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ASSESSING THE POTENTIAL OF MIXED REALITY FOR LANDSCAPE ARCHITECTURE

BY

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THESIS

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ABSTRACT

Virtual reality (VR), mixed reality (MR), and augmented reality (AR) technology has improved over the last decade, and multiple industries have begun to utilize the technology. Some researchers claim that a collective term for virtual reality, mixed reality, and augmented reality should be “extended reality (XR).” In this paper, virtual reality and augmented reality are defined as mixed reality, and the term extended reality is not applied in the paper. The landscape architecture professional practitioners have also utilized mixed reality for specific processes, such as expressing the design idea to project participants through virtual reality. However, whether mixed reality could be applied to the design process as a designing tool, such as Rhino, is questionable. For exploring the potential functions that mixed reality could contribute to professional practice, this thesis mainly focuses on how mixed reality could be utilized in a landscape project and whether mixed reality could facilitate creativity. In the beginning, the literature review was done for collecting information about mixed reality and the general processes of a landscape architecture project. Next, the collected mixed reality tools potentially supportive of professional practice could be classified into seven categories. Some of the categories are tested out and evaluated in the paper. Afterward, a survey was distributed to practitioners to support the listed mixed reality potential contribution to landscape projects. After experiencing a mixed reality design process, the thesis summarizes findings and defined a summary of mixed reality’s potential. Mixed reality can somewhat be utilized in landscape projects. Future works should focus on spreading knowledge about mixed reality, developing more functions in mixed reality software specifically for landscape architecture, and exploring more strategies to improve augmented reality’s contributions in the construction stage.

ACKNOWLEDGMENTS

I need to, first of all, appreciate my Thesis Chair, Professor Conor O'Shea, for his assistance throughout the thesis. When I was looking for a professor who is willing to be my Chair, I thought it will be har for me to find because of my unique topic. However, Professor O'Shea decided to be my Thesis Chair even he dose not have expertise in MR. We worked together and explored the answers of the thesis questions. Moreover, in the end of the research, Prof. O'Shea still spared time to help with my work, even he has many works then.

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CHAPTER 1: INTRODUCTION

Background

The field of landscape architecture has been defined and noticed by the general public since Frederick Olmsted and Calvert Vaux designed Central Park in New York. Before the emergence of computers, landscape architects communicated design ideas to their colleagues or the public only through analog tools like pen and paper. In the 1960s, landscape architects began using primitive Geographic Information Systems (GIS to collect and search for data and record the data through mapping. In the 1980s, the earliest Computer Aid Design (CAD) enabled landscape architects to design in two-dimensions paperlessly.[1] Julius Faco, who was teaching landscape architecture as a professor at the University of Massachusetts in the 1980s, claimed that in the near future, landscape architects could work without paper.[2] In the 2000s, an increasing number of landscape practitioners started to utilize CAD in their workflows. According to Tai's research in 2002, 52% of the landscape architects drafted their projects using computers, and only 14.9% of landscape architects worked without computer aids.[3] In 2012, In 2012, Ahmad and Aliyu organized a research paper about Building Information Management (BIM) software and proposed that the BIM software could tremendously improve the economics and construction aspects of landscape architecture projects. The terminology "Landscape Information Management (LIM)" was proposed by Ahmad and Aliyu to reflect how pivotal the

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[1] Michael Batty, "Defining Geodesign (= GIS + Design?)," *Environment and Planning B: Planning and Design* 40, no. 1 (February 2013): 1–2, https://doi.org/10.1068/b4001ed.
[2] Julius Gy. Fabos, "Paperless Landscape Architecture: Future Prospects?," *Landscape Journal* 2, no. 1 (1983): 13–18, https://doi.org/10.3368/lj.2.1.13.
[3] L. Tai, "Assessing the Impact of Computer Use on Landscape Architecture Professional Practice: Efficiency, Effectiveness, and Design Creativity," *Landscape Journal* 22, no. 2 (January 1, 2003): 113–25, https://doi.org/10.3368/lj.22.2.113.

software could be in improving the landscape architecture workflow.[4] Since 1960, the computational technology for improving the landscape architecture workflow has evolved every decade. A now, in 2020, a new technology that has the potential to be applied in the field of landscape architecture might be emerging.

Since the release of the mobile augmented reality game, "Pokemon Go" caught people's attention in 2016, the term "augmented reality" has been recognized by the general public.[5] Since then, have often been confused by augmented reality and the related term "virtual reality." Both of the terms have the word "reality." However, the technical operating method of virtual reality is entirely different from augmented reality. However, while the technics are different, both virtual reality and augmented reality blur people's senses of "reality" and render new ideas into people's perceptions.[6] Since the 1990s, virtual reality technology has improved tremendously and has been adopted by multiple disciplines, including medical training, military training, and the gaming industry. Medical and military practitioners might combat emergent circumstances the simulation of emergent circumstances saves money for the training.[7] Many people may not have noticed the potential of virtual reality and augmented reality in the gaming industry until the

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[4] Ahmad Mohammad Ahmad and Abdullahi Adamu Aliyu, "The Need for Landscape Information Modelling (LIM) in Landscape Architecture" (13th Digital Landscape Architecture Conference, Anhalt University of Applied Science, University in Köthen, Germany, 2012), 531–40.

[5] Tom Baranowski, "Pokémon Go, Go, Go, Gone?," *Games for Health Journal* 5, no. 5 (October 2016): 293–94, https://doi.org/10.1089/g4h.2016.01055.tbp.

[6] Ryan Yung and Catheryn Khoo-Lattimore, "New Realities: A Systematic Literature Review on Virtual Reality and Augmented Reality in Tourism Research," *Current Issues in Tourism* 22, no. 17 (October 21, 2019): 2056–81, https://doi.org/10.1080/13683500.2017.1417359.

[7] Daren T Nicholson et al., "Can Virtual Reality Improve Anatomy Education? A Randomised Controlled Study of a Computer-Generated Three-Dimensional Anatomical Ear Model," *Medical Education* 40, no. 11 (November 2006): 1081–87, https://doi.org/10.1111/j.1365-2929.2006.02611.x.

release of the Oculus and HTC virtual reality headset in the 2010s.[8] Such "mounted" equipment tremendously improved the experience of virtual reality and made users feel more immersive than the traditional virtual reality technology in the past.

Figure 1.1: Pokemon Go interface (Scott Adam Gordon, Android Authority)[9]

Figure 1.2: People enjoyed with mounted VR equipment (jacksepticeye, NEXT GEN START NOW)[10]

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[8] Fabian Rohr, "Comparison of Best VR Headsets: Morpheus vs. Rift vs. Vive," August 14, 2015, https://web.archive.org/web/20150820001906/http://data-reality.com/comparison-of-best-vr-headsets-morpheus-vs-rift-vs-vive/.

[9] "This Pokémon Go Update Is Showing Us Why ARCore Is Great," accessed December 5, 2020, https://www.androidauthority.com/pokemon-go-arcore-update-913547/.

[10] jacksepticeye, *NEXT GEN STARTS NOW | Spider-Man Miles Morales - Part 1 (PS5)*, 2020, https://www.youtube.com/watch?v=oR5Z7bE9LU8&ab_channel=jacksepticeye.

Augmented reality and virtual reality technology have also been used in the field of landscape architecture for years. The common method of utilizing virtual reality technology in the landscape architecture field is to provide the audience with an immersive experience of the design (Figure 1.3).[11] This allows users to virtually walk around the design, similar to walking in the constructed design environment. The experience has the potential to reduce the gap of the recognition of the design between designers and the audience. In addition to exhibiting potentials designs, landscape architects can combine existing 360-degree filming technology with virtual reality headsets to produce an immersive experience of a potential site (Figure 1.4).[12] Landscape architects can repeatedly revisit the site back in the office through the virtual reality headset, saving time and money by not traveling back to the physical site.

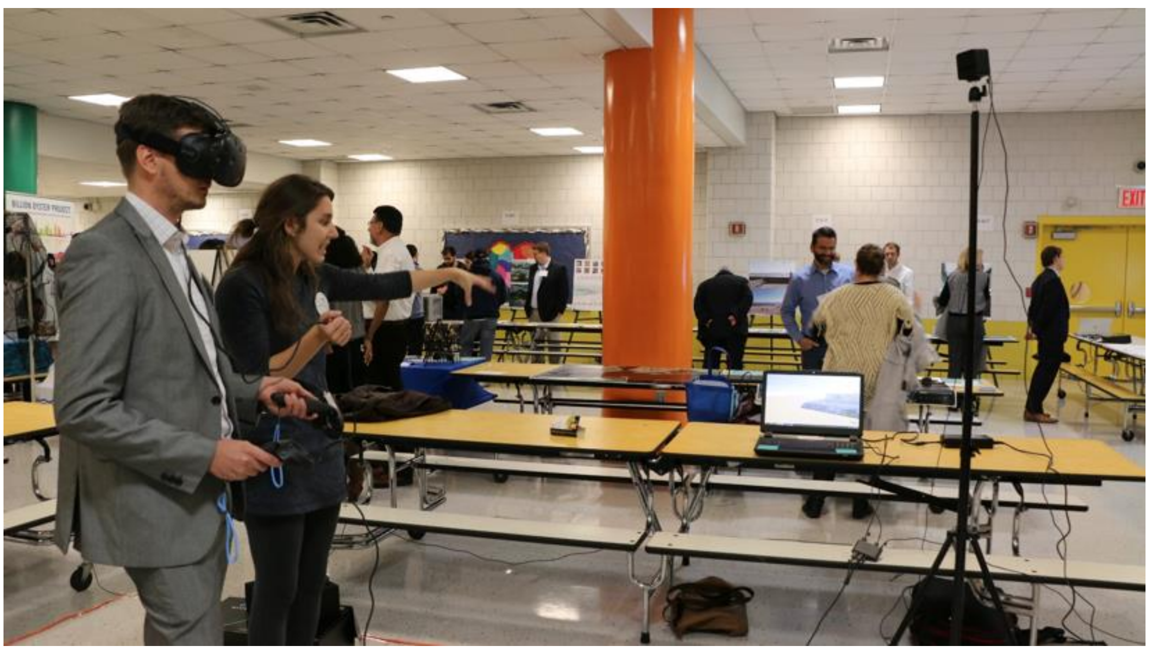

Figure 1.3: Experiencing design idea in virtual reality (Leah Kovach, Scape Team)

[11] Leah Kovach, "How This Landscape Architecture Firm Uses VR To Communicate Design Intent," accessed April 24, 2019, https://blog.irisvr.com/how-this-landscape-architecture-firm-uses-vr-to-communicate-design-intent.
[12] "ASLA Virtual Reality | Asla.Org," accessed November 27, 2020, https://www.asla.org/vr.aspx.

