that this AR tool AR helped them develop actual hands-on skills in making the actual building model online, one stated they strongly disagreed, and two were neutral. In addition, four of them encountered technical issues. However, all five participants enjoyed integrating smartphones in learning.

In the Second AR Experience Questionnaire, I also asked questions about evaluating the current research design. I group them into the table below.

Table 13

Comments on Research Design on the Second AR Experience

Question	**Answer and sample quote**
Q15a. Enough information provided	One participant stated Disagree, two stated Agree, 4twostated Strongly agree
Q15b. Required substantial preparation	Two participants stated Disagree, one stated Neutral, two stated Strongly agree
Q15c. Good quality of facilitation/support	One participant stated Strongly disagree, three stated Agree, one stated Strongly agree
Q15d. Research Padlet are very helpful	One participant stated Neutral, two stated Agree, two stated Strongly agree
Q16. Reasons of your selection	"All instructions were clear in the Padlet which helped me follow the procedures in sequence." "I think overall the information is clear. If they can provide the step like how to transfer .rvt or .dwg file to .skp file, that would be great."

Note. Quantitative answers in the above table are obtained through the Likert Scale. Qualitative data are reported from various participants.

The data suggest that the percentage of participants who thought they needed substantial preparation on this specific AR was equal to the percentage of participants who thought they did not need substantial preparation on this specific AR. This contradicting data indicated that the tool adopted in the experiment very likely impacted the users' experience. Also, four participants agreed that the Research Padlet improved their research experience, and the quality of the facilitation was good. Since only one participant indicated requiring preparation for the first AR, two participants indicating requiring extensive preparation for the second AR suggest that either the second AR was more advanced technically or it created unexpected technical difficulties.

Table 14

Learning Preferences Surveyed on the Second AR Experience

Question	**Answer and sample quote**
Q22. Enjoy short learning sessions	One participant stated Neutral, two stated Agree, two stated Strongly agree
Q23. Reasons of your selection	"I prefer short 10-to-20-minute sessions because it's easier to understand and remember the material in smaller pieces."
Q24. Enjoy working without disruption	Two participants stated Agree, three stated Strongly agree
Q25. Reasons of your selection	"I like working without interruptions. It helps me stay focused and finish tasks faster."
Q26. Enjoy working individually	One participant stated Neutral, two stated Agree, two stated Strongly agree
Q27. Reasons of your selection	"I like working alone. It lets me go at my own pace and make all the decisions. Working alone helps me concentrate better. I can focus on my work without being distracted by others."
Q28. Enjoy working with peers.	Three participants stated Agree, two stated Strongly agree
Q29. Reasons of your selection	"Although I am less focused, but working in a group gives me the advantage of sharing skills and knowledge with different peers."
Q30. Enjoy expressing oneself	Two participants stated Neutral, two stated Agree, one stated Strongly agree
Q31. Reasons of your selection	"Sharing my opinions is important because it helps me feel involved in the conversation and adds to the ideas being discussed."
Q32. Preferred format for expressing ideas	"I prefer written format. As I have the opportunity and time and prepare my ideas and thoughts and refine them when needed before submitting."
Q33. Acceptance of being outside of one's comfort zone	Two participants stated Agree, three stated Strongly agree
Q34. Reasons of your selection	"I always want to try new things and if it is safe I would definitely always try to learn."
Q35. Worked in a small online group	"It was a good experience because it felt more personal, and I could discuss ideas more easily with others."

Note. Quantitative answers in the above table are obtained through the Likert Scale. Qualitative data are reported from various participants.

The data show that all five participants preferred uninterrupted learning periods. While four participants agreed that they would like to work alone, five expressed that they would like to work within group environments. This difference might suggest that the difficulty level of the technology used in the experiment impacted participants' preferences for studying. The more challenging the technology, the greater the collaboration needed when working.

Email Interview from Buffer Faculty

Drawing from the knowledge learned from Creswell, J. W. and Poth (2018) and my own teaching experience over the years, I prepared seven questions related to the screening process. I emailed the question form to the buffer faculty after he selected the last research participant for my project. He answered all seven questions and provided constructive feedback on the research design. The most beneficial suggestion for future research designs would be that "potential candidates should be required to answer a brief questionnaire about why they should be selected or be required to write a short letter explaining why they should be chosen" (F. Lapointe, email interview questions, November 10, 2024).

Summary of Chapter 5

In this chapter, I first explained all the obstacles I encountered before the project's commencement and the strategies adopted for how I solved these difficulties. I then detailed the actions involved in all the stages of the research process. I showcased all the data I collected through progress reports and questionnaires submitted by all research participants. I interpreted participants' experiment discoveries through text descriptions and photographs I retrieved from participants' written reports. I expanded the questionnaires' data presentation by creating Figures captured from MS Forms and Tables for qualitative and quantitative data, respectively. I further listed RQs to be answered and themes from TAM to be addressed by each question planned in each questionnaire.

I discuss the results found from the research process in the following chapter.

Chapter 6. Discussion

Introduction

My overarching research question (RQ), "How can immersive technologies assist in developing hands-on skills remotely," can be addressed by answering the four sub-questions. Drawing from the results introduced in the last chapter, I discuss how these findings answer each of the four sub-RQs in this chapter. To provide convenience for the audience, I restate my four RQs below:

RQ1. How does augmented reality aid in developing hands-on skills remotely?

RQ2. What are the perceptions of individuals regarding using augmented reality in learning hands-on skills at a distance?

RQ3. How feasible is it to adopt augmented reality in developing hands-on skills at a distance?

RQ4. How does employing augmented reality to teach hands-on skills online affect the learning experience?

Discussion on Research Questions from Three Questionnaires from Three Stages

Remarks for the Pre-intervention Questionnaire

Similar Backgrounds. As we can see from the responses from the pre-intervention questionnaire, research participants have been surrounded by various technologies since birth (n=14. Six participants contributed to 14 semantically linked excerpts). Growing up, using different hardware and software innovations in their lives is a common practice. Current generations of college students use smartphones, tablets, and computers, whether purchased or not, to fulfill various academic, social and professional responsibilities. They also must install and learn how to use various applications to fulfill these tasks, such as learning Revit to draw a residential building, navigating a merchandising app before purchasing a product, and meeting with their friends using social media. Various participants revealed similar situations. One participant commented, "I rely heavily on various technologies… My daily routine revolves around my iPhone and iPad Pro, where I use various applications as an aid for life's tasks." Another noted, "I also have a lot of niche apps for different things: a pill tracker, a movie watchlist/tracker, WhatsApp, Google Maps, Transit, the college's app, apps for grocery list making, productivity, news, etc." A third participant described, "I've been surrounded by technology for about XX (I withheld the exact number of years for privacy reasons) years. I grew up playing video games on different consoles and using computers on a regular basis."

Technology Literacy. Participants' answers to technology literacy-related questions were similar. One participant shared, "My familiarity with various technologies empowers me academically, interpersonally, and socially." Another stated, "I cannot conceive my life without technology, as it has become essential in everything I do." It can be rationally deduced that these generations will highly accept innovations and want to integrate them into their lives if such technologies are beneficial.

Hands-On Model-Making. Participants' responses in Q15 disclosed that four out of six research participants were unfamiliar with making physical wooden models by hand. Even though five participants stated in Q10 that they had good knowledge of wood frame structure, and two of them evaluated themselves in Q14 as possessing sound knowledge of making physical wooden models by hand, they responded in Q17 that physically constructing a physical wood-frame structure was still an arduous task, with answers showing one Neutral, two Agree, one Strongly agree. Obviously, selecting and integrating innovative tools into the learning environment can improve students' learning experience, and daily-use devices must conveniently handle the tools chosen. I was unsurprised to see the answers to Q4: All six of them stated that they liked learning about and trying AR.

Answering Research Questions from the First AR Experience Questionnaire

Answering RQ2. For the first sub-question of Q1, "I think AR is a good way to develop hands-on model-making skills online, based on my experience with the intervention in the first iteration," four of five participants answered Strongly agree, and one answered Agree. In the second sub-question, "I think AR is an efficient way to develop hands-on model-making skills online," three participants responded Strongly agree, and two answered Agree. This conveys a convincing message that all participants considered the first AR tool could assist them in developing hands-on model-making skills remotely, which adequately answered RQ2. After experimenting with the first AR, all participants' perceptions toward this AR were that using this AR in a remote learning environment efficiently developed their hands-on model-making skills.

Answering RQ1 and RQ3. Two other questions, Q4 and Q6, also support the findings from the first sub-question in Q1. To Q4, "The AR tool helps develop actual hands-on skills in making the actual physical building model remotely," two participants responded Agree and three stated Strongly agree. One participant shared the reason, "Since I've already explored the virtual version, I feel more confident and prepared. I know exactly where each piece should go because I've had the chance to 'practice' assembling it in the AR environment." Also, Q6 inquired, "The AR tool helps improve knowledge of hands-on skills in making the building model remotely," participants replied, with two agreeing and one strongly agreeing. One individual described in the questionnaire the details of how exactly the first AR helped users improve their model-making knowledge, "I can see how wood studs and beams fit together, which is great for learning about wood frame construction," and four others shared similar experiences, such as, “The AR tool also shows me the steps to build a physical model, making it easier to see how different parts connect.”

This group of data is sufficient to answer RQ1 and RQ3. RQ1 investigated how augmented reality aided in developing hands-on skills remotely. A participant’s reflection said it all: “Tool 3 (the first AR tool) provided the clearest visual understanding, which was crucial for accurate model-making.” Another comment explained that the first AR tool helped users inspect the virtual model closely and in a real sense of environment so all elements constructed in this model could be identified thoroughly individually when users walked around it. RQ3 explored how feasible it was to adopt augmented reality in developing hands-on skills at a distance. When answering Q12, one participant agreed, and four strongly agreed that they liked to use cell phones for studying. A participant’s opinion, which four others echoed: “I find it convenient to gain new knowledge from my phone, as it is very practical, lightweight, it does not require additional hookups or equipment to be attached, and it's easy to carry already.” It is clear that users would inevitably use these readily available tools to study if they had a functional AR tool such as the 3D Warehouse® and a smartphone.

Answering RQ4. RQ4 explored how employing augmented reality to teach hands-on skills online affected the learning experience. Q15 asked whether research participants encountered any technical issues during the AR experiment. A participant shared, “I had sufficient power and Wi-Fi. If the Wi-Fi signal had been weak, my phone plan would have exceeded what would have been necessary to use data instead.” Another participant discovered a similar issue using a smartphone for the AR experiment – it consumed too much battery power compared to their own regular use. While three other participants did not find more technical issues related to using this AR, this data group is adequate to answer RQ4. A trivial matter such as a phone battery capacity would have impacted participants' research experience; other more serious technical problems certainly gave users a negative impression of the chosen AR.

Answering Research Questions from the Second AR Experience Questionnaire

Answering RQ2. To compare the two selected AR tools, Q1 in the Second AR Experience Questionnaire, "Overall, please share what you think about the quality of AR as a way to develop hands-on skills remotely online," was the same Q1 asked in the First AR Experience Questionnaire. It also had a series of sub-questions similar to those in Q1 in the First AR Experience Questionnaire. The first sub-question of Q1 probed, "I think AR is a good way to develop hands-on model-making skills online, based on my experience with the intervention in the second iteration." The response showed that one participant answered Strongly agree, one answered Agree, one selected Neutral, and one selected Disagree. In the second sub-question, "I think AR is an efficient way to develop hands-on model-making skills online," two participants answered Agree, two Neutral, and one Strongly disagree. To comprehensively understand participants' views, these responses must be interpreted in conjunction with users' answers and written explanations to other questions in this questionnaire. For instance, in question 3a, "I would recommend this AR to other architectural students," one participant answered Agree, two answered Neutral, and two selected Strongly disagree. The high number of participants refusing to recommend the second AR tool to other learners was mainly due to their unpleasant experiences, which echoed their answers for the first and second sub-questions. As one participant described their negative experiences, "ARki® seems to be aimed at showcasing professional models in AR rather than at student learning outcomes. The free version is very basic in function compared to the paid version and the Sketchup® AR tool (the 3D Warehouse®)." Another user commented similarly, "The AR tool could offer more flexibility by allowing users to try the paid features a few times before requiring a subscription. Giving users a chance to experience the premium functions first would encourage them to commit to payment." The dataset presented here is sufficient to answer RQ2, indicating that participants perceived this second AR tool as not an ideal candidate in spite of its potential to be used in their learning.

Answering RQ1 and RQ3. One sub-question in Q1 inquired whether the interaction with the model through the second AR tool was easy. Four of five participants expressed that interacting with this AR was challenging. This result aligned with responses obtained from other questions. When answering Q2, "Do you like to learn hands-on skills remotely," a participant revealed, "I didn't particularly enjoy ARki®. A process expected to be easy turned out a bit stressful." Besides, Q7 asked whether working with the AR helped develop actual hands-on skills in making the actual physical building model remotely. One participant expressed, "ARki® didn't really improve or worsen anything." Another described a different experience: "I was unable to get through the features available on this tool because I was having a hard time with my phone and laptop to get into the tool in the first place." Similarly, Q8 inquired whether working with the AR tool helped improve knowledge of hands-on skills in making the building model remotely; one participant strongly disagreed, and one disagreed with the statement. A participant explained their experience in Q9: "No difference in my understanding of the structure after the usage of ARki®." Another user stated "Once again, I was unable to get through the features available on this tool because I was having a hard time with my phone and laptop to get into the tool in the first place." Moreover, for one sub-question of Q1 that asked whether "The AR tool positively affects my model-making learning experience," two participants agreed, and two strongly disagreed. The distinctive discrepancy in participant opinions can primarily be attributed to the fact that two participants could experience the second AR tool's basic functions while three could not access it at all. However, a user with access to the second AR still commented, "The free version is too limited to have added any value that I have not already experienced with the other AR tool." More frustrations were experienced by participants related to the second AR tool, as two participants shared when answering Q5, "Do you have any other comments related to the AR tool?" One user explained, "This tool does not support Androids or Windows, which makes it less user friendly as some countries use mainly Androids and Windows instead of Apple, so this will be a huge problem in working with for such countries." Another participant noted, "I think the ARki® needs improvement in the interconnectivity and the way the interface performs."

The data set presented here is sufficient to answer RQ3 but not RQ1; the data relate mainly to RQ2. Thus, I infer that the experiment of the second AR tool cannot genuinely answer RQ1 on how this AR might help hands-on model-making remotely. Furthermore, Q14 asked whether participants had other comments about this AR experience; statements that participants mentioned the most were still linked to technical issues they encountered. One of the participants shared, "I had a hard time trying to download the app because of the mobile phone used and also the use of Windows and Android, which do not support the app," which strongly suggests that using the second AR tool in developing hands-on skills at a distance is infeasible.

Answering RQ4. Q19 specifically asked, "Did you encounter any technical issues during the AR experiment," four of five participants stated Yes, and one said No. Equally, in the sub-question of Q1, where participants were asked whether they thought the AR needed improvement, four participants strongly agreed so, and one strongly disagreed. Similarly, when answering Q3a, "Would you recommend this AR and like to learn more AR tools?" two participants stated that they strongly disagreed with the statement, while two stated Neutral and one answered Strongly agreed. Even though they experienced more obstacles than expected, and these technical issues restrained them from getting a positive learning experience, participants still held high hopes for using the appropriate AR tool(s) in teaching and learning environments. Q10 asked participants whether AR was worth spreading to the architectural academic learning environment; four participants answered that they strongly agreed that AR is worth spreading, and one agreed. A participant expressed candidly: "I believe AR has the potential to improve architectural academic learning but throughout other tools such as 3D Warehouse® that can be used from different devices and has a reliable and easy setting to navigate." Another user shared:

> AR technology is a valuable tool in architectural education because it allows students to learn through interactive 3D visuals. It helps connect theoretical ideas with real-world applications, making complex architectural concepts easier to understand. AR also supports remote learning and collaboration, meeting the needs of modern education. It is cost-effective by reducing material waste through virtual testing and helps students visualize designs at (a) real scale, making it easier to grasp spatial relationships. This technology improves learning and prepares students for a future where AR and similar tools are commonly used in the architecture field.

This dataset undoubtedly addresses RQ4. The AR tool used in the experiment greatly and negatively impacts learners' experience.

Discussion on Research Questions from Fifteen Reports from Three Stages

Each participant provided three progress reports during the experiment: the first AR tool report, the second AR tool report, and the model-making report. There are 15 reports, each combining descriptive paragraphs and illustrative graphics. All codes were identified by analyzing participants' written reports, and each code was then grouped into themes using the

Technology Acceptance Model (TAM) and a portion of the SECTIONS (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy) framework. I categorized all initial codes into datasets that applicably answer each RQ. While working on each RQ, I realized that some data research participants contributed throughout their project period indeed described multiple facets of reality and could answer multiple RQs. In the following subsections, I start answering each RQ by listing a table that includes details of codes, the codes that answer specific RQs, and codes that scaffold the themes. Some quotations from research participants contained distinctive meanings, but some could be interpreted similarly. Since the meanings are interwoven, codes that answer each RQ are overlapped. I also integrate excerpts from all participants' reports when explaining the process of answering each RQ.