Figure 1.4: ASLA VR film credits (Ian Tuason, Dimension Gate)

Since the 1960s, computational software has had a tremendous impact on the workflow of landscape architecture professional practice. From the invention of GIS to the research of LIM, technology grants landscape designers the ability to collect data more efficiently. The improvement of mapping and design visualization might reduce the gap between designers and the audience. However, technology has not changed the way landscape designers think. Despite an increasing number of landscape architects start to apply CAD in the workflow, designers still enumerate the design idea through a 2D interface. Start-up landscape architecture students are trained to express design ideas in a 2D interface. However, landscape design is always a three-dimensional spatial design. Students spend at least two-semester years to learn to express design ideas on a paper or computer screen.[13] The emerging virtual and augmented reality technology need to be considered to solve the dilemma.

13 Temple Buell Hall and E Lorado Taft Drive, "David L. Hays, Professor and Brenton H. and Jean B. Wadsworth Head Lori Davis, Academic Affairs Coordinator," n.d., 10.

Except for the mentioned function that could be provided by virtual reality in the field of landscape architecture, there is more potential that virtual or augmented reality could work with landscape architecture. For example, sketching the design idea or modeling the design through virtual or augmented reality remains disregarded. On the other hand, the drawback, such as the blurred boundary between the real and virtual world of the technology should also be considered. The designer should be aware of focusing on an issue amplified in the virtual environment, which is not reality a problem in the physical site. The thesis project will explore more possibilities of how designers could utilize virtual reality or augmented reality in landscape architecture, especially for the benefit of professional practice.

The Mixed Reality

To further understand the potential to use virtual reality or augmented reality in the field of landscape architecture, it is helpful to define these related terminologies.

Mixed reality (MR) is a medium where users interact with the virtual objects in a real environment, or conversely, one in which users can experience real objectives in a virtual environment. Some experts consider MR to be either virtual reality or augmented reality.[14] On the other hand, other experts argue that MR is a combination of virtual reality and augmented reality.[15] In this paper, the MR would be defined as a general term of all the technology related to virtual reality, augmented reality, and mixed reality. Some researchers define such a general term as Extended Reality (XR).

[14] C.E. Hughes et al., "Mixed Reality in Education, Entertainment, and Training," *IEEE Computer Graphics and Applications* 25, no. 6 (November 2005): 24–30, https://doi.org/10.1109/MCG.2005.139.
[15] Fumio Kishino, "Http://Vered.Rose.Utoronto.ca/People/Paul_dir/IEICE94/Ieice.Htm," n.d., 15.

Virtual reality (VR) is an environment simulated by a computer. The environment could be similar or significantly different from the actual world. Both these realities enable users to interact with the objectives generated by computers in virtual reality.

Augmented reality (AR) is an interface generated by computers that enable users to interact with virtual objectives in the real world. The users would have an experience that reality has been augmented with virtual images or films.[16]

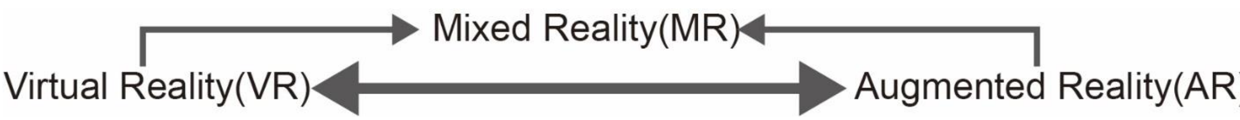

Figure 1.5: The definition of mixed reality in this thesis project

Research Questions and Methodology

Now that we have reviewed a brief history of technological innovation in landscape architecture and taken a broad look at mixed-reality technology, I will explore how the emerging mixed-reality technology might be utilized in the professional landscape architectural workflow.

To narrow this down, I focus on the following questions:

1. Based on the conventional landscape architecture workflow, how can MR technology be utilized as a part of the conventional landscape architecture workflow?
2. How can the MR software inspire designers and communicate their design ideas?

The research method of the thesis project could be classified into two categories and four sections. The first category (Figure 1.6) addresses the first question above, and includes a

[16] "Get Ready to Hear a Lot More About 'XR,'" *Wired*, accessed November 27, 2020, https://www.wired.com/story/what-is-xr/.

literature review, professional practitioner interview, survey distribution and analysis, and defining a mixed reality workflow. For the second category, which addresses the second question, a landscape design project combined with MR software is considered. The second category is an extension of the "mixed reality workflow defining" section in the first category. The method of the second category will be elaborated on in Chapter 5.

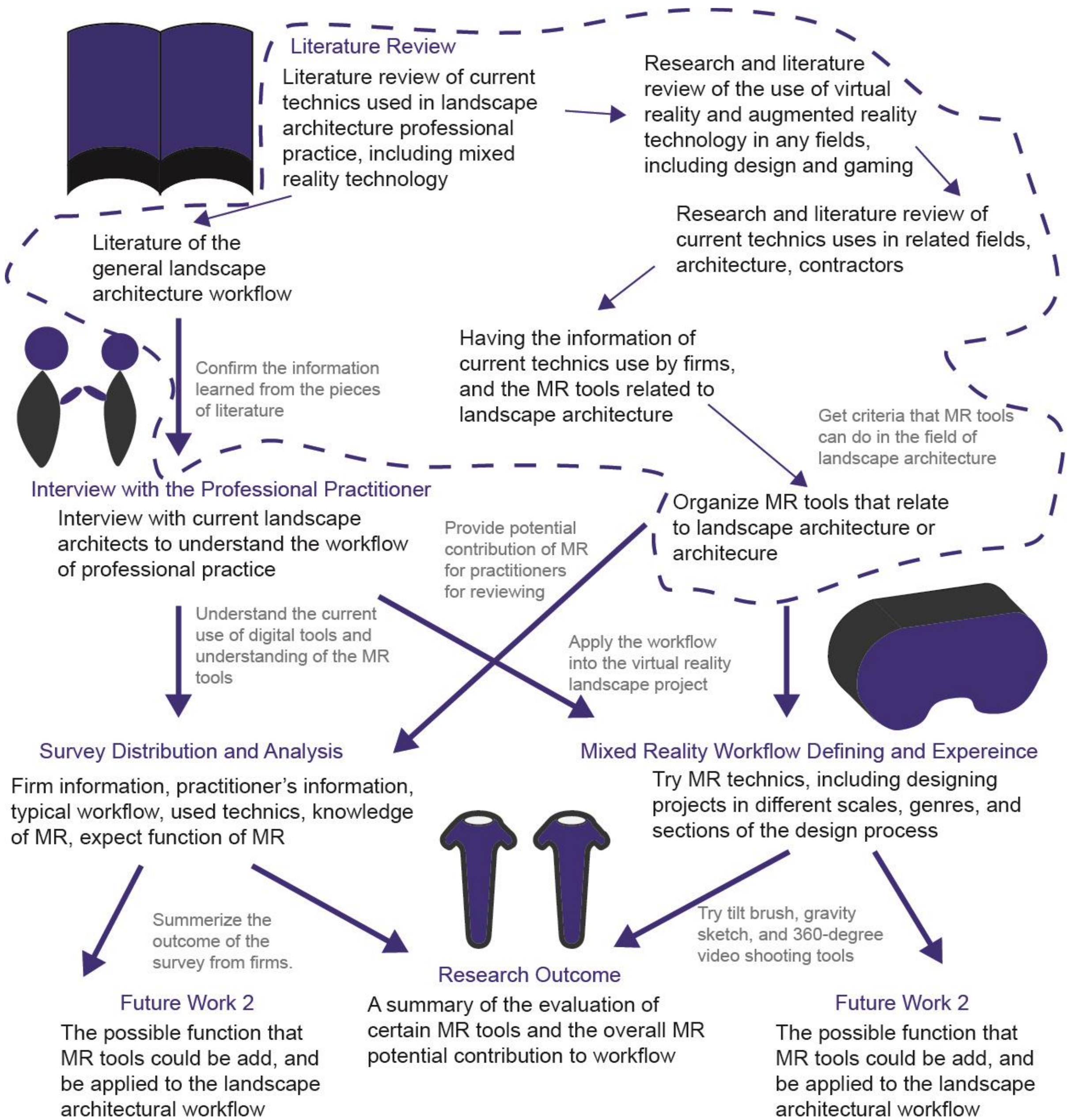

Figure 1.6: Research strategy

In the literature review section, the common technic, and software, including MR technology, utilized in the landscape architecture professional workflow is explored. To understand the benefit of MR for the field of landscape architecture, this thesis first understands the character of each existing software and then summarizes how MR software is currently used in other fields. To firmly understand the potential of MR, Then, a summary of precedents in the gaming industry, medical training, and pilot training shows potential applications for the field of landscape architecture. Third, the design aid software utilized by related disciplines, such as architecture, urban planning, and civil engineering, reveals features that landscape architects might consider. Next, are case studies of landscape architecture projects utilize MR tools. After identifying a list of potential MR software, each software is tested out. The result could clearly figure out how each software could work with the landscape architecture workflow. Finally, to evaluate the potential contribution of the MR software in landscape architecture, professional workflow, clarifying the content of the workflow is required.

Because the workflow of each landscape design project could vary due to the type of the project, the interest of the client, or the nature of the collaboration among other industries involved in the project, I interview a professional landscape architect and confirm the workflow information collected from the literature review is accurate. [17] The notes from this interview are organized and combined with the literature review.

Since an MLA thesis is completed within the academy, the addition of practitioners' points of view could make the research more convincing. Therefore, after establishing the potential of the MR software, a questionnaire was distributed to the landscape architecture practitioners in the Chicago metropolitan area. The survey mainly focuses on how practitioners use MR in their

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[17] Bruce Sharky, "The Design Process and the Life of a Project," in *Thinking About Landscape Architecture*, 2016, 45–64.

work and perspectives on the potential of the MR software. To avoiding confusion, the term "landscape architecture professional practitioner" does not only stand for landscape architects working in firms but also indicated everyone who is working in a landscape architecture firm. Therefore, a landscape architecture professional practitioner could be an architect, urban planner, or even an artist and financial advisor.