Answering Research Question 1

Table 15

Codes that Addressed RQ1 and Themes

Research question (RQ)	Code	Theme
RQ1. How does augmented reality aid in developing hands-on skills remotely?	Help in understanding concepts (both ARs)	PU, IU
	Usefulness in learning (both ARs)	PU, IU
	Not very helpful (ARki®)	PU, IU
	Usefulness in model-making (3D Warehouse®)	PU, IU

Note. PU is the acronym for Perceived Usefulness, and IU is the acronym for the Intent to Use (IU).

Help in Understanding Concepts (Both ARs). All participants reflected on whether the two AR tools helped them understand the learning concepts. I list below some sample comments reflecting the capabilities of the first AR tool. A participant shared, "I think it would be great for people who learn better hands on or who struggle with spatial awareness." Another user expressed the similarity, "Tool 3 provided the clearest visual understanding, which was crucial for accurate model-making." A third participant echoed, "This would also help the user to have closer inspections of how elements are fixed and walk around the model and do changes easily as well." Several comments on the second AR tool follow. One user claimed, "Tool 4 provided the clearest and more advanced visual understanding, which was crucial for accurate model-making." Another participant directly shared a comment on whether these tools help in the model-making stage, "The AR 3D ARki® (Tool 4) and the 3D Warehouse® (Tool 3) are tools that help understand the concept of making a model, and they provided me sufficient understanding and information before I started my hands-on physical model." Appreciation comes strongly from the first AR tool, which enables all participants to walk around the virtual wood structure, pass through from the front of the door opening to the rear side, view the simulated model at any angle the users desire, analyze the details on how each element was connected, even using a real tape measure to measure the virtual elements. Based on my own teaching experience, when learners studied wood frame structure in a traditional classroom setting where only 2D learning materials were provided, students' responses usually were that understanding complicated and abstract concepts was challenging (multiple learners and instructors, personal communication, multiple years). These experiences align with the findings from Q12, the Pre-Intervention Questionnaire, "It is hard to mentally gain wood-frame structure knowledge to reach one's level of performance." Research participants answered this question, with two of six participants stating Neutral, one as Agree, and one as Strongly agree. Therefore, it is likely that learners can better understand the abstract technical wood frame construction details if they can virtualize the details and interact with the 3D model virtually.

Usefulness in Learning (Both ARs). One participant described the usefulness of the first AR, "I can freely walk around the virtual model to explore it from different sides, making it much easier to understand the structure compared to looking at a flat drawing or video." Another user pointed out, "The AR made the navigation of the model possible and clarified any doubt related to the configuration of the framing layout, as it can be walk-thought and viewed at a real scale." In contrast, a user shared their opinion about the second AR, "I'm not very sure if this tool, in particular, would be very useful to gain hands-on experience, as it was tricky to manipulate and errors popped up regularly, refraining my learning experience from being interactive and positive." Another participant shared a similar experience, "It was more challenging to obtain an AR projection than with the previous tool, and this tool was less exciting than the previous one."

Not Very Helpful (ARki®). One participant commented: "Looking at the issues some students faced and the issues which I had, I think even though ARki® app is a good AR tool, it is not user friendly it is very complicated from the uploading process itself." In addition, since "Many features, like Reality Mode, require a subscription," access to the full AR experience was limited. The second AR posed challenges to all five research participants when accessing it. Only two participants could access its basic functions and their experiments were hindered; however, they still projected that this AR has the potential to be a useful tool to assist students in learning.

Usefulness in Model-Making (3D Warehouse®). When describing their own physical model-making experience, a participant shared: "To put them (model pieces) together, I relied on the drawings and 3D Warehouse® model (application) to make sure the wooden members were to assemble accordingly." It seems clear that the first AR tool assisted the participant in visualizing the wood elements and detail connections and assembling the modelling pieces based on the 2D drawings by reading this description.

Answering Research Question 2

Table 16

Codes that Addressed RQ2 and Themes

Research question (RQ)	**Code**	**Theme**
RQ2. What are the perceptions of individuals regarding using augmented reality in learning hands-on skills at a distance?	Easy to use (3D Warehouse®)	IU, PEU
	Happy to use (3D Warehouse®)	IU, PEU
	Unhappy to use (ARki®)	IU, PEU
	Not very helpful (ARki®)	IU
	Usefulness in model-making (3D Warehouse®)	PU, IU, PEU

Note. PEU is the acronym for Perceived Ease of Use, IU is the acronym for the Intent to Use (IU), and PU is for Perceived Usefulness.

Easy to Use (3D Warehouse®). 3D Warehouse® received the most compliments on how stress-free it is to use its function to complete tasks. One research participant praised: “The file was visible, and no prior registration was required to download it or to view it in AR.” One commented: “3D Warehouse® is easy to use, with a simple interface and access to many 3D models.” Another applauded the tool as it “offered the best user experience,” and another shared a similar sentiment, “Tool 3 was the most user-friendly.” The application not only allows users to interact with the exploration of 3D models but also makes it easy for the users to understand the design and structure of the 3D models before building them. A participant remarked that 3D Warehouse® was especially helpful for beginners because users could “quickly start exploring different model types and visualizing structures.”

Happy to Use (3D Warehouse®). All five research participants concur that they are happy to use 3D Warehouse®. One described having “a very smooth experience.” Another explained how “the 3D Warehouse® model cleared out doubts quickly when I needed to confirm the collocation of the bottom and top wooden plates.” One declared, “The agility and clarity it provided is unmatched if I compared it with ARki®.”

Unhappy to Use (ARki®). Participants claim to have **"**very disappointing" and "stressful" experiences when using ARki®. One user revealed that using ARki® was time-consuming because "errors popped up continuously." Another one described the experience as turning oneself to "very disappointing" from excitement, "I was most excited to try ARki®, of all the tools, based on the capabilities shown in the (demonstration YouTube) videos on the Research Padlet. However, my actual experience was very disappointing."

Not Very Helpful (ARki®). Only two research participants could test out the basic functions of ARki®. Both did not actively provide personal financial information in order to activate the subscription, but somehow, they could access its basic functions for unknown reasons. Thus, the accessibility of the application cannot be regarded as standard or normal, as this cannot be replicated. A participant explained, "It is not user-friendly; it is very complicated from the uploading process itself. As a designer, an AR tool should be something that could speed up the process and an easy tool to communicate with clients." Another participant commented, "I didn't make use of ARki® because it was stressful, it took too long, and errors popped up continuously before, so it prevented me from trying to use that tool again." Two users could access the basic functions of ARki®, and both confirmed frustration in using it.

Usefulness in Model-Making (3D Warehouse®). One participant reflected on past learning experiences in our program, noting that paper-based 2D drawings could confuse first-year students who were new to complex materials. AR tools would be very useful to "provide a general sense of the expected model." Another participant wrote that the 2D drawing set and the 3D Warehouse® application provided enough information for the user to be confident enough to build the physical model.

Answering Research Question 3

Table 17

Codes that Addressed RQ3 and Themes

Research question (RQ)	Code	Theme
RQ3. How feasible is it to adopt augmented reality in developing hands-on skills at a distance?	Technology issues (both ARs)	PU, IU
	Cost (both ARs)	PU, IU
	Inclusiveness (ARki®)	IU
	Privacy (ARki®)	PU, IU
	Technology literacy (both ARs)	PU, IU

Note. IU is the acronym for the Intent to Use (IU), and PU is for Perceived Usefulness.

Technology Issues (Both ARs). All research participants experienced technical problems in both ARs. On the one hand, although 3D Warehouse® earned the most compliments from users, its technical issues were still noticeable. Although one user could experience 3D wood frame models in true scale when experimenting with 3D Warehouse®, one user described, “I was unable to diminish the scale if I wanted to double up the digital model.” Some issues were observed when displaying the virtual models in real physical sites. A participant commented, “A perspective factor played in along the technology, even though the model was sized 100%, meaning scaled 1:1 on the chosen site,” but the virtual view still reflected the perspective; thus, the digital model projected on the physical site did not truly represent an authentic 100% actual size. On the other hand, ARki® created more technical challenges for users. The top issue was that ARki® only worked on Apple devices, and no Android equipment could access it. One participant also stated, “It did in a very strange way, and the elevation seemed off.” Another described, “I also experimented with other functions, including the icon, resembling an array of squares. It showed a grid, which I did not understand what it meant, neither could I tell the scale of the grid.” A participant encountered a technical problem before he/she could do anything, "Tool 4 needs an application to be installed… But I further faced more trouble with the downloading."

Cost. This research was designed to be deployed remotely and in an asynchronous format; thus, minimizing expenses used when conducting this project was a top priority. ARki®'s paid subscription strategy is understandable, considering the expenses involved in developing and maintaining such an application; however, it may discourage users from trying it in the first place. As one participant remarked, "I am very averse to this type of subscription gimmick, in part because I always forget to go back and cancel the subscription (I think they count on this)." Besides, a reliable and robust internet service is mandatory. All research participants either used Wi-Fi provided by CC or used commercial providers. This fact implies that it will be challenging if students live in remote geographic areas.

Inclusiveness (ARki®). ARki® only supports Apple devices, not Android or Windows devices. As one participant pointed out, "In the architectural technology program, we are encouraged to use Windows operating systems because they play better with AutoCAD and Revit; thus, not many of us have a Mac, and iPads are exorbitantly priced." Therefore, as one participant remarked, ARki® was not a "very good choice for a learning tool as it excludes a probable majority of students from easily accessing it."

Privacy. In an AR environment, 3D models are to be superimposed on the real world and displayed digitally with their true scale so that users can experience them virtually. This means that a standard eight-foot-high wood wall panel with a 6'-8" door opening model will need to be deployed on a space that is bigger, wider, and higher than this model so users can immerse themselves with the actual 3D dimensions and interact with the model. However, not every participant had the space to experiment with the AR in its true scale, so they had to select other spaces. One participant tried the AR in an outdoor courtyard, one on a balcony, two in open park spaces, and one in the school common area. Also, depending on the scale of the virtual models, two participants experimented with the AR in indoor environments when the displaying scales were not in the 1:1 scale. The second AR also brings another privacy issue. Participants were cautious about being asked to provide their financial information in order to get the 7-day free trial from ARki®. A participant expressed opposition: “You must buy the subscription upfront, and then you have 7 days to cancel without being charged.” I respect the owner of ARki®’s decision on its marketing strategy; however, ARki® may consider other options. Concerning the privacy issue, a participant suggested, “If I can pay for the subscription without needing to use my financial information, I would like to try these features for more options.”

Technology Literacy (Both ARs). Although contemporary young people are digitally connected and oriented generations, the level of their technology literacy plays a crucial role when experimenting with innovations. As well, sometimes, the technical hurdles participants encounter cannot be explained logically and technically. Even though research participants might have a high level of digital literacy, unexpected technical issues could still prevent them from having a satisfying experience. Even though some participants could successfully go through some functions, others might still experience technical difficulties when using the same functions. Some technical matters can be solved relatively easily, while others require more skillful manipulation. One participant was proud, “At first it was challenging to set the panel within the space with appropriate size, then I was able to minimize and rotate the wooden panel easily within the space,” Another needed more trial-and-error moments, “It was not immediately evident how I could reposition and rotate the model, but I figured it out eventually.”

Answering Research Question 4

Table 18

Codes that Addressed RQ4 and Themes

Research question (RQ)	Code	Theme
RQ4. How does employing augmented reality to teach hands-on skills online affect the learning experience?	Efficient in learning (both ARs)	PU, IU
	Technology limitations (both ARs)	PU, IU, PEU
	Suggestions (both ARs)	PU, IU, PEU

Note. PEU is the acronym for Perceived Ease of Use, IU is the acronym for Intent to Use (IU), and PU is for Perceived Usefulness.

Efficient in Learning (Both ARs). On one hand, the first AR tool meets students' needs. Learner appreciation came especially from displaying virtual models outdoors. One participant commented that the first AR "provided a comprehensive sense of the scale and configuration of the [wood] members;" another participant explained the first AR offered "a real sense of the scale of the objects and a clear view of the framing." The most amazing experience reported was when the AR "made possible the navigation of the model to clarify any doubt related to the configuration of the framing layout, as it can be walk-though and viewed at real scale." On the other hand, although ARki® offered users limited opportunities to experiment, the application provided functional features that enabled efficient learning; as one participant commented, "Its interface provided two environment settings for the objects to be placed in."

Technology Limitations (Both ARs). While the first AR tool offered a successful AR learning experience, not every participant experienced the same benefits. Although one participant could measure the 3D dimensions of the virtual wood panel model using a real tape measure, one participant complained that it was impossible to obtain the real measurement along both the vertical and horizontal axis directions. Besides, while others could successfully import the 3D models through their laptops, a participant mentioned that it was challenging to import

3D models. To superimpose the models, participants needed to use their smartphones to scan the generated QR code and then go to the outdoor space promptly, creating connection issues. Some participants needed to bring their laptops outdoors to scan the QR code due to some Wi-Fi connection problem. As well, both the clarity in visualizing and effectiveness in understanding the 3D model are contingent upon whether the model was rendered comprehensively in the first place. If the 3D wood structural model is created with only a series of framing members but without proper and distinct materials' renderings, such as showing the wood grain directions, then the wood frame model will become a 3D with a group of solid-colour wood members when it is superimposed in a real environment virtually. As a result, users could not identify the details of the wood structure, such as two headers on top of the window or door openings, which became just one solid big piece. Also, this type of single-colour model will probably change colour when deploying in AR, as one participant experienced without knowing what the cause was, thus causing incorrect presentation and understanding.

The second AR is designed and operates only on Apple devices, excluding anyone who does not carry such equipment. However, the user's involvement will still be negative even if one has an iPhone. One participant attempted numerous times but could not even set up an Apple ID on the borrowed iPhone, let alone download the application onto the smartphone. Additionally, its subscription structure proved to be problematic. The free-trial concept promoted by ARki® is indeed a misleading marketing strategy discovered by participants. One voiced the unfairness, "Additional features are available upon a subscription." Another participant specified, "Arki® has advanced features but limited functionality without a subscription." Another echoed, "Many features, like Reality Mode, require a subscription, limiting access to the full AR experience… Without access to Reality Mode, Arki® feels limited in helping build hands-on skills." Moreover, four participants who accessed the free version had various experiences. One was disappointed about only being able to view the pre-stored demonstrative house model and could not upload any model. Another uploaded the testing model and discovered that the wood frame structure model became a solid grey colour model. Three of them commented that the unpaid version of the AR only provided viewing of models with the .fbx file extension on the virtual and tridimensional environment and could only experience the basic features. They also needed to use their private email Drive, such as Google Drive, as a transferring method to upload the required models to the application. Furthermore, participants experienced different technical issues when experimenting with the second AR tool. Describing the overall personal experience, one participant noted, "I'm not very sure if this tool in particular would be very useful to gain hands-on experience, as it was tricky to manipulate and errors popped up regularly, refraining my learning experience from being interactive and positive."

Other drawbacks emerged as well. For both ARs, the biggest concern mentioned by research participants is not related to the technology itself but the physical environment that enables the virtual models' full deployment. To experience the AR simulation, users must stay in an empty and big space so the 3D models can be superimposed with true scale in such a space. Of course, experimenting with AR in a big indoor space such as a school common space is ideal; however, in an architectural learning environment, the building models often should be placed outdoors to configure and understand the accurate scale with the actual sites and their surroundings. One participant also commented that it was weather-permissible during this research period but would be impossible if this research was conducted during Canadian winter months or in geographic locations with a severe cold all year long. Another participant noted that the virtual model with wooden grain texture rendering was not clearly visible as it was affected by sunlight.

Suggestions (Both ARs). In the first AR experiment, research participants needed to use their laptops to open the application and then use their smartphones to scan the QR codes. They subsequently needed to go outdoors to superimpose the virtual model. One participant suggested bringing the laptop outdoors simultaneously when scanning the QR code, as the user's Wi-Fi connection might pose a connection challenge. Another participant suggested using a tripod to free one's hands. As for the second AR tool, to create a better viewing experience, a participant suggested using an iPad instead of an iPhone as the screen of the iPad was bigger. Still, a participant reflected, "The 2D drawings contain neuralgic [*sic*] information and data that the AR does not offer. Combining both methods is very powerful."

Discussion on the Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) suggests that several factors influence users' decisions regarding adopting and using the new technology when users are presented with an innovation. The two main variables that TAM evaluates are Perceived usefulness (PU) and Perceived Ease of Use (PEU) (Davis,1989). PEU describes a user's subjective opinion about the easiness of using a piece of technology. PU describes that a user believes a piece of technology will improve their performance. TAM identifies the user's intention and preference to use a new technology based on their evaluation of its usefulness and ease of use after using the innovation (Davis, 1989). Davis also suggested that an individual determines his/her Intent to Use (IU) such a new technology in the future if the individual believes that using that particular technology would enhance his/her own performance.

On the one hand, the questions in the three questionnaires were not only inspired by previous studies that employed TAM but also tailored to fit the contexts in my study. Apart from questions related to research design, learning format preferences, and specific architectural program and model-making experiences, questions were primarily developed to gauge participants' attitudes towards Augmented Reality (AR), including cost-related inquiries derived from the SECTIONS (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy) framework. On the other hand, five research participants submitted 15 reports detailing their experimental work. The contents of these reports addressed Perceived Usefulness (PU), Perceived Ease of Use (PEU), and Intention to Use (IU).