The final step is to try out the potential function of the listed MR software in the former process. A design project focusing on the current landscape architectural issues, such as climate change, environmental pollution, or socio-ecological justice, will be executed by a workflow integrated with MR technology. Thus, an overall evaluation of how MR software could be utilized in landscape architecture professional workflow is defined.

CHAPTER 2: LANDSCAPE ARCHITECTURE PROFESSIONAL WORKFLOW

Literature Review

To begin understanding how MR could be utilized in a conventional landscape architecture design workflow, it is important to define each step of the design process as it occurs in professional practice. Since the goal of this research is to understand the "current" workflow, the literature review mainly includes sources published after 2010. Most of the resources are from the short article published on the landscape architecture websites, such as World Landscape Architecture (WLA). There are limited research papers found in internet libraries, including Taylor & Francis Online, or Landscape Journal. Therefore, the main source referred to here is the book "Thinking About Landscape Architecture" by Bruce Sharky.

Table 2.1: The list of literature related to landscape architecture professional design process

Article	Author	Year	Book/Research Paper/Website
The Design Process and the Life of a Project	Bruce Sharky	2016	Sharky, Bruce. “The Design Process and the Life of a Project.” In *Thinking About Landscape Architecture*, 45–64, 2016.
PRACTICE | Stages of a Landscape Architecture design project	Damian Holmes	2017	Holmes, Damian. “PRACTICE | Stages of a Landscape Architecture Design Project.” World Landscape Architecture (blog), August 6, 2017. https://worldlandscapearchitect.com/practice-stages-of-a-landscape-architecture-design-project/.
Developers: Know The 4 Design Phases of a Successful Landscape Project in Utah	Brandon Leed	2017	Reed, Brandon. “DEVELOPERS: KNOW THE 4 DESIGN PHASES OF A SUCCESSFUL LANDSCAPE PROJECT IN UTAH.” LoftSixFour (blog). Accessed November 28, 2020. https://loftsixfour.com/blog/developers-know-the-4-design-phases-of-a-successful-landscape-project-in-utah/.

Table 2.1 (cont.)

Article	Author	Year	Book/Research Paper/Website
Chapter III: Design Process	John A. Gottfredson	2014	Gottfredson, John A. "Design Process in Landscape Architecture: Developing a Learning Guide for the Design Workshop Archives at Utah State University," 2014, 99.
The Stages of a Landscape Architecture Project	CSS_mainAdmin	2020	CSS_mainAdmin. "The Stages of a Landscape Architecture Project." Creative Shade Solutions, August 7, 2020. https://www.creativeshadesolutions.com/the-stages-of-a-landscape-architecture-project/.
Our Process: Landscape Architecture	Terra Ferma Landscapes	2020	Koch, Brian. "Landscape Architecture." Terra Ferma Landscapes, 2020. https://tflandscapes.com/what-we-do/our-process/process-landscape-architecture/.

Bruce Sharky

Bruce Sharky wrote a guide book for landscape architecture students and professionals, titled or the general public. "Thinking About Landscape Architecture," introduces the core value of landscape architecture, the character of landscape architects, learning objectives for students, the design methodology, and the professional workflow. Since Sharky is a well-established landscape architect and a professor at the Robert Reich School of Architecture at Louisiana State University, his experience and knowledge make the source well regarded by scholars. The design process mentioned in "Chapter 4 The Design Process and the Life of a Project" is comprehensive and unprejudiced. Thus, the workflow elaborated in the book will serve as the main idea.[18]

1. Schematic design (SD)
2. Design Development (DD)

[18] Sharky, "The Design Process and the Life of a Project."

3. Construction Documents (CD)

4. Bidding and Negotiations (B&N)

5. Construction Administration

Damian Holmes

Damian Holmes posits that the design process should be flexible and he lists nine different stages on the WLA website.[19] The stages can adapt to the site's scale, the genre of the project, or client requirements. Therefore, Holmes lists nine stages, which ensures a complete outcome even if one of the stages is removed. The nine stages are:

1. Project Inception & Initiation
2. Concept Design
3. Design Development (Detailed Design)
4. Construction Documentation
5. Tendering (Procurement)
6. Construction
7. Construction Management (Construction Administration)
8. Maintenance
9. Post Occupancy Evaluation

[19] Damian Holmes, "PRACTICE | Stages of a Landscape Architecture Design Project," *World Landscape Architecture* (blog), August 6, 2017, https://worldlandscapearchitect.com/practice-stages-of-a-landscape-architecture-design-project/.

Brandon Leed

Brandon Leed, however, proposes four stages that are required for a "great landscape architecture project".[20] Unlike the flexibility that Damian's approach offers, Leed argues that four basic stages must be applied in a landscape architecture project, and they are:

1. Pre-Design
2. Conceptual Design
3. Design Development
4. Construction Documents

John A. Gottfredson

As a master student at Utah State University, John A. Gottfredson studied the landscape architecture design process for his dissertation. In it, he collected ten research papers related to the landscape architecture design process and synthesized them into one process. Moreover, to prevent the audience from confusing by the terminologies, Gottfredson proposes four terms to enumerate the design process. Furthermore, Gottfredson describes that the design process as "non-linear"[21], and argues that designers always have to revisit the finished stage while working on the next stage. While new ideas or challenges are found in the next stage, the designers need to adjust the content in the previous ones. Gottfredson mainly focuses on the design stage, and phases after construction documentation were not discussed in his research.

[20] Brandon Reed, "DEVELOPERS: KNOW THE 4 DESIGN PHASES OF A SUCCESSFUL LANDSCAPE PROJECT IN UTAH," *LoftSixFour* (blog), accessed November 28, 2020, https://loftsixfour.com/blog/developers-know-the-4-design-phases-of-a-successful-landscape-project-in-utah/.
[21] John A Gottfredson, "Design Process in Landscape Architecture: Developing a Learning Guide for the Design Workshop Archives at Utah State University," 2014, 99.

1. Generate: Site & Cultural Inventory & Analysis, Programming, Inspiration & Precedents, Define Values & Perspective.
2. Develop: Refine Program, Perform Final Site & Cultural Analysis, Conceptual & Schematic Design, Develop Alternatives.
3. Evaluate: Select Scheme from Alternatives, Refine Design, Re-Evaluate, Validate Goals and Metrics.
4. Communicate: Identify Message, Medium, Audience, Produce Design, Implement Design.

CSS_mainAdmin

This article is intended for potential clients to read in order to understand what landscape architects might do in a project.[22] Therefore, the stages listed in the article are rather simple. However, the stages mentioned in the article are also proposed by other pieces of literature. The five stages are:

1. Consultation & Design Brief
2. Design Development
3. Construction
4. Project Closeout
5. Maintenance

[22] CSS_mainAdmin, "The Stages of a Landscape Architecture Project," Creative Shade Solutions, August 7, 2020, https://www.creativeshadesolutions.com/the-stages-of-a-landscape-architecture-project/.

Terra Ferma Landscapes

The final workflow example comes from the official website of Terra Ferma Landscapes.[23] Terra Ferma Landscapes is a San Francisco-based landscape architecture practice that mainly focuses on private residential gardens. On their website, they explain seven stages of a landscape design project in a straightforward manner. The Terra Ferma Landscapes workflow is representative of the general sequence of steps firms use to produce a small-scale project. The seven stages are:

1. Consultation
2. Launch
3. Schematic Design (SD.)
4. Design Development (DD.)
5. Permitting
6. Construction Documents (CD)
7. Construction Observation and Administration
8.

Workflow Organized from Literature Review

After reviewing the stages outlined by these authors, a synthesized workflow can be defined as following stages.

Consultation

A. Initial consultation: the client has an email or phone call to initiate a project.

[23] Brian Koch, "Landscape Architecture," Terra Ferma Landscapes, 2020, https://tflandscapes.com/what-we-do/our-process/process-landscape-architecture/.

B. Return brief/proposal: landscape architects propose a proposal base on the requirement and initial site analysis.

C. Brief project understanding: landscape architects briefly search for the information for the site, concept idea, and regulation.

Concept

A. Concept brainstorming: Landscape architects established design schemes based on the client's requirement and brief project understanding.

B. Document the idea: landscape architects sketch the idea through maps, sections, or perspectives.

Schematic Design (SD.)

A. Background research, inventory, and evaluation

1. Gathering and inventorying the information
2. Interpretation and evaluation of the information collected
3. Search for the applicable laws and regulations

B. Establishing design intent

1. Organizing the physical relations of the various park elements (the program)
2. Considering the circulation: consider which elements are best clustered together to share as entry, parking, and restroom. Designers may create two or three schemes for clients to decide

3. Producing drawings, models, but not to be too detailed: typical elements included in the schematic design packages are a site design plan, sections, perspective drawings, 3-D models, probable cost, and any other supporting graphics.

C. Discuss with the client.

Design Development (DD.)

A. Carefully study and prepare plans for the various systems that will go into the final design package.

1. Grading and drainage including storm-water management
2. Plant species or material types
3. Circulation and parking layouts
4. Materials such as paving, walls, and structures
5. Lighting and wayfinding
6. Site furniture

B. Submit a preliminary package of the project to appropriate government agencies, apply for design review acceptance, prepare for various permits.

Construction Documents (CD)

A. The graphic and written documents for securing the bids and potential contractors

B. Graphic drawings and shop, consisting of plans, details, technical sections, notes, material schedule.

C. Technical specifications. In some cases, for instance, a geotechnical investigation and report with soil testing results and recommendations would also be included.

D. Construction contract (between owner and contractor) and bid documents including various bid forms and related insurance documentation materials.

Bidding and Negotiations (B&N)

A. Before the bid is selected

1. The contractors analyze the plans, detail, and the information included in the technical specifications as well as the bid forms, construction agreement, and insurance requirements.
2. Contractors submit the bid forms and meet with landscape architects before the date of bidding.
3. The certificated contractor will be selected.

B. After the bid is selected

1. After the construction date is established, the landscape architects will create a convenient schedule for a project start-up meeting and other scheduling requirements specified in the contract.
2. The landscape architects need to review the construction materials, shop drawings, and other pre-construction and installation requirements submitted by contractors.
3. The landscape architects have to visit the suppliers listed by contractors and may need to ask contractors to adjust the decision.