Participants reported their actual experiment, such as describing their process of superimposing the 3D wood wall panel model virtually in an open park area. Participants narrated their perceptions of the tools, such as sharing their observations or reflections after experimenting with the ARs. Some excerpts from these reports demonstrate research participants' perceptions of new AR tools. For example, a participant described the PEU, "Tool 3 was the most user-friendly." Another participant described PEU and, subsequently, PU,

> "This tool (3D Warehouse®) offered the best user experience. It allowed interactive 3D exploration of models, making it easy to understand the design and structure before building (it). It was especially helpful for hands-on learning, as users could view every angle and detail, making it ideal for transitioning from digital to physical construction."

Participants provided suggestions about the tool, demonstrating implicitly their IU toward the AR, such as one participant pointed out, "(ARki®) required compatible devices and reliable internet." Participants also explicitly articulated their IU toward ARs. One participant recommended, “This (3D Warehouse®) overall is a better tool to be used in both teaching and discussing with clients in the workplace.”

Addressing Themes of TAM from the First AR Experience Questionnaire

For one sub-question in Q1 that addressed Perceived Ease of Use (PEU), “I think this AR tool is easy or simple to use to develop hands-on skills remotely/online,” three of five research participants answered Strongly agree, and two answered Agree. One participant described, “Everything ran smoothly and was fairly intuitive.” Another participant noted, “The AR tool made it really easy to understand of the configuration of the wood members.” Q6 inquired about participants’ views on Perceived usefulness (PU), “Working with the AR tool helps improve my knowledge/understanding of hands-on skills in making the building model remotely/online.” Two participants answered Neutral, one answered Strongly agree, and two answered Agree. One participant noted, “If the AR tool can incorporate weight calculations and simple structural analysis, it would help students understand the structure more clearly.” Another remarked, “The tool gave a clear idea on how each element is connected to each other and how we could understand as a student on how these elements are fixed. The drastic difference in the method of connection in each part of the frame is easy to observe.” The last sub-question in Q1 explored participants’ potential Intent to Use (IU) the AR, “The AR tool positively affects my model-making learning experience.” Three of five participants answered Strongly agree, and two answered Agree. One participant commented, “Overall, this experience makes the process of creating an actual model easier and more accurate, as I can rely on what I’ve learned from the AR tool.” In summary, research participants perceived that the first AR tool is easy to navigate and operate, and it provides useful functions that assist them in understanding the wood frame structure and developing hands-on model-making skills remotely. The positive learning experience fosters participants' willingness to use this AR tool in the future.

Addressing Themes of TAM from the Second AR Experience Questionnaire

The sub-question in Q1, "I think this AR tool is easy or simple to use to develop hands-on skills remotely/online," addressed Perceived Ease of Use (PEU). One participant agreed with the statement, while two stated Strongly disagree and two Disagreed. A participant shared, "I didn't particularly enjoy ARki®. A process expected to be easy, turned out a bit stressful." Another participant echoed, "It needs more user-friendly improvement." Q6, "Working with the AR tool helps improve my knowledge/understanding of hands-on skills in making the building model remotely/online," explored participants' perceptions toward Perceived usefulness (PU). Two participants agreed with the statement, two expressed Neither agree nor disagree, and one stated Strongly disagree. One participant explained that the AR tool allowed him or her to "image the true scale of the object as well as the sequence of assembling the wooden elements;" however, the participant used the verb "image" and did not clarify whether he or she really had experimented with the AR. Another participant expressed a neutral attitude toward PU as ARki® "didn't really improve or worsen anything" in his or her experience. The sub-question in Q1, "The AR tool positively affects my model-making learning experience," investigated participants' Intent to Use (IU) for the second AR. Two of five participants answered Strongly disagree, two answered Agree, and one expressed Neutral. One participant suggested, "It is best to find tools that can be accessed on multiple operating systems and devices for maximum accessibility to students." Meanwhile, another expressed greater dissatisfaction, "The app kicked me out multiple times. I tried more than a dozen times to get the model imported to ARki®." In summary, the intention to use this AR in future is mixed, as whether the users want to use the new technology in future depends on their attitudes toward PEU and PU.

Addressing Themes of TAM from Fifteen Reports from Three Stages

I analyzed 15 reports from five research participants and identified codes based on their contents. Then, I categorized the codes into themes that addressed variables in TAM.

Codes addressing TAM and RQ1. The same group of codes addresses not only the RQ1 but also the themes of PU and IU from TAM, as shown in Table 15. As we can see from the RQ1 discussion, when commenting on ARs' PU, research participants agreed that both ARs provide the capabilities of enabling users to understand abstract design concepts. Specifically, all five research participants strongly agreed that the first AR tool is beneficial in helping them develop hands-on model-making skills remotely. They also strongly desired to use this AR tool in future learning. Surprisingly, for the second AR tool, even though only two participants could access it and only tested its free and basic functions, they projected its potential PU in learning environments as if it could be deployed fully and successfully. This sentiment suggests that they understand that innovation development takes time and effort, and their IU toward AR tools in general in learning is solid.

Codes addressing TAM and RQ2. The same cluster of codes addresses the RQ2 and the themes of PEU, PU, and IU from TAM, as shown in Table 16. As we can see from the RQ2 discussion, five participants perceived that the first AR tool was easy to use. The first AR tool provided easy-to-follow guides and easy-to-manipulate functions that empowered all research participants to superimpose 3D models in the physical real world smoothly, and the AR tool performed efficiently. Thus, even users new to AR technology could easily experiment with its AR function. All participants also expressed that they were very happy to use this AR as the experiment ran easily, and all tested functions worked well, which could also enable them to develop hands-on model-making skills at a distance. Each participant recognized the value of PU and regards this tool as high PEU; the IUs from five participants are uniformly high as well. In contrast, the comments from two participants who could trial the basic functions of the second AR tool demonstrated that they were disappointed about their experiences and even felt stressed. Besides the unknown reason why these two participants could access the platform without subscribing, another three participants experienced various technical issues, from trying to create accounts on Apple devices to encountering errors when interacting with the tool, which showed that the tool is not PEU. The negative attitudes of PEU and PU impacted participants' IU toward using the second AR tool in the future.

Codes addressing TAM and RQ3. The same collection of codes addresses the RQ3 and the themes of PU and IU from TAM, as shown in Table 17. As we can see from the RQ3 discussion, both ARs presented technical issues. The first AR exhibited particular issues related to specific architecture learning knowledge. For example, it was difficult to determine whether the virtual building model was superimposed in the physical world with an accurate 100% scale. The technical issues discovered in the second AR are mainly related to subscription requirements and the fact that users must use Apple devices. No participants agreed with the second AR's subscription plan when they were required to input their private financial information in order to obtain access to the platform. In particular, the second AR tool can only be deployed on Apple devices, which excludes Android users worldwide. This affects the IU for users, especially for Android users.

Participants demonstrated positive attitudes toward the first AR's PEU and PU. In comparison, participants could not fully trial the second AR, and their PEU was less ideal. Still, participants projected its PU in the learning environment. Participants' individual technology literacy levels also impacted the PU and IU.

Codes addressing TAM and RQ4. The same group of codes addresses the RQ4 and the themes of PEU, PU, and IU from TAM, as shown in Table 18. As we can see from the RQ4 discussion, even though the second AR tool only provided limited AR experience, two research participants projected that this AR tool can enable efficient learning in future. All five participants could fully experiment with the first AR tool and regarded it as an efficient tool for understanding abstract learning concepts and helping them develop hands-on model-making skills remotely. Both AR tools exhibited technology limitations. For instance, while the first AR tool provided a better AR experience and was user-friendly, using a tape measure to measure the virtual model precisely was challenging. The PEU and PU determine the level of the IU in adopting an innovation; in my research, PEU seems to be the fundamental variable that impacts the IU. When experimenting, research participants recognized that not only the PEU and PU of the AR tool itself but also other technologies that contribute to creating the overall positive AR experience play a crucial role in the IU of such innovation. For instance, a smartphone with low-speed Internet hindered a faster and smoother AR learning experience, thus impacting the overall IU of the AR.

Summary on TAM

In PU and IU, the first AR tool performed significantly better than the second AR tool. PU was undoubtedly a foundation of IU, which gauged an innovation's usability. However, the first AR tool had minor PU issues, while the second AR produced significant PU issues. The acceptance level of PU impacted the PEU, and further determined users' IU.

The data are discussed here only in relation to their influence on the PU and IU outcomes. The first AR tool earned compliments over the second AR in PU and IU. Although both AR tools brought challenges to users, the quality of the 3D models required to be imported to the AR applications impacts the IU greatly. If evaluated by TAM and the cost factor from SECTIONS, the first AR had a great PEU, while users envisioned the second AR having a great PU based on their projections. While the first AR had a better PEU, the second AR's subscription scheme scared users off by asking for private financial information. Both AR tools had various technical issues, but the first AR provided excellent IU.

Discussion on Two Factors from the SECTIONS (Students, Ease of use, Costs, Teaching functions, Interaction, Organizational issues, Networking, Security and Privacy) Framework

Getting information about the college's organizational issues was challenging as I am not a full-time faculty member and not at the management level. I obtained the following information through two private telephone conversations with two members of our architectural program. To protect their identities, I used the letters X and Y to represent these individuals. To further ensure anonymity, I intentionally omitted when these occasions happened. I explain these occasions in this report to illustrate the challenges of interacting with the institution.

Organizational Issues

One staff member from CC's IT (Information Technology) department, who had discontinued working for CC, approached X and inquired whether the architectural program was interested in trying virtual reality (VR). Shortly after, a private consultant or sales representative from one VR software company approached X to explore whether our architectural program was interested in exploring their VR tool. Later on, X, with assistance from these two individuals, arranged a pilot VR experiment session among several faculty members. After trialing the pilot experiment and discussing it with the management team, X organized a VR experiment for architectural program students. However, it ultimately did not occur, and X was never informed of the reasons. X later discovered that students in the Architectural Student Club provide all architectural students with opportunities to experiment with this VR tool.

Cost

Cost Related to Organization. X mentioned that iPads were needed to experiment with the abovementioned VR application. After great effort from faculty members, the budget for purchasing several iPads was approved. However, the purchase has not yet been realized due to unknown reasons. Currently, the Student Club has several iPads. Another member, Y, commented that it would be challenging to request funding for new equipment purchases and software subscriptions, as the management team always expresses tightness on budget expenses. Thus, it would be better to get free software and use students' personal smartphones for learning.

Cost Related to Research Participants. This research invitation was sent to every student enrolled in the architectural program in the Fall 2024 semester. It did not specify the smartphone types and models or the Wi-Fi connection requirement to ensure inclusiveness. Discovering technical issues during the research process, I asked all research participants about the equipment they used. Participant A used a 5G plan at home and an iPhone 12 mini. Participant B used a Samsung A32 and an ASUS laptop with a Windows operating system for the first intervention and borrowed an iPhone 5 for the second AR experiment. The internet connections B used were the CC's Wi-Fi, home Wi-Fi, and sometimes the 5G plan given by the carrier on the phone. C used an iPhone X and a 5G plan Wi-Fi at home. Participant D used an iPhone XS for both AR experiments, and the college residence provided the Wi-Fi connection. Participant E used an iPhone 8 with LTE mobile phone data for the first AR and 5G from home for the second AR experiment. All participants did not need to upgrade their Wi-Fi subscription plan nor purchase a new smartphone to experiment with the AR tools in this research. However, to create a positive user experience, designers of innovations must ensure their applications are accessible to a wide range of users. As one participant pointed out in relation to ARki®:

> In the architectural technology program, we are encouraged to use Windows operating systems because they work better with AutoCAD and Revit. Thus, not many of us have a Mac, and iPads are exorbitantly priced, so not everyone has one (I certainly refuse to buy one). They are also not currently available to borrow from the Morningside campus library.

The comments from research participants showed that participants needed to have their own laptops, as the college’s computers were set to prevent the installation of other/new applications. Participants also needed their own high-speed internet connections when working on this project, as the college’s open internet services were challenged to meet the demands of project-related graphic and immersive experiences.

The discussions above demonstrate how institutional and cost issues could and did impact the adoption of innovation in teaching practice.

Discussion on the Existing Model-Making Assignment

Beyond concurring that the AR tool assisted them in developing hands-on model-making skills remotely, research participants also shared their perspectives about the innovative intervention. They voiced that the intervention integrating with the AR tool helped reduce their cognitive load and save time and money when learning about the materials and making the physical model.

Work Efficiency

Reducing Cognitive Load. One participant described in the report, "The 3D Warehouse® model cleared out doubts quickly when I needed to confirm the collocation of the bottom and top wooden plates. The agility and clarity that it provided are unmatched if I compared it with ARki®." Another participant explained, "3D Warehouse® was easier to use for me because it offers more flexibility and quick access to models." One student explained how a tool affects the learning process, "It is best to find tools that can be accessed on multiple operating systems and devices for maximum accessibility to students." As data present, a properly designed AR tool can improve students' understanding of learning content, and an easy-to-use AR tool can help enhance the learning process, thus reducing cognitive load.

Preferring Short Learning Session. Question 17 in the First AR Experience Questionnaire asked, "I like short learning sessions." Three out of five participants answered Strongly agree, while two answered Agreed. When describing their learning preferences, one participant noted, "I like short learning sessions as they help keep me focused and less overwhelmed by too much information." Another student described the views in detail:

> I prefer short learning sessions, like 10–20 minute videos or articles. For example, a quick tutorial on using a design tool or learning a specific architectural technique is easier for me to focus on and remember. Short sessions don't feel overwhelming, and they fit better into my schedule, allowing me to learn a bit every day without too much time commitment.

Time Aspect

Saving Time on Learning. When comparing working on a virtual AR model with building up a physical model, participants demonstrate a preference for working with the virtual format. A participant noted, "The experience (of making the physical model) was the hardest and consumed more time to achieve the same model than using AR 3D ARki® tool or 3D Warehouse® tool." Another participant specified the time needed for making a physical wood panel model, "The overall model took me about 3 hours to complete and an extra hour for the glue to dry off."

Saving Time on Commuting. The innovative learning format eliminates learners' time spent on commuting. Learning through AR online removes the need to travel physically from school to home or workplace and the need to pay for transportation. For example, one participant deployed the AR in the campus residence, while another deployed it on the balcony of their own residence.

Cost Factor

Interacting with the AR Tools. One question in the First AR Experience Questionnaire asked the total dollar amount research participants spent to interact with the AR tool. One participant responded, "Nothing. I already have internet and the tool was free." The other three answered zero amount. The fifth participant claimed to have spent $20. However, this participant did not specify the details of the spending. As data present, integrating a free tool into learning is critical to help learners minimize the financial burden.

Building the Physical Model. A question in the Second AR Experience Questionnaire asked how much research participants spent on building their physical wood panel model. Three students responded that they did not pay any, as one participant explained: "I used materials I already had on hand." The fourth participant reported paying five to ten dollars; the last one reported paying 40 dollars. Both did not specify details on the spending. Even though participants were encouraged to use materials that they have in their households, it is clear that some learners may still prefer to purchase more formal architectural model-making materials. On the other hand, research participants were only required to construct a wall panel model instead of a completed house model, so it is challenging to compare the total dollar amount used in these two types of situations.

Comparison of Efficiency and Effectiveness

Since research participants reflected on their experiences interacting with AR tools and how these tools affected their learning, it is imperative to compare the efficiency and effectiveness of conventional and AR-assisted learning methods.

Cost and Time Factors. Data from research participants show that it took approximately four hours to create the physical wood panel model, and commuting time was not needed. The data also reveal that the cost of constructing a physical wood panel model using balsa wood strips was lower than the cost of producing an actual whole house model, which is understandable, as building a whole house model certainly requires more materials than constructing just a wall panel model. An infographic that visually compares the time and cost factors between conventional hands-on and AR-assisted hands-on teaching methods is presented in Appendix K.

Time Spent on Two Different Models. To further evaluate the effectiveness and efficiency of conventional and AR-assisted teaching methods, it is logical to compare the time variances between creating a virtual 3D wall panel model for AR experimentation and constructing a physical wall panel model. It is also reasonable to assess the time differences between creating a virtual 3D wood house model for AR trials and building a physical wood house model. The results of the comparison are shown on Appendix L.

In order to make this comparison work, I designed an imaginary house model. As well, in order to make the comparison readily justifiable, the dimensions and area of this imaginary house were created based on the model-making assignment in the course I taught and were similar to those in the assignment. Moreover, in order to estimate how many wood members were needed to construct the whole house framing model, both in virtual and physical formats, I adopted one wall panel as the basic calculation unit. Furthermore, in order to graphically illustrate how to estimate the number of wood panels needed, I created two illustrations, one house floor plan view and one house elevation view. Since a house framing design involves many components, such as roof rafters, the illustrations only present a preliminary and rough idea and not a completed design.

An infographic, presented in Appendix L, visually compares the time spent between conventional hands-on and AR-assisted hands-on learning methods for a wood wall panel and a whole wood house structure and explains various details of the comparison. As the evaluation shows, the AR-assisted hands-on learning method outperforms the conventional hands-on method.

Discussions on Working with the Buffer Faculty

Conversations

The open dialogues I had with the buffer faculty enabled me to identify challenges in the process of selecting research participants and to refine my research design. I instantly realized the crucial step I had missed when the buffer faculty asked me about the selection criteria. Before drafting a list of evaluation criteria for the buffer faculty that detailed how to assess and decide which research participant to participate in my study, I reviewed several online resources on related topics, thinking deeply about what type of research participants I wanted to have in my research.

Interacting with the buffer faculty inspired me to develop a survey with questions that were tailored to my research situation. Because this was the first time both the buffer faculty and I were involved in the screening process, I was very interested to know what the buffer faculty might think about it. I searched online resources regarding screening process elevation but eventually found inspiration from the research book authored by Creswell and Poth (2018). Thus, I created an “Email Interview Questions for the Screener (the Buffer Faculty)” (see Appendix H) with seven questions to learn about the buffer faculty’s experiences and views related to the screening process. As CC REB instructed me to find a research assistant as a buffer, I wanted to know whether the buffer faculty’s academic and industrial backgrounds played a beneficial role when assessing research applicants or would any individual, such as someone who came from the student population or administration team, could act as a buffer person. Moreover, I wanted to know whether the selection criteria I provided helped evaluate research participants.

Our conversation also empowered me to develop an effective approach to solving emerging challenges when compensating research participants. When discussing how I would pay research participants while ensuring the process was free from any academic or related risks, we both agreed that it would be better if the buffer faculty contacted participants at the end of the research to keep me further away from participants. The buffer faculty would ask research participants several questions related to compensation, such as what type of payment format research participants preferred. I then informed CC REB, who stated that allocating gifts via buffer faculty was a better way to “remove any academic or related risks” (S. Kishore, personal communication, November 9, 2024).

Email Interview

In the replies from the email interview, the buffer faculty voiced an important opinion related to the screening process. The buffer faculty suggested that in the future, compared to the screening criteria, all potential candidates should write a letter explaining the reasons why they should be selected. Also, the buffer faculty proposed that potential candidates should “attach a college transcript or summary of grades” when applying because this would help the buffer faculty in evaluating the applicants. However, I wonder whether such a practice will obtain REB approval. The buffer faculty also clarified questions asked by applicants, such as research timelines and the software and hardware used. Since I was separated intentionally by the buffer setting, the comprehensiveness of the information provided in the Invitation to Participate letter proved well-prepared. Additionally, the buffer faculty commented that his experience as a professor who recognized the teaching circumstances in CC and the research topics, as an architect who mastered construction knowledge and knew the industrial trend in adopting immersive innovations in practice, helped him screen research applicants.

Discussion on the Research Design

My primary purpose was to investigate whether AR technology can assist in developing hands-on model-making skills remotely and to learn about students’ perspectives on using AR to teach specific areas of knowledge.

Design-Based Research

Bakker (2018) stated that design-based research is a framework to describe concepts and processes, compare tools used, evaluate the effects of interventions, explain phenomena, predict the outcomes of adopting specific interventions, and design and develop strategies to improve and advise future practice and other educational practitioners. Shattuck and Anderson (2013) explained that design-based research enables research projects to focus on the design and evaluation periods effectively. Sandoval (2014) discussed that “design research, as a means of uncovering causal processes, is oriented not to finding effects but to finding functions, to understanding how desired (and undesired) effects arise through interactions in a designed environment” (p. 30). In my study, I initially planned for two iterations. However, I later conducted more iterations after examining periodic results obtained from different research participants. This is consistent with design-based methods. The iterative process was designed for specific purposes and is user-oriented (Scott et al., 2020). The more exploration toward the chosen technology, the better understanding of how the chosen technology could assist in developing hands-on model-making skills at a distance as well as what the potential drawbacks such technology might imply. As suggested by Bakker (2018), "educational ideas for students and teacher learning are formulated in the design but can be adjusted during the empirical testing of these ideas" (p.3).

The iterative nature of DBR enabled me to test the technologies in a cyclical format. I explored two AR tools. I learned how they worked in a learning environment and discovered specific improvements that could be made or issues that could be avoided for future experiments. AR technologies explored in the AEC field, such as 3D Warehouse®, are available on the commercial market and have a wide range of applications and technology implications. However, not all these platforms are suitable for studying hands-on model-making skills remotely. I also learned that technical factors significantly impacted participants’ experiences, as per the TAM model. For example, an AR experiment created a negative learning experience for a specific group of participants, such as participants only using Android equipment. I also learned that student research participants enjoyed learning knowledge and skills through AR. Certain specific AR technologies helped them learn more efficiently and improved their perception of their academic performance. Although participants encountered various issues when experimenting, their attitudes towards using AR in the educational setting were enormously positive.

The research design effectively guides the researcher in conducting the study and successfully collecting users' feedback. However, I would improve two aspects in future research of this type. One is the preferred work format, as every participant's preference may differ. Another is that the researcher should regularly remind participants about their data privacy.

Work Format Preferences

All participants expressed that they preferred to work alone, and they also could work collaboratively with peers, depending on the task's nature. One participant responded, "Working in a group environment is more fun and challenging as well as it allows peers to exchange knowledge and skills." Another expressed, "I feel comfortable working in both: groups or individually. It mostly depends on which types of tasks."

This research was originally designed with a stage where all participants could collaborate, sharing progress and ideas about the AR experiment. However, to ensure zero academic and social risks, two REBs suggested that individuals work alone. If participants could work together at some points during the research, the overall time this research needed would be shortened as learners could get inspiration from others' experiences and avoid making the same mistakes. However, it would be a big challenge for every research participant to work on this research at the same time since each research participant may be in different academic semesters and time zones; thus, their workload and tasks will be greatly different from each other.

Privacy Concerns

Even after signing the consent form, one participant still asked me questions after completing this research. This participant was concerned that the recording of our MS Teams meeting would be watched by other college personnel. I assured this participant again. In the future, it would be a good practice to address privacy concerns throughout the research period.

Discussion on the REB

It is evident that Research Ethics Boards strive to protect the privacy of researchers and research participants. However, in a society where humans are so digitally connected, should the REB consider approving novel compensation methods, such as e-transfer, for researcher participants?

Additionally, researchers should prepare themselves for unanticipated complications when conducting their research studies in real-life learning environments. Researchers who are graduate students studying at AU and plan to conduct studies in other institutions with student populations should prepare their studies to meet the challenges of two REB approvals. Even though the AU REB paid careful attention to possible issues in their review, there is another level of attention to the impact of research on students by the second review. For example, researchers may be required by the project site's REB to find an appropriate person to act as a buffer between themselves and potential student research participants to minimize any academic or social risks. Also, their studies may require additional approval by the institution if they involve student participants from multiple academic departments or by one single academic department if they only involve student participants from a single department.

Summary of Chapter 6

In this chapter, I discussed, using thick data description (Cohen et al., 2018) as appropriate to qualitative research, my interpretation of data collected through three questionnaires and 15 reports. I first interpreted data from the pre-intervention questionnaire about modern learners' academic, social, and professional backgrounds. This provided supporting information that it is inevitable to adopt innovations in the educational environment with tools readily available to learners. Based on the First AR Experience Questionnaire, I detailed the corresponding quantitative and qualitative data to answer each RQ. I explained and answered each RQ using related quantitative and qualitative data obtained from the Second AR Experience Questionnaire. In addition, I used data collected from 15 reports to answer each RQ, meanwhile aligning responses to each RQ through the TAM and SECTIONS frameworks.

In the next chapter, Conclusion, I answer my overarching research question and further discuss the significance and limitations of my research.

Chapter 7. Conclusion

Introduction

In this chapter, I outline the significance of my design-based research study and present its limitations. First, I explain how the data collected through this research answered my overarching research question. Then, I summarize a prototype that other educators who desire to adopt AR tools in their hands-on skills teaching could follow. I also list several limitations that impacted my research, such as technological issues. I further present recommendations based on my study, and I conclude by assessing my overall research design, data collection, and outcomes.

Significance of This Research

Answering the Overarching Research Question

My overarching RQ was, “How can immersive technologies assist in developing hands-on skills remotely.” To answer this question in detail, I analyzed 15 journal reports and three questionnaires in the previous chapter 6. AR (3D Warehouse®) superimposes a 3D model onto a real environment with a true scale and enables the users to not only view the abstract design and understand the construction wood members in detail but also to virtually experience the model by walking through it, wandering around it, and even measuring each constructing wood member via a physical tape measure. Integrating a smartphone that most learners carry nowadays into the learning environment, AR innovation offers a game-changing teaching method for educators while providing learners with a fun and engaging educational setting. Users generally perceive AR as an innovative tool to help them learn, even though some AR tools, such as ARki®, do not offer a smooth and effective experience. All research participants agree that AR will be the future. As one participant commented, “This (AR) tool, with no doubt, is the future of design.” However, users’ different experiences with AR experiments influenced their perception of the usefulness of the tool. One participant shared, "I think it (3D Warehouse®) would be great for people who learn better hands-on or who struggle with spatial awareness." Another echoed similarly, "SketchUp (3D Warehouse®) is the more practical choice for studying building models and developing hands-on skills remotely. It's free and provides all the features I need for detailed exploration and model planning." Participants described the first AR tool with great enthusiasm. A user shared how feasible it was, "It (3D Warehouse®) provided a clear resolution, scale and configuration of the (wood) members. The technology easily set up the model on the ground floor. No adjustment of elevation height was required. The viewing was accurate." Another participant shared a similar perspective, "It (3D Warehouse®) was especially helpful for hands-on learning, as users could view every angle and detail, making it ideal for transitioning from digital to physical construction." One participant commented about the feasibility of the 3D Warehouse® with a detailed description of functions: "The AR tool's zoom function adds to the hands-on feel, as I can focus on specific details or step back to see the model's full scale."

Participants' reports and questionnaires also demonstrated that adopting the appropriate AR tool in teaching is crucial. The first AR tool, which is developed for all subject areas and not specifically for architectural usage, attracted unanimous positive feedback in helping research participants develop hands-on model-making skills at a distance. The second AR tool, which is developed solely for architectural professional application, could not get approval from all research participants. The primary obstacles were its subscription setting and unforeseeable technical issues. In a competitive commercial and educational market where many applications emerge, a slight misstep may lead to a negative impression from users, no matter how good the application may be. Besides, the quality of the 3D model rendering plays a crucial role in helping learners understand the object to fulfill its academic objectives. In addition, using the assessment frameworks from TAM and SECTIONS, AR tools with high values in PEU, PU, and IU, such as 3D Warehouse®, enabling fast learning and ease of use, are a better choice based on the current technology available. Furthermore, traditional 2D drawing teaching methods are still indispensable for ensuring successful and effective learning.

As AR is under the umbrella of immersive technologies, this study shows that well-chosen AR could assist learners in developing specific hands-on skills at a distance; therefore, immersive technologies can certainly assist in developing hands-on skills remotely.

Serving as a Future Reference

Overall, this research illustrates that specified and carefully selected AR tool(s) can help students develop hands-on model-making skills remotely. In the current technological advancement environment, immersive technologies, which include AR and VR (Qian et al., 2023), are being researched constantly. Based on this study, a particular AR surely assists learners in developing hands-on skills at a distance. Therefore, the conclusion is that immersive technologies can be used to help learners develop hands-on skills remotely. However, the effectiveness of the learning outcomes depends on which AR tool is adopted in the learning environment and the intervention design.

Moreover, although researchers have claimed that AR and VR "are not ready to be fully adopted in the construction industry" (Davila Delgado et al., 2020, p. 17), it is expected that, as architecture is closely related to construction in the AEC industry, the innovative teaching strategy designed in this study will provide an applicable roadmap for educators in construction programs. Meanwhile, since innovations are "rapidly evolving" (Rankohi and Waugh, 2013, p. 17), computer experts may develop more content-related AR systems in the near future (Diao and Shih, 2019). Thus, the findings of this study will serve as a valuable reference for other researchers.

Creating a Prototype of Teaching Hands-On Skills

This exploratory research leads me to propose a potential prototype of teaching hands-on skills that other educators could follow to create their unique pedagogical intervention for teaching specific hands-on skills using particular innovations. Since there are numerous types of hands-on skills learners need to learn in classrooms, I use the model-making assignment from our architectural program as an example to explain the prototype below.

First, educators decide what type of hands-on skill to teach in class, which must be related to a specific assignment. Educators must dissect the learning content into small steps or components, select and simplify the required learning step(s), and identify the specific hands-on skill they want to deliver. The skill identified should only be a part of the whole skill set needed to complete such an assignment, as the available AR may have technical restraints that prevent the whole set of skills from being deployed. Besides, resource limitations may pose challenges to educators in designing and implementing this AR learning activity, such as not having access to the required equipment. In my research, the assignment required that each learner build a physical wood frame house model based on their own residential design drawings; my research aimed to explore the learning of model-making hands-on skills through a wall panel with only several studs and one opening, and it was not for an entire house model. However, learning the hands-on model-making skills from this experiment should empower students to construct the entire house model.

Second, finding and testing a proper innovation is the second crucial task for educators. Educators should learn and evaluate the tool before conducting the research. My personal learning journey suggests that the step of intensive reading and constant evaluation is the most challenging. I spent the past five or six years searching for a solution to support teaching hands-on skills remotely. I started by reading technology news from various sources, such as PCMag (https://www.pcmag.com/), searching academic journals, such as Procedia Computer Science (https://www.sciencedirect.com/journal/procedia-computer-science), later expanding my readings to projects that conducted in other academic disciplines, such as Engineering projects that published in Journal of Trends in Higher Education (https://www.mdpi.com/), and gradually narrowing down to AEC field, such as Journal of Construction Engineering and Management (https://ascelibrary.org/journal/jcemd4). The intensive reading and constant searching enabled me to envision a tool with the potential to achieve what I wanted.

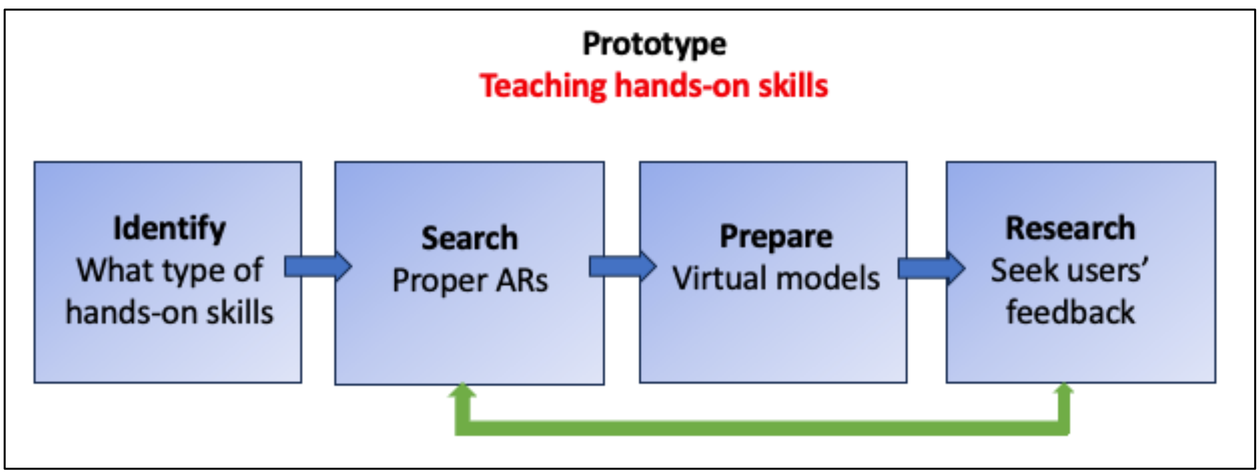
Third, educators must prepare the visual 3D model for hands-on skills learning. The 3D model must be created in professional 3D software to establish a virtual object base, with each individual component built up correctly and precisely according to the learning materials so that the renderers can add patterns for each individual element. In my research, the 3D model must be rendered with wood grain patterns through professional rendering software, with each element being rendered with wood grains based on the correct direction of the wood grains so that the users can differentiate each wood member by its grains; next, the file extension of this 3D model must meet the configuration requirement for the AR platform intended for use. Alternatively, educators can remotely purchase suitable 3D models created by other creators through various online modelling platforms, such as Sketchfab (https://sketchfab.com/store), or search for useful 3D models through OER (Open Educational Resources) resources, such as OER Commons (https://oercommons.org/oer). Finding an existing virtual 3D model that exactly meets the teaching requirement may be the second major challenge for most educators as the specific 3D model used in teaching such specific hands-on skills may not be produced by 3D model creators yet. However, educators can consider adopting a 3D model that is similar to what they envision. Still, they must inspect such a model and decide whether this model consists of similar learning content and can be used to deliver the same learning outcomes.

Finally, educators must conduct research that seeks learners' perspectives. The research design should empower the contribution of in-depth and constructive feedback from research participants.

Figure 26 below illustrates the steps of the prototype of teaching hands-on skills.

Figure 26

Graphic Illustration of the Prototype of Teaching Hands-On Skills



Note. The blue arrow direction indicates the workflow direction. The two green arrows show that users' feedback influences the AR selection, and the AR selected impacts the users' experience.