Construction Administration

A. Landscape architects negotiate with owners and make the decision of the materials depends on the owner's interest and cost.

B. Landscape architects negotiate with contractors and discuss the change and allow sufficient time for contractors to react.

C. Landscape architects should ensure the construction is consistent with the design.

Maintenance

In some cases, the contracts between landscape architecture firms and clients include maintenance of the constructed project. The maintenance includes keeping the facilities in good quality, securing the plants are healthy, and the safety of the site. Some landscape architecture firms also provide a maintenance service for a project designed by other landscape firms.

Interview with the Professional Practitioner

To verify the design workflow outlined in the literature review, Nan Hu, a landscape designer employed by Dix.Hite + Partners, was interviewed.[24] Dix.Hite + Partners is a medium-sized landscape architecture firm focusing on public park design, urban design, and community design in Longwood, Florida. The interview took place in March 2020. The prepared workflow information applied in the interview mainly references Sharky's workflow. Therefore, the concept and consultation, which are not listed in Sharky's book, was not included in the workflow. To check if there is any stage that usually exists in a landscape project, Nan's first and second question was about the process before the schematic design stage. Nan also introduced

[24] Nan Hu, Landscape Architecture and Mixed Reality: An Interview, March 20, 2020.

the two kinds of patterns of how landscape architects work with participants from architects, civil engineers, and community members. After the discussion about the workflow information, Nan provided some perspectives about the advantages and shortcomings of utilizing virtual reality technology in the professional workflow.

How Clients Select a Landscape Architecture Firm

A. The clients should deliver firm information, introduction, main designer profile, team members, and former projects to the clients. Clients select a firm based on the materials mentioned.

B. In some cases, clients will directly contact firms based on their reputation or portfolio published on the websites.

C. Also, clients can host a competition to call for entries. The concept is usually finished before the firms and clients have formal contract.

Concept Design

A. Before the schematic design stage, there is a conceptual design phase.

B. The concept process mainly shows the mood and preliminary design to clients.

C. A community-scale project usually has multiple conferences(charrette) with architects, civil engineers, community members, government agents.

Schematic Design (SD)

A. During the SD process, landscape architects incorporate feedback collected from discussions with the architects, civil engineers, government agents, and community members. The design scheme is based on the combination of the feedback and comments from all the participants.

B. A preliminary cost estimate is also created at this stage.

Two kinds of workflow

A. Integrate: all people who participate in the project have conferences multiple times to make sure that all people are at the same pace. The landscape architects know the design changed by architects right after the conference. Moreover, landscape architects can give architects feedback or point out some problems while the landscape design is installed in the design. Thus, architects can adjust the design after the conference. A similar interaction happens among architects, landscape architects, civil engineers, contractors, government members, and community members. The step before construction is longer, but the construction section will be fluent. The correction of construction documents seldom happens in the construction section.

B. Handover: after submitting the materials to the next company responsible for the project. The former company will not change anything for the rest of the project. For example, the architects submit all the materials to the landscape architects then move forward to the other project. The architects will not adjust the project unless the client wants to change the design during the construction section. Therefore, although the process before construction proceeds faster than the integrated workflow, the efficiency of the construction stage is disappointing. If there is any problem or mismatch of the shop drawings found while constructing, asking a company to revisit a project that has been defined as completed is inefficient.

The site plan(masterplan) 's job that VR modeling cannot replace

The site plan is suitable for a designer to develop a design idea. The designers can make a draft on the site plan easier than making a draft in a 3D model. Moreover, it is easier for designers to concern the relationship between the site and the surrounding object. The functions are difficult to be replaced by a VR tool. At least, we currently think like that. The summary of potential of the mixed reality is introduced in Chapter 3.

Nan's perspective of utilizing MR in landscape architecture projects

A. The landscape architects could show the clients the real-world experience of the proposed design. Therefore, the client may not want to adjust the design after the beginning of the construction process.

B. Virtual reality could give the designers a good sense of scale. If a company creates a virtual reality environment earlier than the design process, designers can directly sketch in the proposed site. The software for making an environment for sketching is mentioned in Chapter 3. The function especially benefits the newly-entered practitioners to get adept at the sense of space.

C. The VR tool can help illustrate the vertical elements such as a wall or fence design that can not be shown in a site plan.

Resource Synthesis

For further research, the workflow is the combination of the literature review and the interview with the professional practitioner. The two stages before the schematic design have been adjusted. The consultation and concept stages in the workflow summarized from the literature review have been combined into a single "concept stage." Moreover, the charette stage has been added to the workflow before the schematic design stage. The universal workflow (Figure 2.1) in the dissertation would be concept, charette, schematic design, design development, construction documents, bidding and negotiations, construction management, and maintenance.

Figure 2.1: The universal workflow defined in the thesis dissertation

CHAPTER 3: EXISTING MIXED REALITY SOFTWARE

Mixed Reality Software Related to Landscape Architecture

In 2015, Dafna Fisher-Gewirtzman, associate professor in the department of architecture and town planning at the Israel Institute of Technology, organized an overall assessment of the reality simulation function of architecture, landscape architecture, and urban planning. In Fisher-Gewirtzman's point of view, the environment simulated by virtual reality benefits the decision making for designers and clients. Moreover, virtual reality grants designers the illusion of designing in the real world.[25] The thesis proposed in Chapter 1 that landscape architects started to use virtual reality technology for discussion and communication with clients or project participants. However, VR's ability to actually grant designers a sense of drafting in the real-world still remains questionable. Research or case studies on sketching in virtual reality are scarce. Scholars have revealed that MR technology has tremendous potential to contribute to the field of landscape architecture, even directly design in virtual reality.[26] To explore and test out the potential of existing MR tools and verify former studies completed by scholars, collaborative MR software related to the field of landscape architecture was identified. In Chapter 3, multiple MR software is introduced and classified into seven categories. Each software is researched, and some of the software is tried out. The primary function and some features of each software are listed. The seven categories are organized as follows.

1. Virtual Reality Sketching software
2. Virtual Reality Experience Producing Software

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[25] M.E. Portman, A. Natapov, and D. Fisher-Gewirtzman, "To Go Where No Man Has Gone before: Virtual Reality in Architecture, Landscape Architecture and Environmental Planning," *Computers, Environment and Urban Systems* 54 (November 2015): 376–84, https://doi.org/10.1016/j.compenvurbsys.2015.05.001.
[26] Zhuo Wei, Ningning Xie, and Wenna Feng, "Modern Landscape Design Based on VR Technology and Wireless Internet of Things System," *Microprocessors and Microsystems*, November 2020, 103516, https://doi.org/10.1016/j.micpro.2020.103516.

3. 360 Degree Filming Software
4. Augmented Reality Sketching Software
5. Mixed-reality Showcasing Software
6. Virtual Reality Co-working Software
7. Augmented Reality Construction Aid Software

Virtual reality sketching software

Designers create the design idea in a three-dimensional pattern. However, for a more effective workflow, the paper is a more reasonable decision as a medium to communicate the ideas. Virtual reality technology now has the potential to grant landscape architectures a chance to sketch ideas directly in a three-dimensional medium.

Table 3.1: List of virtual reality sketching software

Program Name	Type	Main Function	Features Overview
Gravity Sketch	VR	Directly design in virtual reality for designers at every level.	1. Has multiple drawing tools enable users to control the shapes and colors. 2. A simple alignment and snap functions grant designers making the design more accurately. 3. Designers could use the accurate scale function to make the design in scale.
Google Tilt Brush	VR	Directly sketch in virtual reality for artists.	1. Comparing with Gravity Sketch, the drawings are not as detailed as in Tilt Brush. 2. Multiple brushes could be chosen. Therefore, the Tilt Brush is suitable for sketching ideas in virtual reality. Moreover, users can add animation or lights to the design. 3. Compatible for more streaming software and social media, which makes communication with clients more convenient.

Table 3.1: (cont.)

Program Name	Type	Main Function	Features Overview
MasterpieceVR	VR	The environment and avatar modeling tool in virtual reality	1. The subtraction tool, which is similar to the Boolean difference in Rhino, makes designers feel more comfortable while designing. 2. Texture painting function enables designers to make the design more detailed in virtual reality. 3. The "component" function, which is similar to the one in Sketchup, makes the design process more efficient.
Google Blocks	VR	Essential virtual reality modeling software for amateurs	1. The software provided multiple shapes to put in the virtual world. 2. Users can simply control the size, color of the shape.
Oculus Medium	VR.	An advanced virtual reality modeling tool for designers	1. Snap, alignment, and ortho tools grant designers make the model more accurately. 2. The custom brush tool is suitable for firms to work on similar projects. 3. The subtraction tool is compatible with the custom brush tool and makes the process more efficient.

Virtual reality experience producing software

The reality simulation has been considered the main contribution of virtual reality technology to the field of landscape architecture. Shushan et al. have already taken simulated reality as a research tool to solve the question about building environments.[27] On the other hand. Dafna discusses what is "reality" since the reality could be simulated as authentic as the real

[27] Yossi Shushan, Juval Portugali, and Efrat Blumenfeld-Lieberthal, “Using Virtual Reality Environments to Unveil the Imageability of the City in Homogenous and Heterogeneous Environments,” *Computers, Environment and Urban Systems* 58 (July 2016): 29–38, https://doi.org/10.1016/j.compenvurbsys.2016.02.008.

world through virtual reality.[28] Experiencing a simulated environment through a virtual reality tool is the most popular feature of how MR technology could bring to the environment-related field. The following software (Table 3.2) is suitable for simulation an environment related to landscape architecture projects.

Table 3.2: List of virtual reality experience producing software

Project Name	Type	Main Function	Features Overview
Unity	AR/VR	A game producing software for designers to create a large-scale environment.	1. The topography generation tool and plant inserting tool make creating an environment easily. 2. Sketchup, 3ds Max, Blender, and Rhino models could be imported into the software compatibly. 3. High-quality rendering tool which can create a realistic environment. 4. Users could export the designed environment into a VR or AR format.
Unreal Engine	AR/VR	Comprehensive environment generating tool for designers to create a large-scale space. The competitor of Unity. Both two software shared similar functions.	1. The topography generation tool and plant inserting tool make creating an environment quickly. 2. Sketchup, 3ds Max, Blender, and Rhino models could be imported into the software compatibly. 3. High-quality rendering tool which can create a realistic environment. 4. Users could export the designed environment into a VR or AR format.
Lumion	VR	Generate a 360-degree panorama after rendering the model.	1. The easiest model rendering tool for landscape designers. 2. Compatible with multiple trending modeling software in professional practice.
Enscape	VR	Provide a walk-in experience of the rendering model through virtual reality.	1. A handy tool for landscape designers to render the model. 2. Compatible with multiple trending modeling software in professional practice.