Working with a Buffer Faculty

When CC's REB asked me to find a research assistant, I did not think much about who to look for. However, the more I interacted with the buffer faculty, the more I realized that finding the right person was crucial. Also, the more specific a study is, the greater the challenge of finding an appropriate buffer. In the “Limitations” section below, I discuss five challenges regarding finding a buffer faculty.

Limitations

Technology Limitations

Personal Digital Devices. The challenge is obtaining the appropriate equipment to experiment with the AR in this research. Considering the inclusiveness of research and teaching, I did not specify what type of smartphone or computer research participants should use. This consideration inconvenienced one research participant as this student grew up in a region where only Android and Windows equipment was available, as the second AR tool was developed solely for Apple devices.

Software Service. The project site could not provide technical support for my study as the new AR applications or any software add-ins could not be installed on the college’s shared computers. Based on my experience working with EON (Lu, 2022a), I got technical support from the software company and their software engineers when we encountered technical issues. Thus, when one research participant first discovered the pay subscription issue using the second AR tool, I contacted the software company and got advice immediately. However, their suggestion to ask our student participants to input their financial information to obtain free access was rejected by the research and faculty participants.

Use of the Internet. Cohen et al. (2018) already specified that one of the drawbacks of using the Internet is that one has “no control over the experimental conditions and environment in which the involvement takes place” (p. 415). Employing the Internet to conduct this study proved to be excellent overall, but it did bring undesired outcomes. For example, one connection problem occurred during the first MS Teams meeting between research participant A and me. A was using CC's public Wi-Fi while sitting in the common hall full of students at one campus. Too many students using the same source of Internet network simultaneously might cause low bandwidth issues (Nakutavičiūtė, 2022), resulting in inaccessibility or low quality of the online experience.

Cost. As discussed in the previous chapter, the cost factor impacts what AR tool(s) educators should adopt in teaching. Finding an application that offers free access to learners or is compatible with existing educational platforms used in the academic program enhances user experiences. Educators must also consider whether the chosen innovation requires any additional equipment other than a smartphone to operate. For example, a headset is generally needed to experiment with VR.

Researcher Limitations

Challenges in Finding Voluntary Participants. Based on my prior research experiences at the project site, one drawback of recruiting volunteers for this architectural program was that students were unfamiliar with conducting research, so the number of interested participants was limited. For example, in one of the survey studies (Lu, 2023a) I conducted in the Fall 2023 semester, only four voluntary responses from 58 students in the course were submitted within four weeks. I added two extra weeks and wished to obtain more responses, but my efforts failed. To increase the response rate for the current study, I adopted some practical recruiting strategies suggested by the CC REB team (S. Kishore, personal communication, November 6, 2023). For instance, I explained in the letter of Invitation to Participate to potential research applicants that their contribution and time would be compensated with an amount that had been suggested and approved by CC REB. I also set up tiers for each phase of data collection to ensure those "who do one or more or all are still eligible to get all forms of compensation" (S. Kishore, personal communication, November 6, 2023). Still, I was unsurprised by the low research application rate. Out of 454 students enrolled in the current semester (L. Zhou, personal communication, September 17, 2024), the buffer faculty received eight applications on time and one late submission. While the response rate was less than two percent, I had enough research participants for my study. Besides, the buffer faculty and I were concerned that finding more research participants might be challenging because the experiment process might put too much pressure on the students as the workload in our architectural program was notably heavy.

Challenges When Interacting with Research Participants. An issue that took the buffer faculty and me over three weeks to resolve was that one research participant quit the research without notifying us, and left us wondering about their research progress. Eventually, the buffer faculty discovered this student's health-related issue through other faculty members. After I consulted with CC REB and waited for another week, the buffer faculty asked this participant whether continuing this research was possible. Even though dropouts are normal in research studies and were expected in the design of my study, the buffer faculty wondered whether a proper mechanism existed so that research participants could communicate with the researcher or the buffer faculty promptly.

Challenges in Finding a Buffer Person. Finding a buffer faculty member for my specific research presented five challenges. First, from the academic viewpoint, this person must know how this program works, such as what courses it offers each semester. Also, this person must know how this program operates, such as what program routes it offers and what type of students are enrolled in each of these program routes. Second, from the industry viewpoint, this individual must possess a deep understanding of the building industry and the trends in the AEC field and must recognize the importance and urgency of our architectural students learning about innovations while in school. Third, from the research viewpoint, this individual must understand my research and the correlation between my research objective and the course content. This person must also know students' characteristics and academic performances and understand the importance of finding reliable participants in research. In addition, this person must be fair to every student. Fourth, from the administration's perspective, this person should be someone the CC REB will trust and approve. Seeking an administrative staff member in our architectural program to act as a buffer person was not ideal because an administrative person might know how the architectural program works, but does not have knowledge of the building industry, either in the workplace or the classroom. Fifth, from a personal value standpoint. I did not discuss compensation with the buffer faculty when inviting him to embark on this recruitment journey. Neither the buffer faculty nor I could project how many hours the process would need. Therefore, this person must have a good heart, be willing to contribute their own time and help others, and have an authentic interest in research. Questions about the compensation of this individual arose in conversation with my supervisors. I honestly did not think of this before. Should the buffer faculty be compensated using an hourly rate or as a whole project? How much was the hourly rate fair to recognize the effort contributed by this individual? Reflecting on the whole research process now, from screening research applicants before the research started to compensating each participant at the end of this research, I realized how many hours the buffer faculty member had contributed, and I am greatly indebted to him.

Recommendations

Research

Design-based research (DBR). DBR is a practical and effective approach for exploratory studies like mine. It helped me design my research and achieve my research goal. I aimed to explore the possibility of adopting AR technology to assist students in developing hands-on model-making skills at a distance. In my study, I adopted a DBR approach. Specifically, I used the DBR concept to design and evaluate the research intervention. I designed an intervention with a series of steps to test the innovations. According to McKenney and Reeves (2013) and Shattuck and Anderson (2013), DBR is a flexible, iterative, and effective process that enables researchers to design and evaluate educational research. The iterative nature of DBR enabled me to collect student participants' feedback, study their perspectives, revisit my original research and intervention designs, and eventually revise them or add additional strategies to improve my study results. I used TAM and a portion of the SECTIONS model to evaluate the AR tools used in the experiment.

Project Management. Finding a method to manage the project efficiently is crucial. Since participants had various academic and employment schedules and I wanted to accommodate their needs, every participant carried on their experiments according to their own timetables. In addition, the project progress was complicated, given that every participant had different digital literacy levels, the digital devices used were different, and the technical issues encountered while experimenting with the AR tool were unique. I found it challenging to keep track of who was doing what and at which stage. Since I was planning to have everyone experiment with the AR at the same time, I did not prepare a solid strategy to deal with a situation like that. However, the MS Teams environment allowed me to adapt quickly as described below. Also, since I adopted the MS Teams function to host the first online preparation meeting, participants have sent me various inquiries and messages through the Activity or Chat channel via the MS Teams platform during each iteration.

During the early stage of the project, I was occupied with finding a solution to this emerging situation. After deliberating strategies for several days, I determined that using the time stamp function provided by MS Teams would be the most effective and straightforward approach. Since each participant had one individual MS Teams channel with me, all our interactions, whether messages, photographs, or recordings, were stored in MS Teams. Both parties in each MS Teams could access these items, each with a specific time stamp that implied the conversational context. This function significantly helped me manage the project. I could quickly search for each participant's progress, such as what we had discussed before, what issues the participant encountered, when this happened, and so on. While I have used Gantt charts before, like TeamGantt (https://www.teamgantt.com/what-is-a-gantt-chart), for architectural project management and as a tracker for research projects, this technology was unnecessary. The one-on-one MS Teams channel helped me effectively manage each occurrence in this study. Best of all, MS Teams recorded every interaction at the exact times with all detailed correspondences.

Researchers

Project Float Time. Researchers should prepare additional time beyond the regular project float time. I allocated project float time while designing this study. Reflecting on my study after completion, I realized I must prepare more project float time in each stage because unexpected complications could arise during the research. For instance, I prepared float time for each approval procedure based on what I learned about the REB processing times available on AU and CC's websites, as well as my email conversations with REB officials from both institutions. I did not expect the CC REB to request that I find a buffer person to assist with recruiting research participants. Considering who would be an appropriate buffer candidate and finalizing this person took extra time in the REB process.

Another example is that I knew participants would be busy with various academic tasks, so I planned to start the experiment with a flexible time frame. Still, I could not have imagined that the project timeline would sprawl so widely; each participant commenced, experienced, and completed their experiments at different times. For instance, the project's starting time alone presented a significant challenge. Two participants started on different days in the same week; one dropped out without any notification, another started a week later, one postponed several more days, and another started almost one month apart. Additionally, since one participant dropped out, I had to find another replacement participant. I initially scheduled one week for each iteration and two weeks of float time for the project. In fact, the overall experimenting time spanned about ten weeks.

Interactions. In-depth interactions with each participant were critical in obtaining constructive feedback in my study. It had a small sample size of five research participants, but I had in-depth interactions with each participant. Each participant and I were connected almost daily when experimenting with the AR tools. We reconnected after I revised my intervention based on their progress reports or when I checked their availability at such a timeframe. My study used mixed methods, including three questionnaires and 15 progress reports, which enabled me to collect adequate quantitative data and abundant qualitative feedback from five participants. The progress reports improved the intervention and enhanced the experience and research outcomes.

Educators

Prototype. A prototype of teaching hands-on skills was developed after I completed this exploratory study. Educators can use the prototype to design their content-specific teaching intervention to explore whether specifically designed AR tools available from the commercial market can be integrated into teaching specific hands-on skills remotely. The prototype illustrates a straightforward process educators can follow to achieve their end goal. Certainly, to validate a prototype, researchers must go through "confirmatory research that looks at a large sample size for validation and impacts" (W. Wu, personal communication, October 28, 2024). Future research with a larger sample size will be necessary to prove a statistically significant value.

Lifelong and Life-wide Learning. Constant learning from various individuals and sources enhances my teaching career. Educators working in post-secondary institutions are experts in their academic disciplines and/or possess expertise in their respective industry backgrounds. Based on my experience, continuous learning through various situations and from different personnel and curiosity about a wide range of newly emerging topics play a critical role in designing and conducting my research. Interacting with different participants inspired me to refine my intervention, and I was influenced by their ideas and suggestions for the innovations adopted in my project. I also valued their feedback on enhancing my study and my future teaching. Particularly, individuals have shown an interest in trialling the AR, 3DWarehouse®, after I shared my research results with them. On the one hand, students in my two courses in the current semester are interested in conducting the AR experiment using their current semester-four Elementary School design project. Students believe the AR experience will equip them with new skills to aid them in job searching (two students, personal communication, January 13-15, 2025).

On the other hand, a professor teaching another section in the same semester-four design project is interested in adopting 3DWarehouse® in the current semester after learning about my research outcomes. Indeed, we are currently collaborating to explore how to redesign an existing assignment using new AR learning content to achieve the same learning objectives. The document I created to guide research participants in uploading self-created 3D models and navigating the platform to experience the AR will be used as part of the new assignment instructions. I will also create a webpage showing all the required steps to complete this new assignment. Once we complete the reconfiguration, this new AR assignment will be implemented across three sections in the current semester-four design course.

Industries

AEC industry. More research exploring learning various hands-on skills remotely is indispensable. The AEC field benefits significantly from adopting the BIM notion in business practice, such as developing the concepts, drafting the construction documentation, administering contracts, and managing construction site projects. While the 3D BIM digitally represents a structure and hosts various data about this structure (National BIM Standard, n.d.), it is typically only exhibited through a 2D computer monitor. With AR technology enabling superimposing the 3D models into the physical real world, every trade at the job site or the office could see their respective or whole virtual presentation with a true scale (Sanner, 2019). Although not every architecture office, engineering firm or construction company has incorporated AR technology into their practices, students who have gained AR experience in industry-relevant programs or schools will certainly have benefits when looking for jobs and working in the industry.

The AEC industry involves numerous hands-on skills, whether compulsory in the office environment or at the job site settings, and whether complex or simple. However, the scope of my study only covers a small portion of the hands-on skills required. AR technology also enables hands-on skills learning in a safe environment without time or location constraints; thus, more research similar to my study is needed. Hence, the AEC industry must encourage more research to explore learning various hands-on skills remotely, and my study provides a possible way of learning.

Architectural Software Industry. Based on participants' unanimous IU toward the AR functions powered by the 3D Warehouse® platform, it is recommended that educators in the Architectural field select this AR tool when conducting an AR experiment with their students. It is also recommended that architectural educators create their 3D models in SketchUp® or convert their models built from other file formats to the SketchUp® file format and render these models to be as accurate and realistic to the real learning content as possible.

Of course, if cost is not a concern or teaching institutions will cover the software subscription fees for all users, other specific AR platforms could be explored and adopted. Since users' digital literacy skills influence their experience and the IU, it is suggested that users receive special training before experimenting with a specific AR tool. Based on participants' feedback, it is also suggested that software developers consider the diverse backgrounds of potential users when developing innovations. These innovations should be designed to benefit society as a whole and not create further divisions among users.

Final Notes

I implemented an innovative intervention to explore empirically and experimentally whether specific AR(s) can assist in developing hands-on activities at a distance (Maxwell, 2004). The causal relationship between the planned intervention, the assumption, and the research outcome was solid (Maxwell, 2004). To find out whether teaching hands-on skills remotely through AR was practical, one of the fundamental concepts in the design of this project was that this research was built upon some prior knowledge possessed by the potential participants. For instance, participants studied specific construction concepts and acquired certain architectural knowledge before participating; additionally, participants used computers or smartphones before joining the project. These considerations ensured that confusion and information overload were minimized in the experiment.

Creswell and Poth (2018) proposed that project participants should be allowed to have their voices heard and opinions counted. Qualitative aspects of this research design ensured that the participants were engaged throughout the research process and participated in democratic conversations with me. In addition, I interacted asynchronously with each project participant, communicated with them to learn about their views and evaluated whether certain types or degrees of new learning were constructed through the AR experiment. I also collected data in various forms to understand the situation and users' feedback. I was interested in obtaining specific knowledge, such as how project participants reacted to the intervention, how they felt about their learning process before the intervention, and how it might affect their new learning experience and thoughts. Participants freely voiced their opinions and feelings about using the intervention to develop hands-on skills remotely.

Moreover, the intervention design included a series of steps with specific sequences, employing specific innovations and learning materials. Designing an intervention that involved several technologies resulted in the emergence of unexpected technical issues during the research process. I used a design-based research approach to designing, conducting, and evaluating the intervention. The process was iterative and participant-oriented. The iteration cycle of the intervention design ensured that project participants could fully understand and test the intervention. Most importantly, it empowered participants' voices to be heard and opinions counted. Adopting this design-based research approach allowed for adaptation in response to ongoing data collection and analysis.

Collecting and analyzing current data enabled me to consolidate a conclusion for my research. Collecting and analyzing past data helped me to explain why I wanted to conduct the current study and to ensure that my research would not be a structure without a solid foundation. The findings of this study relied on the contributions of each research participant, who provided their thoughts and suggestions through their written reports and responses to questionnaires. The outcomes of my research not only guide the next step of my teaching practice but also create a reference roadmap for other educators who want to adopt AR in teaching hands-on skills remotely.

Summary of Chapter 7

In this chapter, I introduced the significance of my research by first explaining how the data collected answered my overarching research question. Then, I presented a prototype of teaching hands-on skills that could assist other educators who want to use AR to teach hands-on skills at a distance. I also explained the limitations of this study. I reviewed my overall research design and its outcomes, and I presented my recommendations related to research, researchers, educators and industries.

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Appendix A: Invitation to Participate

Developing Hands-On Model-Making Skills Remotely Through Augmented Reality in Architectural Technology Program

July 12, 2024

Principal Investigator (Researcher)	Supervisors
Yi Lu, Candidate, Doctor of Education in Distance Education, Email: ylu65@my.centennialcollege.ca	Dr. Cindy Ives Professor Emerita, Distance Education Athabasca University, Canada Email: cindyi@athabascau.ca Dr. Mohamed Ally Professor, Faculty of Humanities and Social Sciences Researcher, Technology Enhanced Knowledge Research Institute (TEKRI) Athabasca University, Canada Email: mohameda@athabascau.ca

My name is Yi Lu, and I am a Doctor of Education (EdD) program student at Athabasca University. As a requirement to complete my degree, I am conducting a research study to investigate whether augmented reality (AR) can assist research participants in developing hands-on model-making skills remotely in an architectural program. I am conducting this project under the supervision of Dr. Ally and Dr. Ives.
I invite you to participate in this project because you are studying in an Architectural Technician/Technology program and learning wood frame structure.

The purpose of this research project is to explore if an intervention would assist in developing hands-on skills remotely, specifically, how hands-on model-making skills can be developed via AR. I seek feedback from you, the volunteer research participants, about the quality of the intervention as a remote learning solution. In this study, the intervention is integrating AR into course learning materials. You and other volunteer research participants will use one or two selected ARs to learn hands-on skills that should help you to construct a physical partial wood-frame wall panel at a distance.

Your participation in this project will involve four steps in each part of the research. This research has two parts, each including the same four steps. The first step is to join online audio-recorded Microsoft Teams meetings through Centennial College's official Microsoft Office Teams platform and complete a pre-AR experience questionnaire deployed through the Microsoft Office Forms platform. The second step is to experiment with the interventions and take notes using a smartphone and computer. The third step is to reflect on your experience and provide written feedback through the Microsoft Office Teams platform. The last step is to complete one first-AR experience and one second-AR experience questionnaire, both deployed through the Microsoft Office Forms platform. This research will be conducted entirely online. The time commitment is estimated at five to ten hours. Each step may take approximately 10–20 minutes. The time for all team meetings will be arranged to fit your schedule. After each experimental period, you may complete all reflections, written reports and online questionnaires.

All information you provide during the study will be saved and secured in Centennial College's Microsoft Office Suites system. All questionnaire data submitted in the Microsoft Forms is anonymous. All data will be aggregated and reported as group data. Your identity will never be associated with your responses, and no individual will be identified in any presentation or publication. The college's Microsoft Suites system employs two-step password sign-in authorization techniques, ensuring the data stored in the College cloud is secured. Analytical information and transcribed files are stored on my computer with password protection; only I can access them. All data will be stored for five years after the research is completed and will be deleted after five years. The completed research report will include screenshots of online videos or product pictures of the models to clarify the research process or illustrate the research results. However, you will be notified in advance whether any images of your finished physical wood panel wall will be chosen, and proper citations will be made. Video screenshots will only show the AR tool experience and never your face.

The research should benefit you and the academic community. You will have a unique opportunity to explore an innovative way to study and comprehend complex and abstract AEC (Architecture, Engineering, and Construction) knowledge and cutting-edge AR tools. Additionally, you will gain a rare opportunity in a college environment to learn how research is conducted and contribute to enhancing an innovative teaching and learning strategy by providing feedback. The experience gained from this experiment can be applied or transferred to other academic areas and subjects. This research will benefit the teaching profession by setting an example of how to adopt AR in teaching hands-on skills at laboratories and promote educational equity by empowering learners in remote regions to develop essential hands-on skills remotely. I do not anticipate you will face any risks as a result of participating in this research. Your time will be compensated per the approval of two research ethics boards from Athabasca University and Centennial College. Upon completing the entire research, you will receive CAD100, paid through a Centennial College bookstore gift card. If you leave the study before completion, you will receive a $25 Centennial College bookstore gift card for each completed questionnaire. If you reside outside of Ontario during the study, an e-transfer option is available.

Thank you for considering this invitation. If you have any questions or would like more information, please contact me (the principal investigator) by e-mail at ylu65@my.centennialcollege.ca or my supervisors, Dr. Ally mohameda@athabascau.ca and Dr. Ives cindyi@athabascau.ca. Students who are interested in becoming research participants must email/register with Professor Francis Lapointe at flapoint@my.centennialcollege.ca five business days after receiving this Invitation, and the screening will be conducted by Professor Francis Lapointe.

Thank you.

Yi Lu

This project has been reviewed by the Athabasca University Research Ethics Board. Should you have any comments or concerns about your treatment as a participant, the research, or ethical review processes, please contact the Research Ethics Officer by e-mail at rebsec@athabascau.ca or by telephone at 780.213.2033. In addition, this project has been reviewed by the Centennial College Research Ethics Board. Should you have any comments or concerns about your treatment as a participant, the research, or ethical review processes, please contact the Research Ethics Officer by e-mail at ethics@centennialcollege.ca.

Appendix B: Informed Consent Form

Developing Hands-On Model-Making Skills Remotely through Augmented Reality in Architectural Technology Program

August 15, 2024

Principal Investigator (Researcher)	**Supervisors**
Yi Lu, Candidate, Doctor of Education in Distance Education, Email: ylu65@my.centennialcollege.ca	Dr. Cindy Ives Professor Emerita, Distance Education Athabasca University, Canada Email: cindyi@athabascau.ca Dr. Mohamed Ally Professor, Faculty of Humanities and Social Sciences Researcher, Technology Enhanced Knowledge Research Institute (TEKRI) Athabasca University, Canada Email: mohameda@athabascau.ca

You are invited to take part in a research project entitled "Developing Hands-On Model-Making Skills Remotely through Augmented Reality in Architectural Technology Program."

This form is part of the process of informed consent. The information presented should give you the basic idea of what this research is about and what your participation will involve, should you choose to participate. It also describes your right to withdraw from the project. In order to decide whether you wish to participate in this research project, you should understand enough about its risks, benefits and what it requires of you to be able to make an informed decision. This is the informed consent process. Take time to read this carefully as it is important that you understand the information given to you. Please contact the principal investigator, Yi Lu, if you have any questions about the project or would like more information before you consent to participate.

It is entirely up to you whether or not you take part in this research. If you choose not to take part, or if you decide to withdraw from the research once it has started, there will be no negative consequences for you now, or in the future.

Introduction

My name is Yi Lu, and I am a Doctor of Education (EdD) program student at Athabasca University. As a requirement to complete my degree, I am conducting a research study to investigate whether augmented reality (AR) can assist research participants in developing hands-on model-making skills remotely in an architectural program. I am conducting this project under the supervision of Dr. Ally and Dr. Ives.

Why are you being asked to take part in this research project?

You are being invited to participate in this project because you are studying in an Architectural Technician/Technology program and learning wood frame structure.

What is the purpose of this research project?
The primary purpose of this study is to investigate whether AR can assist student research participants in developing hands-on model-making skills remotely in an architectural program. Exploring student participants' experiences will provide information on adopting innovative and situation-appropriate pedagogical approaches in future teaching in architectural programs and other academic programs in AEC (Architecture, Engineering and Construction).

What will you be asked to do?
Your participation in this project will involve four steps in each part of the research. This research has two parts, each including the same four steps. The first step is to join online audio-recorded Microsoft Teams meetings through Centennial College's official Microsoft Office Suites and complete a pre-AR experience questionnaire deployed through the Microsoft Forms platform. The second step is to experiment with the interventions and take notes using a smartphone and computer. The third step is to reflect on your experience and provide written feedback through the Microsoft Office Teams platform. The last step is to complete one first-AR experience questionnaire after the first-AR experience and one second-AR experience questionnaire after the second-AR experience, both deployed through the Microsoft Forms platform.

The research is entirely conducted online through Centennial College's official Microsoft Office Suites. Throughout the entire process, you will only interact with me privately and in a one-to-one format on Centennial College's official Microsoft Office Suites. The research is not part of any of your current courses, is not associated with any grade items in any courses in the current semester, and will take place outside of your class time. Each step will be scheduled for your convenience.

To participate in this study, you will need to use a smartphone and/or a computer. If you do not have your own computer, Centennial College also provides computers for its students to use across all campuses.

Students who are interested in becoming research participants must email/register with Professor Francis Lapointe at flapoint@my.centennialcollege.ca and the screening will be conducted by Professor Francis Lapointe.

This research will be conducted entirely online. The time commitment is estimated at five to ten hours. Each step may take approximately 10–20 minutes. The time for all team meetings will be arranged to fit your schedule. After each experimental period, you may complete all reflections, written reports and online questionnaires.

What are the risks and benefits?
I do not anticipate you will face any risks as a result of participating in this research. The research should benefit you and the academic community. You will have a unique opportunity to explore an innovative way to study and comprehend complex and abstract AEC (Architecture,

Engineering, and Construction) knowledge and cutting-edge AR tools. Additionally, you will gain a rare opportunity in a college environment to learn how research is conducted and contribute to enhancing an innovative teaching and learning strategy by providing feedback. The experience gained from this experiment can be applied or transferred to other academic areas and subjects. This research will benefit the teaching profession by setting an example of how to adopt AR in teaching hands-on skills at laboratories and promote educational equity by empowering learners in remote regions to develop essential hands-on skills remotely.

Your time will be compensated per the approval of two research ethics boards from Athabasca University and Centennial College. Upon completing the entire research, you will receive CAD 100, paid through a Centennial College bookstore gift card. If you leave the study before completion, you will receive a $25 Centennial College bookstore gift card for each completed questionnaire. If you reside outside of Ontario during the study, an e-transfer option is available.

Do you have to take part in this project?

As stated earlier in this letter, involvement in this project is entirely voluntary. Throughout the entire research period, you may withdraw from participation at any time without giving any reason or worrying about any consequence. If you participate, you can refuse to answer any questions. No one will know if you are participating, and your participation or withdrawal will not affect your grade. If you are registered with Centennial College's CALCS (The Centre for Accessible Learning and Counselling Services), all existing accommodations will apply when working on this study.

Once you complete and submit questionnaires digitally through Centennial College's official Microsoft 365 Office Suites (Forms platform), the data collected cannot be removed as all data in the Forms platform becomes automatically integrated with other data submitted by other research participants. For documents or feedback submitted on Centennial College's official Microsoft 365 Office Suites (Teams platform), you can request the removal of your data up to one week after the completion of the second iteration. After this point, all data will be integrated, and individual removal will not be possible.

How will your privacy and confidentiality be protected?

The ethical duty of confidentiality includes safeguarding participants' identities, personal information, and data from unauthorized access, use or disclosure. All information you provide during the study will be saved and secured in Centennial College's Microsoft Office Suites system. All questionnaire data submitted in the Microsoft Forms is anonymous. All data will be aggregated and reported as group data. Your identity will never be associated with your responses, and no individual will be identified in any presentation or publication. The college's Microsoft Suites system employs two-step password sign-in authorization techniques, ensuring the data stored in the College cloud is secured. Analytical information and transcribed files are stored on my work computer with password protection, and I am the only one who can access them. All data will be stored for five years after the research is completed and will be deleted after five years.

How will my anonymity be protected?

Anonymity refers to protecting participants' identifying characteristics, such as name or description of physical appearance. The completed research report will include screenshots of online videos or product pictures of the models to clarify the research process or illustrate the research results. However, you will be notified in advance whether any images of your finished physical wood panel wall will be chosen, and proper citations will be made. Video screenshots will only show the AR tool experience and never your face. If anonymity is desired, I assure you that every reasonable effort will be made to ensure your anonymity; you will not be identified in publications without your explicit permission.

How will the data collected be stored?
The signed consent forms, the notes you created, and all questionnaire data will be kept and safeguarded in Centennial College's official Microsoft 365 Office Suites, with two-step authentication, for five years. I will be the only person who has access. After that, all information will be deleted permanently from Centennial College's official Microsoft 365 Office Suites. In addition, I will download all the information and save it onto an external hard drive. I am the only person who has access to this hard drive. All information will be kept on the hard drive for five years. After that, they will be deleted permanently from this hard drive.

The data collected in this research project may be used in an anonymous form by me in subsequent research studies exploring similar lines of inquiry. Such projects will still undergo ethics review by the research-related Research Ethics Board. Any secondary use of anonymized data by me will be treated with the same degree of confidentiality and anonymity as in the original research project.

The researcher(s) acknowledge that the host of the online survey (Centennial College's official Microsoft 365 Office Suites Forms platform) may automatically collect participant data without their knowledge (i.e., IP addresses.) Although this information may be provided or made accessible to the researchers, it will not be used or saved without the participant's consent on the researcher(s) system. Further, because this project employs e-based collection techniques, data may be subject to access by third parties as a result of various security legislation now in place in many countries. Thus, the confidentiality and privacy of data cannot be guaranteed during web-based transmission.

This study will use (Centennial College's official Microsoft 365 Office Suites Teams platform) to collect data, which is an externally hosted cloud-based service. When information is transmitted over the internet, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies or hackers). Further, while the researcher(s) will not collect or use IP address or other information which could link your participation to your computer or electronic devices without informing you, there is a small risk with any platform such as this of data that is collected on external servers falling outside the control of the research team. If you are concerned about this, we would be happy to make alternative arrangements (where possible) for you to participate, perhaps via telephone. Please contact Yi Lu for further information. Recordings (audio/video) will also be saved in a password-protected file on my local work computer with password protection.

Please note that participants are expected to agree not to make any unauthorized recordings of the content of a meeting and data collection session.

Who will receive the results of the research project?
The existence of the research will be listed in an abstract posted online at the Athabasca University Library's Digital Thesis and Project Room, and the final research paper will be publicly available. Direct quotations or personally identifying information will not be reported; reporting is only in aggregate or summarized form. Audio/video recordings will not be used in the dissemination of the research. The report of this research project will be available on the course-related website or provided to participants after the project is complete.
The results (paper) of this research will be available upon request through Centennial email and/or online in Athabasca University's Digital Thesis Room.
https://dt.athabascau.ca/jspui/handle/10791/2

I plan to present my study at specific academic conferences, such as "2025 Graduate Student Research Conference", Centennial College's "Teaching and Learning Symposium 2025," and other conferences that are related to the AEC industry, such as "BIM & Digital Construction 2025." I will also share my study in the "Teaching and Learning Digest Call for Entries," managed by the Centre for Faculty Development and Teaching Innovation, Centennial College.

Who can you contact for more information or to indicate your interest in participating in the research project?
Thank you for considering this invitation. If you have any questions or would like more information, please contact me (the principal investigator) by e-mail at ylu65@my.centennialcollege.ca or my supervisors, Dr. Ally mohameda@athabascau.ca and Dr. Ives cindyi@athabascau.ca. If you are ready to participate in this project, please complete and sign the attached Consent Form and email it to Professor Francis Lapointe one week (five business days) after receiving this Informed Consent Form.

Thank you.

Yi Lu

This project has been reviewed by the Athabasca University Research Ethics Board [REB File # 9371]. Should you have any comments or concerns about your treatment as a participant, the research, or ethical review processes, please contact the Research Ethics Officer by e-mail at rebsec@athabascau.ca or by telephone at 780.213.2033. In addition, this project has been reviewed by the Centennial College Research Ethics Board. Should you have any comments or concerns about your treatment as a participant, the research, or ethical review processes, please contact the Research Ethics Officer by e-mail at ethics@centennialcollege.ca.

Informed Consent

Your signature on this form means that:

- You have read the information about the research project.
- You have read the information about the research project.
- You have been able to ask questions about this project.
- You are satisfied with the answers to any questions you may have had.
- You understand what the research project is about and what you will be asked to do.
- You understand that you are free to withdraw your participation in the research project without having to give a reason, and that doing so will not affect you now, or in the future.
- You understand that if you choose to end your participation during data collection, any data collected from you up to that point will be retained by the researcher, unless you indicate otherwise.
- You understand that your data is being collected anonymously, and therefore cannot be removed once the data collection has ended.
- You understand that students who are interested in becoming research participants must email/register with Professor Francis Lapointe at flapoint@my.centennialcollege.ca and the screening will be conducted by Professor Francis Lapointe.
- You understand that this research is an independent project and is not associated with any grade items in any courses in the current semester. Therefore, there is no academic risk for research participants.
- You understand that you may ask for professional assistance through Centennial College's Mental Health Resource if you encounter mental challenges or discomforts. You can reach out to the online consultation through Centennial College's Mental Health Resource (https://www.centennialcollege.ca/student-life/student-services/student-experience-office/resources#:~:text=Mental%20Health%20and%20Wellness&text=For%20emotional%20support%20or%20if,456%2D4566%20or%20TEXT%2045645.) Or call the Mental Health and Wellness hotlines: 1888-377-0002 (for domestic students), 18444519700 (for international students).
- You understand that if you are registered with Centennial College’s CALCS (The Centre for Accessible Learning and Counselling Services), all existing accommodations will apply when working on this study.

	YES	NO
I agree to be audio-recorded	○	○
I agree to be video-recorded	○	○
I agree to be photographed	○	○
I agree to the use of direct quotations	○	○
I agree to the use of audio recordings in dissemination	○	○
I agree to the use of video recordings in dissemination	○	○
I allow my name to be identified in any publications resulting from this project	○	○

I allow **de-identified data** collected from me to be archived/deposited in Centennial College's official Microsoft 365 Office Suites system and Yi Lu's work computer	◯	◯
I allow **identifiable data** collected from me to be archived/deposited in Centennial College's official Microsoft 365 Office Suites system and Yi Lu's work computer	◯	◯

Your signature confirms

- You have read what this research project is about and understood the risks and benefits. You have had time to think about participating in the project and had the opportunity to ask questions and have those questions answered to your satisfaction.
- You understand that participating in the project is entirely voluntary and that you may end your participation at any time without any penalty or negative consequences.
- You have been given a copy of this Informed Consent form for your records; and
- You agree to participate in this research project.

____________________________ __________________________
Signature of Participant Date

Principal Investigator's Signature:

I have explained this project to the best of my ability. I invited questions and responded to any that were asked. I believe that the participant fully understands what is involved in participating in the research project, any potential risks and that they have freely chosen to participate.

____________________________ __________________________
Signature of Principal Investigator Date

Appendix C: General Notes for Questionnaires or Email Interviews

I will explain the following to study participants before they take questionnaires.

Guides for Questionnaires or Email Interviews

The pre-intervention questionnaires, the 1st post-intervention questionnaires and 2nd post-intervention questionnaires or email interviews will be distributed through Centennial College's MS Forms system in asynchronous and online formats.