[28] Portman, Natapov, and Fisher-Gewirtzman, "To Go Where No Man Has Gone Before."

360 Degree filming software

The 360-degree filming technology has surprised people since 2017.[29] Scholars from multiple disciplines applied the 360-degree filming technology into their fields. Pope et al. collect four case studies of theatre research, testing the perceptual difference between performing in front of the audience or a 360-degree filming simulated environment.[30] On the other hand, Holmberg et al. create a VR environment base on 360-degree filming technology to clarify if people feel anxious in a shopping center.[31] The virtual journal created by 360-degree filming technology is typical in multiple social media recently. The listed software may provide a critical contribution for site visiting in the landscape architecture workflow in the future.[32]

Table 3.3: List of 360 Degree Filming Software

Project Name	Type	Main Function	Features Overview
Insta360 One X	Hard ware	360-degree camera	1. Record 360-degree image, video, or streaming in a 360-degree medium. 2. Compatible with smartphones.
Adobe Premiere Pro	VR	Advanced video editing tool on windows/Mac	1. With the plugin, the software could edit the video or add variable effects in the video 2. The software could make the original 360-degree video into a more suitable format for viewers
Insta360 Studio	VR	Simple video editing tool on windows/Mac	1. A handy tool to transfer an original 360-degree video to a ready-to-watch format.

29 Sarah Jones, "Disrupting the Narrative: Immersive Journalism in Virtual Reality," *Journal of Media Practice* 18, no. 2–3 (September 2, 2017): 171–85, https://doi.org/10.1080/14682753.2017.1374677.

30 Vanessa C. Pope et al., "The Geometry of Storytelling: Theatrical Use of Space for 360-Degree Videos and Virtual Reality," in *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17: CHI Conference on Human Factors in Computing Systems, Denver Colorado USA: ACM, 2017), 4468–78, https://doi.org/10.1145/3025453.3025581.

31 Trine Theresa Holmberg et al., "Social Anxiety Can Be Triggered by 360-Degree Videos in Virtual Reality: A Pilot Study Exploring Fear of Shopping," *Cyberpsychology, Behavior, and Social Networking* 23, no. 7 (July 1, 2020): 495–99, https://doi.org/10.1089/cyber.2019.0295.

32 Jones, "Disrupting the Narrative."

Table 3.3 (cont.)

Project Name	Type	Main Function	Features Overview
VeeR Editor	VR	Simple video editing tool on a smartphone	1. A handy tool to transfer an original 360-degree video to a ready-to-watch format. 2. There is similar variable software on the markets

Augmented reality sketching software

The augmented reality technology can identify a users' location and provide the digital image, video, or 3D dynamic graphic into the users' smartphone or tablet computer.[33] The listed software (Table 3.4) records the user's location and saves the location of the drawings into the database. Therefore, the software could keep the sketch in the same position inside the augmented reality, whether the smartphone is moved or not.

Table 3.4: augmented reality sketching software

Project Name	Type	Main Function	Features Overview
IScape	AR	Put plants or pavement in a space.	1. Users can place the plants or pavements in the space through smartphones or pads. 2. Users can geolocate the design and also adjust the sunlight.
ARLandscaper	AR	Put plants or pavement in a space.	1. Low-level configuration of iScape.
Fologram	AR	Sketch through any smartphone and tablet computer.	1. Users could sketch simple curves through augmented reality, which makes people feel the sketching is realistic. 2. With Grasshopper, designers could change the curve into any kind of shape. Nevertheless, the shape still follows the track sketched through smartphones or tablet computers.

[33] Satish Kumar, "How Does Augmented Reality Work?," November 26, 2017, 4.

Mixed reality presenting software

The earliest sample of a case showcasing the landscape design works to the audience is a master thesis project done by Gram Garden. Garden sets a paper with a graphic for scanning and locating the model and presents a mixed reality experience in the Unity software.[34] As technology improved tremendously and quickly, the augmented reality designed for landscape architects is emerging in 2020. Structure studio, a firm that spends all the efforts to develop software for landscape architects, published a YARD as a tool for designers to introduce the design idea through merely a smartphone or tablet computer.[35] The list is the MR software that is considered helpful for presenting

Table 3.5: List of mixed reality presenting software

Project Name	Type	Main Function	Features Overview
YARD in Vip3D	AR	Put a model made by Vip3D in an environment and can adjust the model directly in AR.	1. An add-in of Vip3D, which is a program for landscape architecture. Users can draw the design in Vip3D just like drawing in AutoCAD 2. Users can place the model in the real world and look at it through tablet computers. 3. Users can also edit the texture or pavement in the AR mood.
Virtualist	VR/AR	Simple rendering tool through both AR and VR.	1. Users can put textures, adjust sunlight, and add light sources in the software. The function is similar to Lumion, Enscape. 2. Users can also use the AR mode to do the same functions. 3. Users can use the VR mode to take notes in the model.

[34] Gram Garden, *Augmented Reality Landscape*, 2017, https://www.youtube.com/watch?v=oRWJdyNGRgc&ab_channel=GramGarden.

[35] Structure Studios, “YARD - Augmented Reality Designer - From Structure Studios,” accessed November 29, 2020, https://www.structurestudios.com/yard.

Table 3.5: (cont.)

Project Name	Type	Main Function	Features Overview
SimLab	VR/AR	A plugin for multiple modeling or drawing software to present ideas in virtual reality	1. After specific settings in the original model in Sketchup, Rhino, or any compatible software, the design in the virtual reality could be interactive. 2. SimLab could do simple rendering before the users dive into the VR mode.
Gravity Sketch	MR (AR+VR)	Showcase the design idea in a mixed reality setting.	1. Through a computer-based virtual reality headset and a webcam for recording, designers could present a mixed reality presentation to the audience.
Google Tilt Brush	MR (AR+VR)	Showcase the site analysis in a mixed reality setting.	1. Through a computer-based virtual reality headset and a webcam for recording, designers could present a mixed reality presentation to the audience.
Fologram	AR	Showcase the model in an AR setting.	1. The model could be set on a 1:1 scale inside the AR Viewers could have a realistic scale to experience the design model. 2. Designers could adjust the light in Fologram. 3. The layers in the Rhino are synchronized with Fologram. Users could turn on and off the layers in Fologram.

Virtual reality co-working software

Liang Gong's research group develop a virtual reality interactive multi-user design tool through the Unity software. The VR tool is to test out if designers feel co-creating in virtual reality is effective. The result shows that the VR co-working software provides a great experience to designers who work together remotely. The research outcome serves as an indication that remote co-creating would be more common in the future while artificial intelligence becomes much advanced.[36] Several companies have already developed the software (Table 3.6) that grants designers a co-working function.

Table 3.6: List of Virtual reality co-working software

Project Name	Type	Main Function	Features Overview
Gravity Sketch	VR.	The software provides a co-creating mode which is in a beta stage.	1. Designers could design together in the same virtual reality.
The Wild	VR/AR	The software provides a co-creating mode.	1. The Wild was mainly built for architecture rather than landscape architecture. However, the software features are still practical for landscape architecture projects, such as curving, extrusion, and moving tools.

Augmented Reality Construction Aid Software

In 2017, Fazel and Izadi published a paper focusing on utilizing augmented reality technology to build a real-world project. Fazel and Izadi create software that grants designers the ability to set the instruction of how, where, and what to build a structure.[37] The research serves as a pioneer of the AR aid construction. In 2020, a Melbourne-based company Fologram Pty Ltd released a comprehensive augmented reality plugin, Fologram, for Rhino. The Fologram aims to integrate the augmented reality technology with the traditional architecture workflow.[38] The landscape architecture could also get familiar with the software immediately. One of the most impressive features is that Fologram could export the construction guild into a smart glass,

[36] Liang Gong et al., "Interaction Design for Multi-User Virtual Reality Systems: An Automotive Case Study," *Procedia CIRP* 93 (2020): 1259–64, https://doi.org/10.1016/j.procir.2020.04.036.
[37] Alireza Fazel and Abbasali Izadi, "An Interactive Augmented Reality Tool for Constructing Free-Form Modular Surfaces," *Automation in Construction* 85 (January 2018): 135–45, https://doi.org/10.1016/j.autcon.2017.10.015.
[38] "Fologram," accessed November 29, 2020, https://fologram.com/.

HoloLens, published by Microsoft. The workers could follow a clear indication created by AR and build the structure quickly.

Research of the Mixed Reality Software

For further understanding, the MR software's potential, the numbers of MR software would be deeply researched or tested out. Due to the limitation of the budget and time, there are only four types of functions that are discussed.

Virtual tour for site visiting

The site visiting has long seemed like the essential process of a landscape project—no matter the project's genre or the site's scale.[39] Large enterprises such as AECOM, Smith group, and Stantec usually receive project requirements from anywhere in the country, even from other countries. In such a situation, assigning a landscape architect to the site need a large budget. What companies always do is sending part of the members in the group assigned for the project. The designers on a business trip then take photos or shoot videos for recording the site. Therefore, the designers in the company could also realize the site from the recordings.

Inspired by this tradition, the 360-degree site visiting could potentially be a new way to record the site. In the thesis, the Insta 360 One X camera is applied for the site visiting. An affiliated software designed for the camera, Insta 360 Studio, provides simple editing functions for designers to manage the files. Any VR software could view the final result in the market or simply purchase a Google Cardboard (Figure 3.1). The Google Cardboard is the most straightforward VR headset out there on the market. Users just put a smartphone opened the VR video on YouTube in the Google Cardboard and can experience the virtual site visiting.

[39] Mark Francis, "A Case Study Method For Landscape Architecture," n.d., 15.