Questions in Questionnaires or Email Interviews will be created in Centennial College's MS Forms, and a link will be sent to all volunteer study participants.

Creating questions and collecting data in MS Forms will ensure that all data collected is anonymous. No one will know who the participant is, and no one will know who answers what. All study participants will be notified and reminded that each questionnaire or email interview will have a completion deadline.

Preparation

Before sending out the pre-intervention questionnaire link to study participants, I will ensure study participants clearly understand the concept of augmented reality (AR): it is a type of technology that allows digital images and information to be displayed in the physical environment. https://www.investopedia.com/terms/a/augmented-reality.asp

Before participating in the AR experiment, I will ask study participants to watch two YouTube videos demonstrating how AR works and to use their smartphones to practice the game Pokémon. Also, study participants will be asked to watch the AR applications-related tutorials to become familiar with the selected AR applications.

1. Pokémon GO - Official Shared AR Experience Tutorial Trailer

https://www.youtube.com/watch?v=PMTC7vbdA9Y

2. ARki® 2.0 Augmented Reality Architecture

https://www.youtube.com/watch?v=iqfy7nOI22o

Filling In the Questionnaires or Email Interview

I will remind study participants to read each question carefully because some of the questions may look similar, but they inquire about different information. I will also remind study participants to reflect and write as much as possible for any “fill in the blank questions” to get a comprehensive picture of their views and experiences.

Reference Sources

The pre- and post-test questions from the following projects inspired the questions in my pre- and post-intervention questionnaire, or email interview.

Title of the Research	Authors and Year of Publication
Questions Related to Content and Innovations	
Augmented reality experience in an architectural design studio	Alp et al., 2023
Public participation in urban design with augmented reality technology based on indicator evaluation	Wang & Lin, 2023
A virtual education intervention to approximate hands-on learning: via task-centered learning praxis	Doran, 2022
Augmented Bridges: Investigating the potential of augmented reality for the design of a configurable bridge	Symeonidou et al., 2022
Comparing traditional and mixed reality-facilitated apprenticeship learning in a wood-frame construction lab	Wu et al., 2020
A combined effort in the standardization of user interface testing	Vianen et al., 1996
Questions Related to Learning Style	
An inquiry into the learning style and knowledge-building preferences of interior architecture students	Demirkan, 2016
Enhancing visualization skills, improving options and success (EnViSIONS) of engineering and technology students	Veurink et al., 2009
Nasa-Task Load Index (NASA-TLX); 20 Years Later	Hart, 2006
Index of Learning Styles Questionnaire, questions #7 and #21	Soloman & Felder, 1999
Questions Related to Investigation Format	
K-12 Saskatchewan Distance Education: Digging Deeper Into 21st Century Classrooms During a Pandemic	Shields, 2022

Appendix D: Pre-Intervention Questionnaire

This questionnaire will be deployed before the first iteration.

Questions	Answers
Please read each question carefully, as some of the questions are similar but NOT the same. What is Augmented Reality (AR): AR is a type of technology enabling digital images and information to be displayed in the physical environment. https://www.investopedia.com/terms/a/augmented-reality.asp	Likert Scale 1–5. 5 being strongly agree and 1 being strongly disagree.
Questions Related to Innovations	**Answers**
Q1. Tell me about your experience with various technologies (NOT including AR). (For example, I always use a cellphone to pay bank bills, I play Pokemon games using my cellphone, or I meet with my friends/families online via meeting tools like MS MS Teams, with my computer or with my cellphone, or I play video games with teammates from around the world, etc.)	Please elaborate on your answers (write more details).
Q2. Have you experienced augmented reality (AR) before (like, watching/playing AR games, or have you heard about it from other people).	Yes/No.
Q3. If you answered "yes" to the question above, can you specify which AR tool you have used before, AND explain what you know about AR.	Please elaborate on your answers (write more details).
Q4. I like to learn about and try AR technology.	Yes/No.
Q5. If you answered "yes" to the question above, can you specify the reasons? (For example, I always like to learn new technology; or, I think learning more new technologies is good for finding a job/studying at school, or I like to play games to relax or play with friends, and so on.)	Please elaborate on your answers (write more details).
Q6. Do you feel comfortable using or working with various technologies in life (social and academic)? Please share the reasons.	Please elaborate on your answers (write more details).
Questions Related to Architecture	**Answers**
Please read each question carefully, as some of the questions are similar but NOT the same.	
Q7. Have you taken any classes before, so you know the basics of architectural concepts/knowledge (For example, elevations, floor plans, construction details, wall assembly, wood frame structure, residential building, foundation, and so on?)	Yes/No.

Q8. If you answered "yes" to the question above, please specify which class(es) you have taken (For example, your high school's technology class, or, the ARCH101 class at the Architectural program at Centennial).	Please elaborate on your answers (write more details).
Q9. How would you rate your level of understanding of architectural knowledge (For example, elevations, floor plans, construction details, wall assembly, wood frame structure, residential building, foundation, and so on). I have a good understanding of architectural knowledge.	Likert Scale 1–5.
Q10. How would you rate your level of understanding of reading architectural drawings (For example, reading and understanding plans/elevations/sections/3D perspectives). I have a good understanding of architectural drawings.	Likert Scale 1–5.
Questions Related to Wood Framing Knowledge	**Answers**
Q11. How would you rate your level of understanding of wood frame residential/house structure knowledge (For example, wood studs, lintels, top plates, bottom plates, wood beams, and how different wood elements are built together to form the house structure). I have good wood frame structure knowledge.	Likert Scale 1–5.
Q12. Based on your experience, how hard did you have to study (mentally) to accomplish your level of performance? It is hard for me mentally to gain the wood-frame structure knowledge to reach my level of performance.	Likert Scale 1–5.
Questions Related to Constructing a Wood Framing House Model	**Answers**
Q13. Do you like to learn hands-on skills (making actual/physical objects)? Can you share the reasons?	Please elaborate on your answers (write more details).
Q14. How would you rate your level of manual (by hand) wood model-making knowledge? I have good knowledge of making physical wood models by hand.	Likert Scale 1–5.
Q15. How would you rate your level of manual (by hand) wood model-making skills? I am new to making physical wood models built by hand. (I have never made one before.)	Yes/No.
Q16. How would you rate your level of manual (by hand) wood model-making skills? I am good at making physical wood models built by hand.	Likert Scale 1–5.
Q17. Based on your experience: It is hard for me to physically construct the physical wood-frame structure.	Likert Scale 1–5.
Questions Related to Learning Style	**Answers**

Q18. I prefer to get new information from a) pictures, diagrams, graphs, or maps. b) written directions or verbal information. c) Both	Select your choice.
Q19. I prefer to study a) in a study group. B) alone. c) Both	Select your choice.

This is the end of the pre-intervention questionnaire. Thank you!

Appendix E: First AR Experience Questionnaire

This questionnaire will be deployed at the end of the first iteration.

Questions Related to Innovations	**Answers**
Q1. Overall, please share what you think about the quality of AR as a way to develop hands-on skills remotely online.	Likert Scale 1–5. 5 being strongly agree and 1 being strongly disagree.
Qa. I think AR is a good way to develop hands-on skills online, based on my experience with the intervention in the first iteration.	Likert Scale 1–5.
Qb. I think AR is an efficient way to develop hands-on skills online.	Likert Scale 1–5.
Qc. There was enough information provided by AR to enable me to understand the wood frame structure or the concepts better.	Likert Scale 1–5.
Qd. There was enough information provided by AR to enable me to improve my physical model-making skills.	Likert Scale 1–5.
Qe. I felt immersed in the AR environment when I was using the AR application.	Likert Scale 1–5.
Qf. I found this AR fun to use.	Likert Scale 1–5.
Qg. I think this AR tool is easy or simple to use to develop my hands-on skills remotely/online.	Likert Scale 1–5.
Qh. I get dizzy when using the AR tool.	Likert Scale 1–5.
Qi. I found the AR functions needed improvement.	Likert Scale 1–5.
Qj. Some functions of the AR did not work properly.	Likert Scale 1–5.
Qk. Interaction with the model through the AR tool is easy.	Likert Scale 1–5.
Ql. The AR tool makes the scale in the model-making process more understandable.	Likert Scale 1–5.
Qm. The AR tool makes the model more realistic.	Likert Scale 1–5.
Qn. The AR tool positively affects my model-making learning experience.	Likert Scale 1–5.
Q2. How much money have you spent in order to work on this project, such as purchasing model building materials or paying for the internet subscription? (in Canadian Dollar)	Please elaborate on your answers (write more details)
Q3. Do you have any other comments related to the AR application?	Please elaborate on your answers (write more details)
Questions Related to Architecture	**Answers**
Q4. Working with the AR tool helps develop my actual hands-on skills in making the actual physical building model remotely/online.	Likert Scale 1–5. Add one answer choice: “I don’t feel able to answer this question yet.”

Q5. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, this AR tool shows the relationships of various wood elements so I know I should place the wall wood studs on top of the bottom plate when I make the physical house model etc.)	Please elaborate on your answers (write more details).
Q6. Working with the AR tool helps improve my knowledge/understanding of hands-on skills in making the building model remotely/online.	Likert Scale 1–5. Add one answer choice "I don't feel able to answer this question yet."
Q7. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, this AR tool improves my understanding of the steps to build the actual physical house model, or, I understand more about wood frame structure concepts, or, I understand more about functions of various wood elements, etc.)	Please elaborate on your answers (write more details).
Q8. How much total (in Canadian dollars) did you spend to interact with the AR tool? (For example, I need to upgrade my internet connection so to interact with the AR tool)	Please elaborate on your answers (write more details).
Q9. If not mentioned in the above questions, do you have any comments or questions about your AR experience?	Please elaborate on your answers (write more details).
Questions Related to the Research Design	**Answers**
Q10. Questions Related to the Research Design	
Qa. There was enough information provided by the researcher/user manual/experiment to enable me to understand how to use AR better.	Likert Scale 1–5.
Qb. I needed to learn a lot of things before I could get going with this AR experiment.	Likert Scale 1–5.
Qc. The quality of the facilitation in supporting my learning in this experiment is good.	Likert Scale 1–5.
Q11. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, you believe that your performance would be better if you got more practice before starting the experiment, etc.)	Please elaborate on your answers (write more details).
Q12. I like to use my cellphone to gain new knowledge.	Likert Scale 1–5.
Q13. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I think using use my cellphone for learning is fun, or, using cellphones	Please elaborate on your answers (write more details).

for learning eases my anxiety in gaining new knowledge, etc.)	
Q14. Did you encounter any technical issues during the AR experiment, such as no Wi-Fi signal, no internet, low bandwidth, or no power? Or, did your smartphone have limited space to install/run AR apps.	Yes/No.
Q15. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q16. If not mentioned in the above questions, do you have any comments or questions about your AR experience?	Please elaborate on your answers (write more details).
Learning Preferences	**Answers**
Q17. I like short learning sessions.	Likert Scale 1–5.
Q18. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I like to read learning materials or watch learning videos for 10–20 minutes each, etc.)	Please elaborate on your answers (write more details).
Q19. I like to continue working without disruption.	Likert Scale 1–5.
Q20. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I like to work continuously on building a model without taking a break)	Please elaborate on your answers (write more details).
Q21. I like to work individually.	Likert Scale 1–5.
Q22. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q23. I like to work with peers/in a group environment.	Likert Scale 1–5.
Q24. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q25. I like to express my opinions to others.	Likert Scale 1–5.
Q26. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q27. What kind of format for expressing your ideas makes you feel most comfortable? And why?	Please elaborate on your answers (write more details).
Q28. I am interested in unusual experiences outside of my comfort zone, as long as they are safe.	Likert Scale 1–5.
Q29. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).

(For example, this coming new AR learning experience.)	
Q30. Have you ever worked in a small online group of learners before? Can you share your experience? Can you share the reasons?	Please elaborate on your answers (write more details).
Learning experiences	**Answers**
Q31. Did you really understand what you needed to do in this AR experiment? Can you share what you needed to do in this AR experiment?	Please elaborate on your answers (write more details).
Q32. Do you have more questions related to this coming new AR experience?	Please elaborate on your answers (write more details).

This is the end of the First AR Experience Questionnaire. Thank you!

Appendix F: Second AR Experience Questionnaire

This questionnaire will be deployed after the second iteration finishes. This questionnaire can be deployed as an email if study participants prefer.

Questions Related to Innovations	**Answers**
Q1. Overall, please share what you think about the quality of AR as a way to develop hands-on skills online remotely	Likert Scale 1–5. 5 being strongly agree and 1 being strongly disagree. (NASA's Task Load Index uses different wording.)
Qa. I think AR is a good way to develop hands-on skills online, based on my experience with the intervention in the second iteration.	Likert Scale 1–5.
Qb. I think AR is an efficient way to develop hands-on skills online (for example, increasing the speed of learning/developing).	Likert Scale 1–5.
Qc. After the experiment, I like to use AR to learn hands-on skills remotely/online.	Likert Scale 1–5.
Qd. There was enough information provided by AR to enable me to understand the wood frame structure or the concepts better.	Likert Scale 1–5.
Qe. There was enough information provided by AR to enable me to develop my physical model-making skills.	Likert Scale 1–5.
Qf. I felt immersed in the AR environment when I was using the AR application.	Likert Scale 1–5.
Qg. I found this AR fun to use.	Likert Scale 1–5.
Qh. I think this AR tool is easy or simple to use to develop my hands-on skills remotely/online.	Likert Scale 1–5.
Qi. I think AR provides a better representation of learning process.	Likert Scale 1–5.
Qj. I get dizzy when using the AR tool.	Likert Scale 1–5.
Qk. I found the AR functions needed improvement.	Likert Scale 1–5.
Ql. Some functions of the AR did not work properly.	Likert Scale 1–5.
Qm. Interaction with the model through the AR application is easy.	Likert Scale 1–5.
Qn. The AR tool makes the scale more understandable in the model-making process.	Likert Scale 1–5.
Qo. The AR tool makes the model more realistic.	Likert Scale 1–5.
Qp. The AR tool positively affected my model-making learning experience.	Likert Scale 1–5.
Qq. Overall, I am satisfied with learning hands-on model making skills remotely/online.	Likert Scale 1–5.

Qr. Overall, I am satisfied with my learning experience.	Likert Scale 1–5.
Qs. I am satisfied with adding a new AR tool to my learning environment/course.	Likert Scale 1–5.
Q2. Do you like to learn hands-on skills remotely (learn to make actual/physical objects online, and then create the actual/physical objects)? Can you share the reasons?	Please elaborate on your answers (write more details).
Q3a. Would you recommend this AR to other architectural students?	Likert Scale 1–5.
Q3b. I would like to learn and use more AR tools in future courses.	Likert Scale 1–5.
Q4. How much money have you spent in order to work on this project, such as purchasing model building materials or paying for the internet subscription? (in Canadian Dollar)	Please elaborate on your answers (write more details).
Q5. Do you have any other comments related to the AR application?	Please elaborate on your answers (write more details).
Questions Related to Architecture	**Answers**
Q6. Working with the AR tool helped develop my actual hands-on skills in making the actual physical building model remotely/online.	Likert Scale 1–5.
Q7. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, this AR tool shows the relationships of various wood elements so I know I should place the wall wood studs on top of the bottom plate when I make the physical actual house model. etc.)	Please elaborate on your answers (write more details).
Q8. Working with the AR tool helps improve my knowledge/understanding of hands-on skills in making the building model remotely/online.	Likert Scale 1–5.
Q9. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, this AR tool improves my understanding of the steps to build the actual physical house model, or, I understand more about the wood frame structure concepts, or, I understand more about the functions of various wood elements, etc.)	Please elaborate on your answers (write more details).
Q10. Based on your experience, do you think AR is worth spreading to the architectural academic learning environment? (AR here is a general term, not specifically referring to the AR platform you used in this experiment.)	Likert Scale 1–5.

Q11. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I think AR is a good learning tool in learning new knowledge, or, I think AR is too complicated to be used in a class/learning environment, etc.)	Please elaborate on your answers (write more details).
Q12. How much total (in Canadian dollars) did you spend on building this physical model?	Please elaborate on your answers (write more details).
Q13. How much total (in Canadian dollars) did you spend to interact with the AR tool?	Please elaborate on your answers (write more details).
Q14. If not mentioned in the above questions, do you have any comments or questions about your AR experience?	Please elaborate on your answers (write more details).
Q15. Questions Related to the Research Design	**Answers**
Qa. There was enough information provided by the researcher/user manual/experiment to enable me to understand how to use AR better.	Likert Scale 1–5.
Qb. I needed to learn a lot of things before I could get going with this AR experiment.	Likert Scale 1–5.
Qc. The quality of the facilitation in supporting my learning in this experiment is good.	Likert Scale 1–5.
Qd. Contents listed on the Research Padlet are very helpful in knowing the research process and steps.	Likert Scale 1–5.
Q16. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I believe that my performance would be better if I had more practice before starting the experiment, etc.)	Please elaborate on your answers (write more details).
Q17. I like to use my cellphone to learn new knowledge.	Likert Scale 1–5.
Q18. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I think using my cellphone for learning is fun, or, using cellphone for learning eases my anxiety in learning new knowledge, etc.)	Please elaborate on your answers (write more details).
Q19. Did you encounter any technical issues during the AR experiment, such as no Wi-Fi signal, no internet, low bandwidth, or no power? Or, does your smartphone have limited space to install/run AR apps?	Yes/No.
Q20. If you answered the question above by choosing one of the options, can you specify the reasons? Please elaborate on your answers (write more details).	Please elaborate on your answers (write more details).