A first-person storytelling style suitable while the video is defined to be informative is applied in the video. In the video, the designer tries to explain what the idea found on the internet. Several problems with the site have been found, and the designer could point them out in the video. Moreover, any quick idea and information that was designed figured out during the filming could also be narrated in the video. While recording the video, the designers are suggested to record the video in many pieces. Each short video should last around two minutes for easier editing and also saving the hardware. After shooting the video, the designers could import the short videos in any software listed in Chart.3.3 for further editing (Figure 3.2). The final result on YouTube (Figure 3.3) has been delivered to the instructor, Christopher Ball, and the JOUR 460 class students for peer-reviewing.

Figure 3.1: Experience virtual reality with smartphone and Google Cardboard

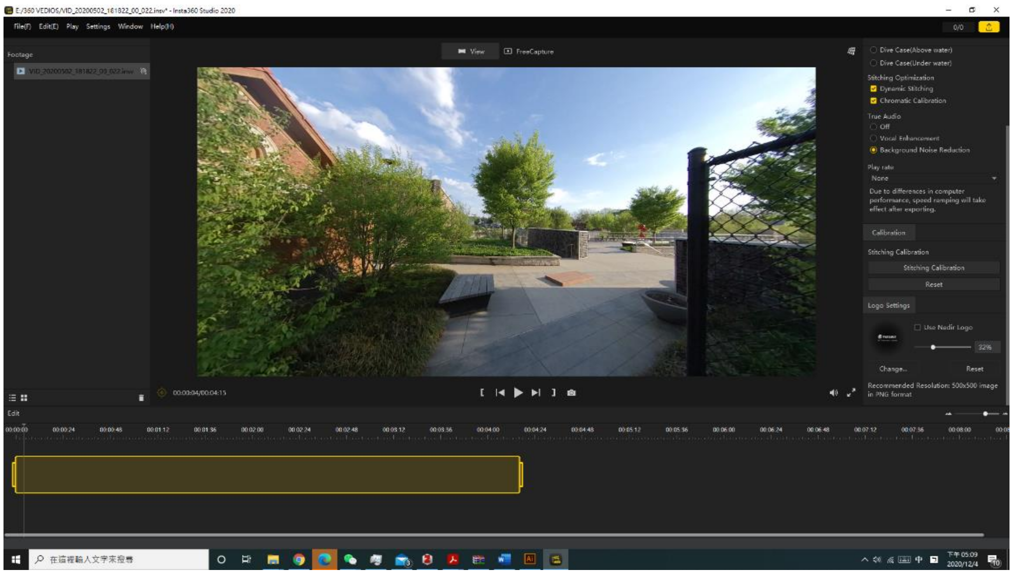

Figure 3.2: The interface of Insta 360 Studio

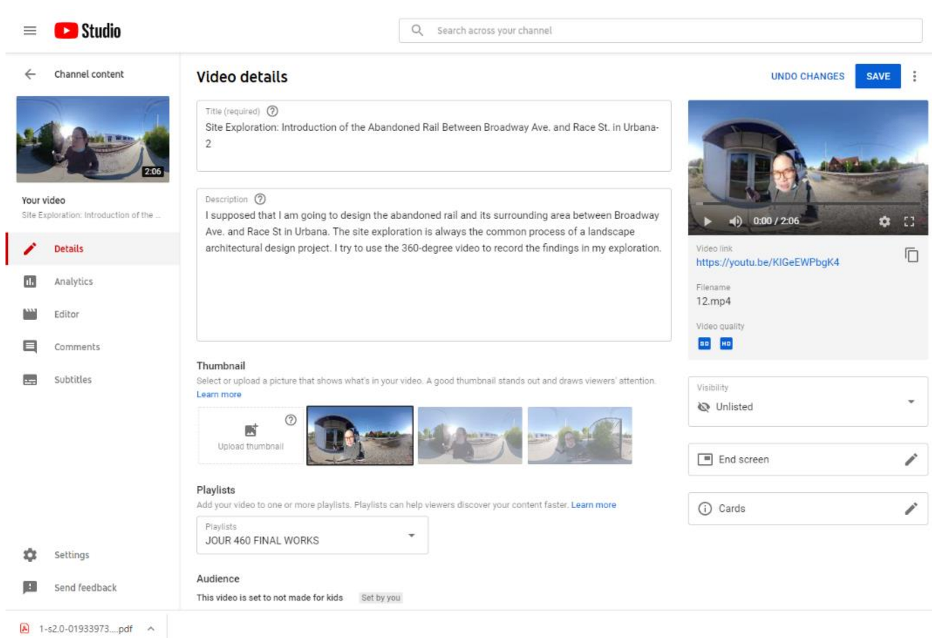

Figure 3.3: The final result on Youtube

The advantage of the 360-degree site visiting is that the technic does not take a long time for designers to learn. If a designer knows how to use Adobe Premier, the 360-degree video editing is not a challenge. Next, designers can easily narrate any information in the video to enhance communication with their colleagues. The JOUR 460 class's feedback confirms that the video is informative and helpful for understanding a site. Moreover, the hardware is not expensive. The entry-level equipment, Insta 360 One X camera priced 400 dollars, and the Google Cardboard priced around 20 dollars.

On the other hand, some feedback mentions that viewers quickly get virtual reality dizziness, which is three-dimensional dizziness usually caused by virtual reality while watching the video.[40] Moreover, such a site visiting is not efficient to be applied in a small-scaled project, including residential or green roof design. The traditional method, such as taking photos and labeling the idea or issue on a map, seems more efficient in a small-scale project.

Immersive design and modeling

The second thesis question is whether the MR tools provide an immersive space that can facilitate creative thinking. For testing out the potential function, Chapter 5 will focus on this topic.

Mixed reality design communication

The mixed reality communication in landscape architecture has been discussed in Chapter 1. In Chapter 3, numerous software considered helpful for communication is listed. Usually, practitioners bring the document with site information, graphics with design ideas, or animation of the design model to communicate with them. Moreover, designers bring papers and pens to the meeting and immediately provide some quick design ideas to the clients. The traditional

[40] Sandra L. Calvert and Siu-Lan Tan, "Impact of Virtual Reality on Young Adults' Physiological Arousal and Aggressive Thoughts: Interaction versus Observation," *Journal of Applied Developmental Psychology* 15, no. 1 (January 1994): 125–39, https://doi.org/10.1016/0193-3973(94)90009-4.

approach has long seemed practical. However, every traditional approach used to be innovative ideas while releasing. The new technology should always be considered so that the industry could be improved.

A. Google Tilt Brush: real-time site analysis and concept developing

The Google Tilt Brush is primarily used for artistic design. Artists are inspired and enumerate ideas in virtual reality. Tara, who has completed research about how VR could blur a user's recognition of the physical world and virtual world, mentioned that Google Tilt Brush is not only a software that provides variable styles of digital drawing tools but also produces a medium for users to communicate the ideas.[41] From Tara's research, the Google Tilt Brush should also have the potential to be utilized in a landscape project.

The character of Google Tilt Brush here is supposed to serve as a medium for communication. A case study done by Hill, a master of landscape architecture, would be discussed for the large-scale project. Hill's thesis research[42] concludes that Tilt Brush is a potential tool for site analysis. The following steps are how Hill test out the Google Tilt Brush.

1. A three-dimensional model of a proposed site created by the three-dimensional scanner settled on a drone.
2. Import the model into Pix.4D software to create an Obj. file, which is the only format that could be imported into Tilt Brush

[41] Tara Chittenden, "Tilt Brush Painting: Chronotopic Adventures in a Physical-Virtual Threshold," *Journal of Contemporary Painting* 4, no. 2 (October 1, 2018): 381–403, https://doi.org/10.1386/jcp.4.2.381_1.
[42] Drew Hill, "HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE DESIGN PROCESS AT VARIOUS SCALES," 2019.

3. Invite several landscape architecture students to do a site analysis, concept developing and visualize the result (Figure 3.4) through the painting tools in Google Tilt Brush

4. Distribute questionnaires to the students for feedbacks

5. Summarize the research according to the drawing in Google Tilt Brush and the students' feedback

Figure 3.4: A student's transportation and hotspots analysis (Drew Hill, Utah State University)

Figure 3.5: A student's concept developing with groups (Drew Hill, Utah State University)

Hill's experiment was taken place in a lab at Utah State University. Students gathered and test out the headset. However, a trending industry, VR game streaming, brings out the idea that designers could also use the build-in chatting function (Figure 3.6) in the Oculus Quest or Stream-VR to communicate with the clients. The success of the virtual conference software, such as Zoom or Microsoft Teams, during the COVID pandemic in 2020 could be a sample that the real-time interactive function provided by Google Tilt Brush potentially becomes a mainstream design communication medium in the future.

Figure 3.6: Virtual chat room interface with Steam VR in Google Tilt Brush

The advantage of the Google Tilt brush for design communicating is enormous. First, people need to spend time learning how to map or understand a map. Showing ideas on a map might not be a suitable approach to communicate with clients who are not in a relevant major. Therefore, a three-dimensional visualized analysis and concept development presented in mixed reality may potentially benefit communication. Moreover, the build-in chatting room function simulates the in-person communication scenario for designers and clients.

However, the drawback is also significant. First, the quality of the model made by Pix4D is not favorable. Clients who do not have relative knowledge might be confused by a vague model. Moreover, the efforts with Google Tilt Brush is hard to be transferred to other parts of the workflow. The drawings made by Google Tilt Brush mismatch the typical drawing in documentations. The designers may not decide the approach since the workload might be doubled.

B. IScape: real-time design idea sharing

IScape is an augmented reality application on smartphones or tablet computers, providing users with an interface to decorate a space. Similar applications are including ARLandscaper and Ikea Place, while Ikea Place is mainly for Ikea's furniture business. However, Ikea Place is the pioneer of applying AR as a tool to simulate a decorated space. To prevent customers from purchasing furniture with a non-suitable size to fit the rooms, Ikea produces Ikea Place. Ikea Place becomes an excellent example of using AR to propose a design example before purchasing the materials and start the construction.[43]

IScape, an AR software introduced after Ikea Place, focuses on garden design. The general feature of iScape is to put plants in a garden virtually. Moreover, designers could put some textures or pavement in the garden. Designers can also edit a graphic just like other photo editing software but made explicitly for landscape designs.

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[43] Selcen Ozturkcan, "Service Innovation: Using Augmented Reality in the IKEA Place App," *Journal of Information Technology Teaching Cases*, August 13, 2020, 2043886920947110, https://doi.org/10.1177/2043886920947110.

IScape AR was first tried out at the beginning of the thesis's spectrum. The software works great in the smartphone that is being utilized in the thesis. However, while the software is updating, the requirement of the hardware becomes higher. Since the application demands higher software quality, the smartphone utilized in the thesis cannot successfully place the item in the AR. The most recent report is unavailable in the research.

The general workflow is as the list below.

1. Capture the site through a smartphone or tablet. The application now only supports IOS systems

2. Start the quick design by placing pavements, textures, rocks, water features, outdoor furniture, fences, or plants into the site captured in the AR (Figure 3.7)

3. Discuss with the client, or save the image of the current view in AR and submit the picture to the clients

Figure 3.7: The current environment of a site(upper) and the site decorated with the design idea(lower)[44]

The advantage of iScape is all about efficiency, especially for a small-scale project, such as a backyard garden. The landscape architects could generate numerous schemes for clients to reference in a short time. Moreover, the iScape developer keeps

[44] "Enable a Smooth Decision-Making and Positive Landscaping Experience," accessed December 5, 2020, https://www.iscapeit.com/blog/enable-a-smooth-decision-making-and-positive-landscaping-experience.

updating the asset library. Thus, an increasing number of materials could be decided while designing. The interface is also user friendly. The designers could place the trees automatically scaled to the real world size. Both the picture editing mode and AR mode provide scaling function if designers supposed to place a smaller or larger plant. Due to the friendly interface of iScape, most of the practitioners do not need that much time than can adeptly operate the technic. To conclude, the software works perfectly in the proposed role.

The drawback of iScape is the high hardware requirement. An iPhone 8 is still incompatible with the software. Moreover, the fully-charged battery run out in merely thirty minutes. The software script needs refinement.

C. Fologram: AR design tour

The founder of Fologram aims to develop an AR tool based on the existing workflow in the architecture industry. Therefore, instead of developing an independent software, the Fologram Company introduces a plugin in Rhino and Grasshopper. Fologram could synchronize the Rhino model to IOS equipment, such as the iPhone or iPad. Therefore, designers can bring the laptop with any IOS equipment and illustrate the model on a physical scale through AR. The functions are considered beneficial for landscape architects.

The AR communicating is the most comfortable feature to manipulate in Fologram. Designers only need to spend less than thirty minutes and can be good at all the functions for AR communicating. The general workflow is listed below.

1. Finish the model and open the Fologram interface in Rhino (Figure 3.8). Synchronize the model to the IOS system through the QR code generated by the plugin.

2. Designers can move, scale, and edit the model in the Fologram application (Figure 3.9, Figure 3.10).

3. The edited model synchronizes to the Rhino in PC. Therefore, designers could also find that the model in PC was changed

4. Fologram synchronizes the layers set in the Rhino. Therefore, designers could turn on or off the layers while communicating with the clients (Figure 3.11)

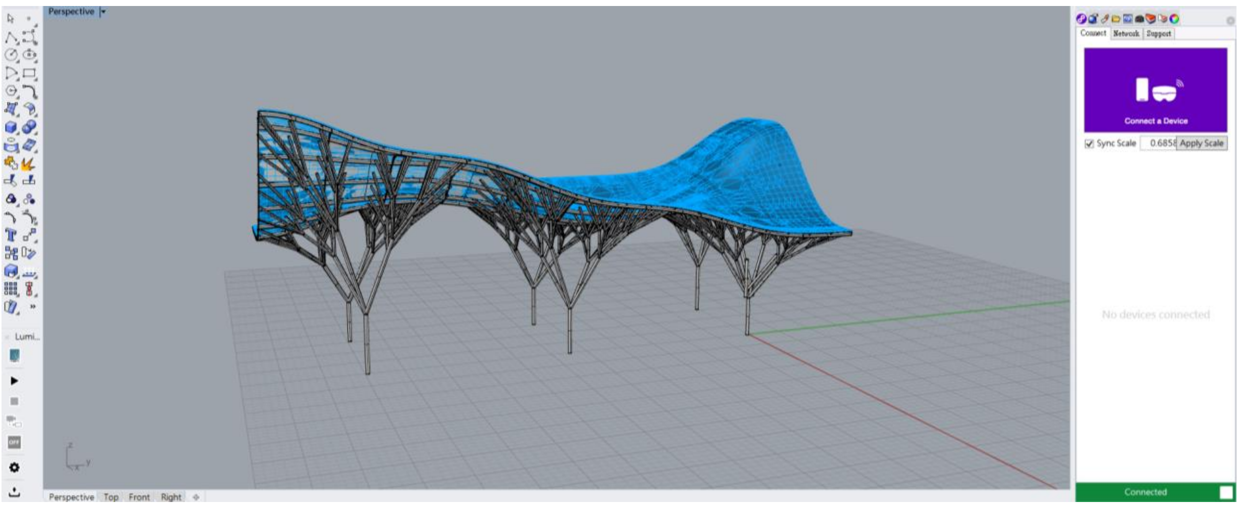

Figure 3.8: The rhino software, the Fologram interface, and the landscape canopy model

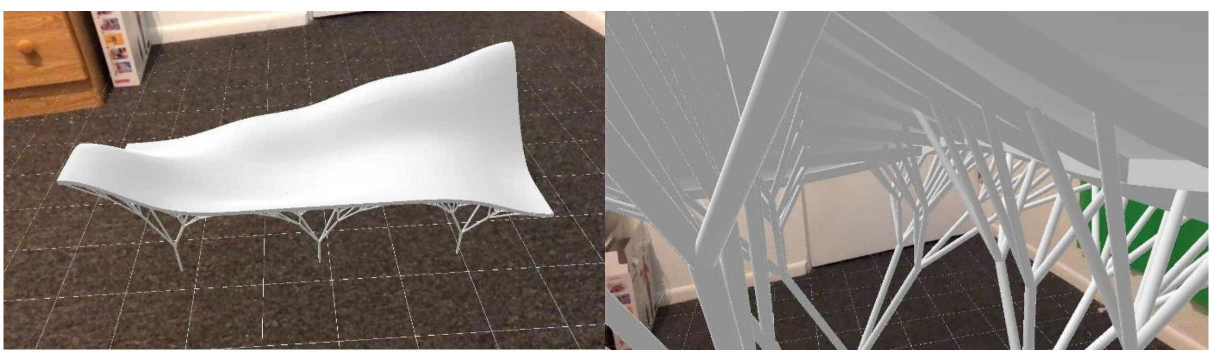

Figure 3.9: Place the model in the augmented reality(left). Scale the model(right).

Figure 3.10: Designers can edit the model in AR

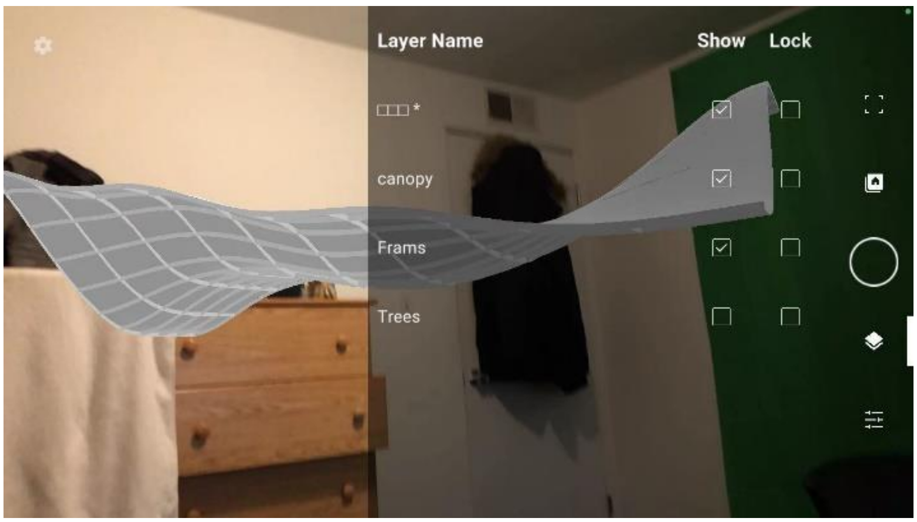

Figure 3.11: Designers can turn on or off the layers for communication

The advantage of the Fologram in AR communicating is that designer could easily show out the model in an augmented reality medium. Moreover, since Fologram is a Rhino-based software, practitioners will not encounter a knowledge gap while learning. The moving and scaling function is suitable for in-face communication. Practitioners could also turn on or off the synchronized layers to make the communication more focused.

The drawback of Fologram in AR communicating is also tremendous power consumption. The iPhone 8 runs out of power in thirty minutes. Moreover, medium or large-scale landscape projects are not suitable for Fologram since viewing a large model in the AR interface since zooming out a landscape model into one to one scale will cover all the real-word background (Figure 3.12).

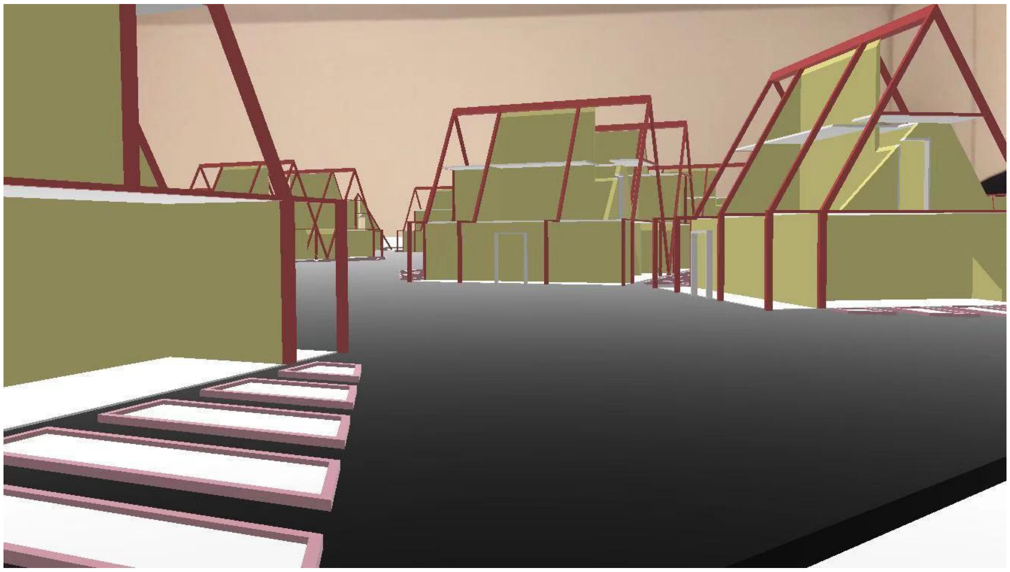

Figure 3.12: Large model could block the real-world background and downgrade the advantage brought by AR

Augmented reality construction assistance

Another function that Fologram could provide is construction assistance. Through Grasshopper, Fologram could provide a real-time construction aid for the constructors. Fologram Company argues that the Fologram could make construction safety, time-saving, and cost-cutting.