Q21. If not mentioned in the above questions, do you have any comments or questions about your AR experience?	Please elaborate on your answers (write more details).
Learning Preferences	**Answers**
Q22. I like short learning sessions.	Likert Scale 1–5.
Q23. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I like to read learning materials or watch learning videos for 10–20 minutes each, etc.)	Please elaborate on your answers (write more details).
Q24. I like to continue working without disruption.	Likert Scale 1–5.
Q25. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, I like to work continuously on building a model without taking a break)	Please elaborate on your answers (write more details).
Q26. I like to work individually.	Likert Scale 1–5.
Q27. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q28. I like to work with peers/in a group environment.	Likert Scale 1–5.
Q29. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q30. I like to express my opinions to others.	Likert Scale 1–5.
Q31. If you answered the question above by choosing one of the options, can you specify the reasons?	Please elaborate on your answers (write more details).
Q32. What kind of format for expressing your ideas makes you feel most comfortable? And why?	Please elaborate on your answers (write more details).
Q33. I am interested in unusual experiences outside of my comfort zone, as long as they are safe.	Likert Scale 1–5.
Q34. If you answered the question above by choosing one of the options, can you specify the reasons? (For example, this coming new AR learning experience.)	Please elaborate on your answers (write more details).
Q35. Have you ever worked in a small online group of learners before? Can you share your experience? Can you share the reasons?	Please elaborate on your answers (write more details).
Q36. Do you have more questions related to this new AR experience?	Please elaborate on your answers (write more details).
Q37. AR is suitable for online education.	Likert Scale 1–5.
Questions Related to NASA's Task Load Index	**Answers**

Q38. Mental demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, reading, etc.)? Was the task easy or demanding, simple or complex?	Likert Scale 1–5. 1 being extremely hard and 5 being extremely easy.
Q39. Physical demand: How much physical activity was required (e.g., cutting, trimming, putting wood pieces together, erecting wood pieces, setting wood pieces straight or stand, etc.)? Was the task easy or demanding?	Likert Scale 1–5. 1 being extremely hard and 5 being extremely easy.
Q40. Time demand: How much time pressure did you feel when experimenting with the AR? Was the pace slow, or did you need more time?	Likert Scale 1–5. 1 being more time is needed, somewhat more time is needed, neutral, the time is somewhat right, and 5 being time is perfect for me.
Q41. Effort: Based on your physical model-making experience, how hard did you have to work/study (mentally and physically) to accomplish your level of performance?	Likert Scale 1–5. 1 being extremely hard and 5 being extremely easy.
Q42. Performance: How successful do you think you were in accomplishing the goals of the task set by the researcher?	Likert Scale 1–5. 1 being very unsuccessful and 5 being very successful.

This is the end of the Second AR Experience Questionnaire. Thank you!

Appendix G: General Notes for Screening Research Participants

Terminology	Definition
Buffer Faculty	is someone who assists the researcher in screening and selecting the research participants.
Research Applicant	is someone who applies to this research after receiving the mass email of Invitation to Participate sent by the administrative office in the project site.
Research Participant	is someone who will participate this research after screening process is completed and submitting the signed Informed Consent Form to the screener.

Notes to the Buffer Faculty

Please do not tell each research applicant who the other research applicants are.

Thank you for helping the researcher with the screening process.

At the beginning of the Screening Process

At the beginning of the screening process, the buffer faculty, please share the following with applicants:

The researcher will have in-depth communications/interactions/collaborations with each research participant in a one-to-one setting.

The overall process is briefly described below: The researcher will introduce the project to each of you, and then you will follow the steps related to the intervention and try the intervention. Each of you will record your detailed experience and reflections on each step in the process and provide in-depth feedback in writing, with texts or graphic illustrations (such as screenshots); the researcher will then improve the intervention based on comments, and subsequently, you will take the 2nd round of the experiment.)

This research is primarily Qualitative research, mixed with some quantitative data. (**Qualitative research** collects and analyzes non-numerical and rich-in-detailed data to "understand concepts, opinions or experiences." https://www.scribbr.com/methodology/qualitative-research/). Thus, providing in-depth, constructive and thoughtful feedback to the researcher is critical to ensuring the project's success.

This research is scheduled to be conducted in October and November 2024; however, it may be extended to December 2024 if various research situations arise.

Criteria to be Used in Screening Research Participants

Criterion	Yes	No
The applicant is genuinely interested in the research topic.		
The applicant is willing to try different AR apps/approaches.		
The applicant is willing to dedicate sufficient time to explore and experiment with the AR apps/approaches.		
The applicant eagers to learn new skills.		
The applicant contributes their time, also makes flexible arrangements in participating learning activities.		
The applicant makes effort to complete assigned tasks or what they have started.		
The applicant puts in effort, overcomes challenges and finds solutions to archive a common goal.		
The applicant provides meaningful feedback, both positive and negative feedback, that can lead to finding solutions.		
The applicant articulates their experiences, thoughts, and suggestions clearly		
The applicant completes tasks they've agreed to and adheres to deadlines/schedules.		
The applicant is comfortable using smartphones, tablets, or other electronic devices that support AR apps/approaches.		
The applicant can complete a hand-on learning activity, such as building a wood stick model.		
The applicant is comfortable conducting learning activities online.		
The applicant has an overall grade of A and above in the ARCH Design and Project course in Winter2024 or Summer 2024 or Fall 2023.		

After Completing the Screening Process

After completing the screening, please do not tell each selected research participant who the other selected research participants are. Research participants will/should not know who the other researcher participants you choose are.

You can send the "Informed Consent Form" to each selected research participant. After they read, consider, ask questions, and sign and return the form to you, you can send the signed

Informed Consent Form to me and tell me the names and Centennial College email addresses of these research participants. At that point, each of these research participants and I will start the one-to-one communication.

Please also keep the records and contact information of other research applicants. If some selected research participants drop out during the research process, you can provide the researcher with different selections.

Thank you once again for helping the researcher with the screening process.

Appendix H: Email Interview Questions for the Screener (the Buffer Faculty)

Please answer the following questions. Thank you!

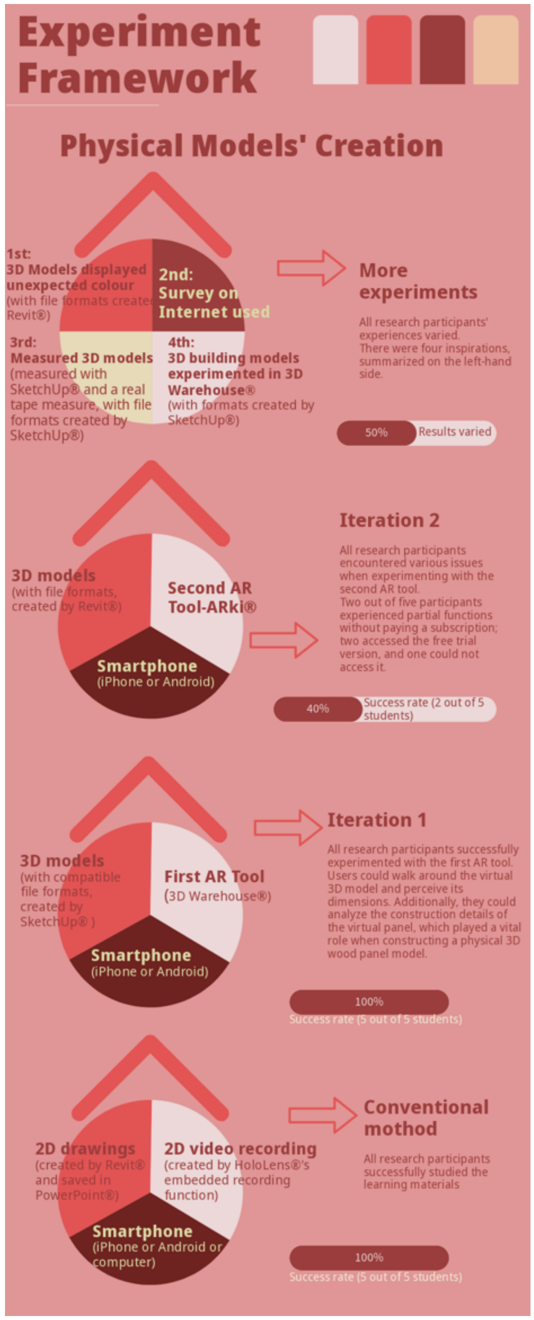
Questions	Answers
Have you encountered any challenges in the screening process?	
Can you share your thoughts about the screening criteria?	
Do you think your experience and knowledge, such as teaching or industrial experience, help screen research applicants?	
Did research applicants ask any questions or raise any concerns related to the screening process? If yes, can you briefly describe what were those?	
How did you communicate with research participants?	
What tools or software did you use to manage research participants' data?	
What changes will you recommend in order to improve the screening process?	

Reference Sources

The following source inspired the questions in the email interview for the buffer faculty.

Title of the Source	Authors and Year of Publication
Qualitative Inquiry and Research Design: Choosing Among Five Approaches	Creswell, J. W. & Poth, C. N., 2018

Appendix I: Infographic of Experiment Framework



This infographic was created with a template from Adobe Express® (https://www.adobe.com/uk/express/). The link to a larger PNG (Portable Network Graphic) version is: https://www.notion.so/Dissertation-Yi-Lu-Appendix-I-1a340851528280d2bc5cc6d9e021877f

Appendix J: Infographic of Findings

This infographic was created with a template from Adobe Express® (https://www.adobe.com/uk/express/). The link to a larger PNG (Portable Network Graphic) version is: https://www.notion.so/Dissertation-Yi-Lu-Appendix-J-1d140851528280d4ad59d6bcebb53214

Appendix K: Comparison of Time and Cost Factors

Time Aspect

Hands-On Model-Making Time		Assignment-Related Commute Time	
Conventional Method	AR-Assisted Method	Conventional Method	AR-Assisted Method
40 Hours	4 Hours	5-10 Hours/Week	0 Hour

Quantitative Data Comparison Of Time And Cost Factors Between The Conventional Hands-On Teaching method And The AR-Assisted Hands-On Teaching Method

Hands-On Model-Making Cost		Assignment-Related Commute Cost	
Conventional Method	AR-Assisted Method	Conventional Method	AR-Assisted Method
$60-250 CAD	$0-40 CAD	$6.6 CAD Round-Trip	$0 CAD

Cost Aspect

This infographic was created with a template from Adobe Express® (https://www.adobe.com/uk/express/). The link to a larger PNG (Portable Network Graphic) version is: https://www.notion.so/Dissertation-Yi-Lu-Appendix-K-1d140851528280318778e5b6e19bbafe

Appendix L: Comparison of the Time Needed to Build Two Different Types of Models

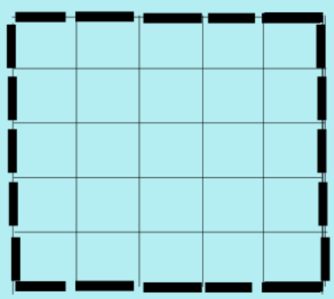
Potential Time Variances on Two Different Types of Models

	Time needed to build one wood wall panel model with approximate dimensions of 7'-6" W x 7'-3" H	Time needed to build a two-storey four-bedroom house model with approximate dimensions of 37'-6" W x 37'-6" L x 14'-6" H
AR-Assisted Method Creating a virtual 3D model, using SketchUp® or Revit®, for AR experiment	Researcher's projection: 1 hour	Researcher's projection: 4-8 hours
Conventional Method Creating a physical 3D model using physical materials	Reported by research participants: 4 Hours	Data obtained from baseline: around 40 Hours

Note: 1, W means Width, H means Height, L means Length.
2, Wall panel dimensions are from the Microsoft PowerPoint document in Tool 1 in Iteration 1.
3, One wall panel acts as a basic calculation unit in this comparison.
4, To get the most accurate comparison for model-making time, both for virtual and physical models, the house model dimensions are inspired by the model-making assignment and are similar to those dimensions.
5, The researcher's projection on the time needed to complete each model is based on students' average skill levels, and to the best of the researcher's ability.
6, The two illustrations below, house floor plan view adn house elevation view, show how to calculate the number of wall panels this house model has,
7, The two views below are for illustration purposes only; they are not to scale and do not represent a true architectural floor plan and elevation.

House Floor Plan View

Each side of the house is 37'-6", the width of each wall panel is 7'-6", thus, each side has five wall panels.

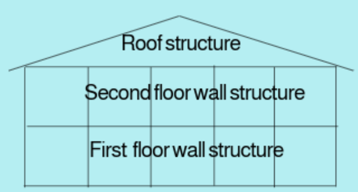


Based on the design dimensions and the illustration on the left-hand side:
Each storey has four sides and each side has five wall panels, so each storey has 20 panels. Thus, the two-storey house has 40 wall panels.
Additionally, this framing has several interior wall partitions.

Each thick line on the perimeter refers to the plan view of one wall panel, with 7'-6" W.
Drawing is not to scale.

House Elevation View

Each floor height is 7'-3", thus, the height of a two-storey house is 14'-6" (not including the roof structure height).



Based on the design dimensions and the illustration on the left-hand side:
Each elevation shows two floors, and each floor has five wall panels, totalling 10 panels. Thus, a two-storey framing with four elevations has 40 wall panels.
Additionally, this framing has roof rafters, ceiling joists, and floor joists for two floors.
Each square indicates one wall panel, with 7'-6" W x 7'-3" H
Drawing is not to scale

This infographic was created with a template from Adobe Express® (https://www.adobe.com/uk/express/). The link to a larger PNG (Portable Network Graphic) version is: https://www.notion.so/Dissertation-Yi-Lu-Appendix-L-1d8408515282803bb65ff9837574bc29

Appendix M: Athabasca University Ethics Certification

Athabasca University

CERTIFICATION OF ETHICAL APPROVAL

The Athabasca University Research Ethics Board (REB) has reviewed and approved the research project noted below. The REB is constituted and operates in accordance with the current version of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2) and Athabasca University Policy and Procedures.

Ethics File No.: **25778**

Principal Investigator:
Ms. Yi Lu, Doctoral Student
Faculty of Humanities & Social Sciences\Doctor of Education (EdD) in Distance Education

Supervisor/Project Team:
Dr. Cindy Ives (Co-Supervisor)
Dr. Mohamed Ally (Co-Supervisor)

Project Title:
DEVELOPING HANDS-ON CONSTRUCTION ON-SITE SKILLS REMOTELY THROUGH AUGMENTED REALITY IN ARCHITECTURAL TECHNOLOGY PROGRAM

Effective Date: August 08, 2024 **Expiry Date**: August 07, 2025

Restrictions:

Any modification/amendment to the approved research must be submitted to the AUREB for approval prior to proceeding. Any adverse event or incidental findings must be reported to the AUREB as soon as possible, for review.

Ethical approval is valid *for a period of one year*. An annual request for renewal must be submitted and approved by the above expiry date if a project is ongoing beyond one year.

An Ethics Final Report must be submitted when the research is complete *(i.e. all participant contact and data collection is concluded, no follow-up with participants is anticipated and findings have been made available/provided to participants (if applicable))* or the research is terminated.

Approved by: **Date: August 08, 2024**

Katie MacDonald, Chair
Faculty of Humanities & Social Sciences, Departmental Ethics Review Committee

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Athabasca University Research Ethics Board
University Research Services Office
1 University Drive, Athabasca AB Canada T9S 3A3
E-mail rebsec@athabascau.ca
Telephone: 780.213.2033

Appendix N: Centennial College Ethics Certification

CENTENNIAL COLLEGE

September 19, 2024

Yi Li
Faculty, SDRE
Centennial College
ylu65@my.centennialcollege.ca

REB application # 2024/25-07: "Developing Hands-On Construction On-Site Skills Remotely Through Augmented Reality In Architectural Technology Program"

Dear Yi,

The Centennial College Research Ethics Board involving Human Subjects has reviewed your application and provides approval for this above-named study. The approval is based on the following:

1. The Centennial REB must be informed of any protocol modifications as they arise
2. Any unanticipated problems that increase risk to the participants must be reported immediately
3. You have one year approval for the study; if needed, an annual renewal form will be required at that time
4. A **study completion** form is submitted upon completion of the project

Please note that you are responsible for obtaining any further Institutional Approvals that might be required to complete your project. TCPS2 states that it is the responsibility of the researchers to obtain necessary permission for secondary use of information for research purposes. Furthermore, the responsibility of privacy and confidentiality with regards to such data rests with the organization, whose principal responsibility is to safeguard entrusted information.

On behalf of the Research Ethics Board at Centennial, I would like to wish you every success with your project.

Sincerely,

Sowmya Kishore
Ex Officio Chair
Research Ethics Board Involving Human Subjects
Centennial College
Email: skishore@centennialcollege.ca
Tel: 416.289.5000 ext. 52318

See where experience takes you.