The name Fologram originates from AR glasses, HoloLens. The constructors can wear the glasses and receive the construct instruction (Figure 3.13) through Fologram. Instead of construction documents, the Fologram simulates how the structure should be constructed in the AR glasses. The workers will feel like the instructions appear in the real world (Figure 3.14). Therefore, the constructer could make the construction easier.

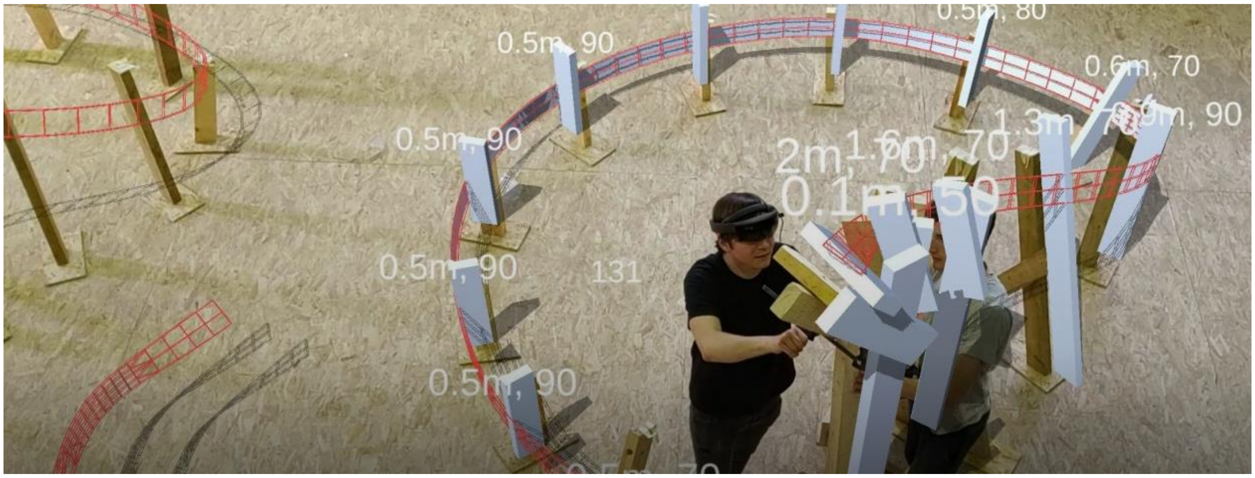

Figure 3.13: Fologram can provide AR instruction for constructor wearing HoloLen[45]

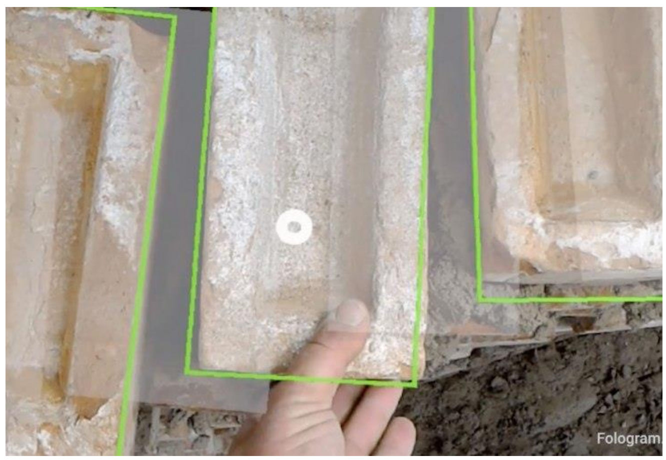

Figure 3.14: Complex brick structure construction. The instructions generated through Fologram in AR glasses[46]

Similar to the AR communication workflow, the designers need to bring a laptop with Rhino and Grasshopper opened in advance. Afterward, use Fologram to synchronize the

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[45] "How Fologram Sees the World and Then Builds in It," *DesignWanted* (blog), January 21, 2020, https://designwanted.com/tech/fologram/.

[46] "This Is How a Complex Brick Wall Is Built Using Augmented Reality | The Strength of Architecture | From 1998," accessed December 5, 2020, https://www.metalocus.es/en/news/how-a-complex-brick-wall-built-using-augmented-reality#.

Grasshopper parameter to the IOS devices. The general workflow of the construct instruction is as below.

1. Create the structure in Grasshopper in most detail (Figure 3.15)
2. Breakdown the structure into pieces (Figure 3.16)
3. Use the Grasshopper to label information, such as layers
4. Designers can adjust the working layer (Figure 3.17)
5. Workers wear AR glasses and follow the instruction (Figure 3.18)

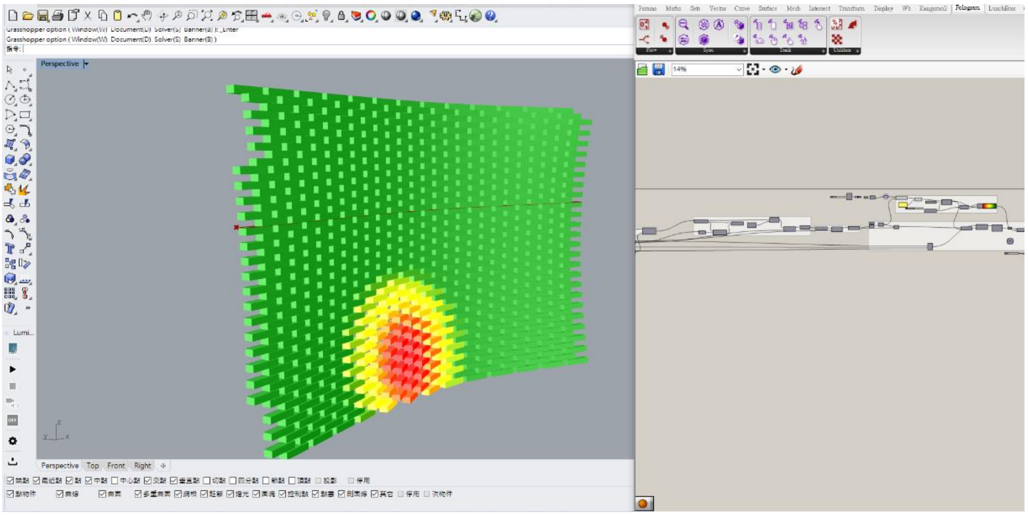

Figure 3.15: Designers must build the model as detailed as possible in Grasshopper

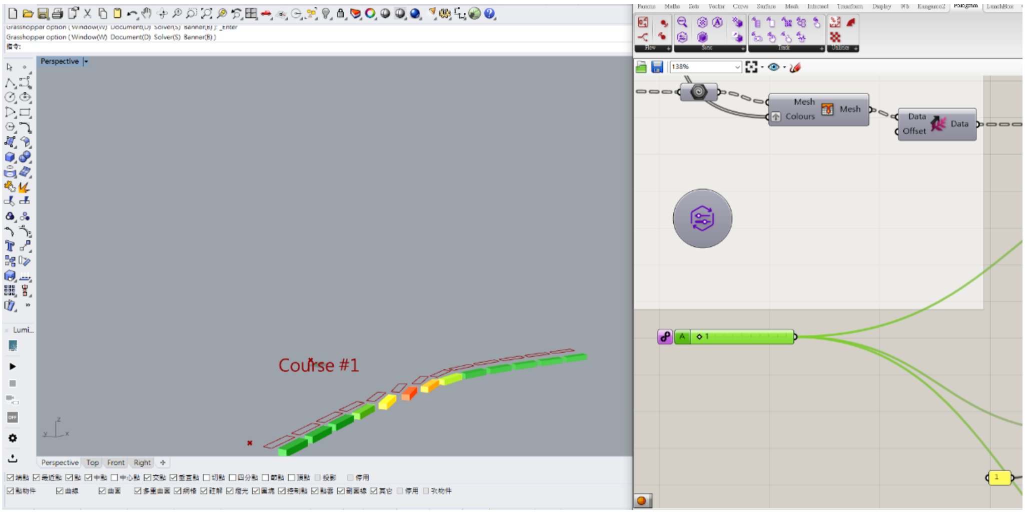

Figure 3.16: Break down the structure into layers

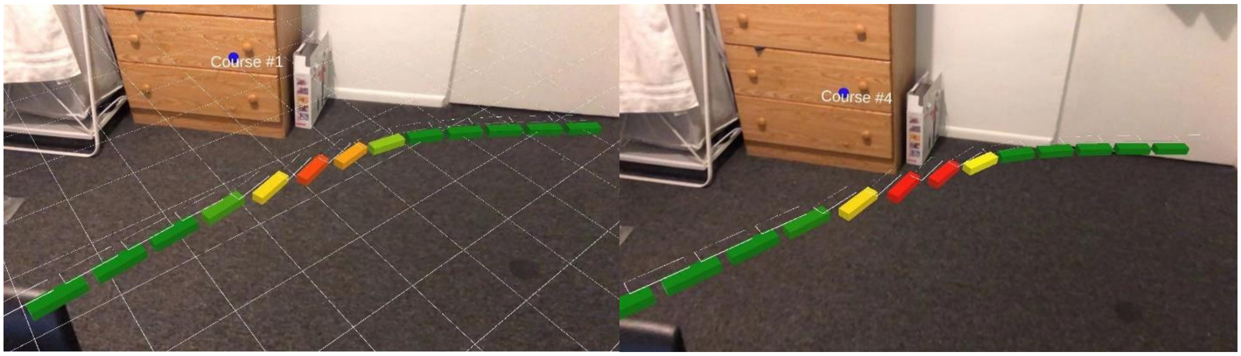

Figure 3.17: Designers could adjust the working layer through AR devices

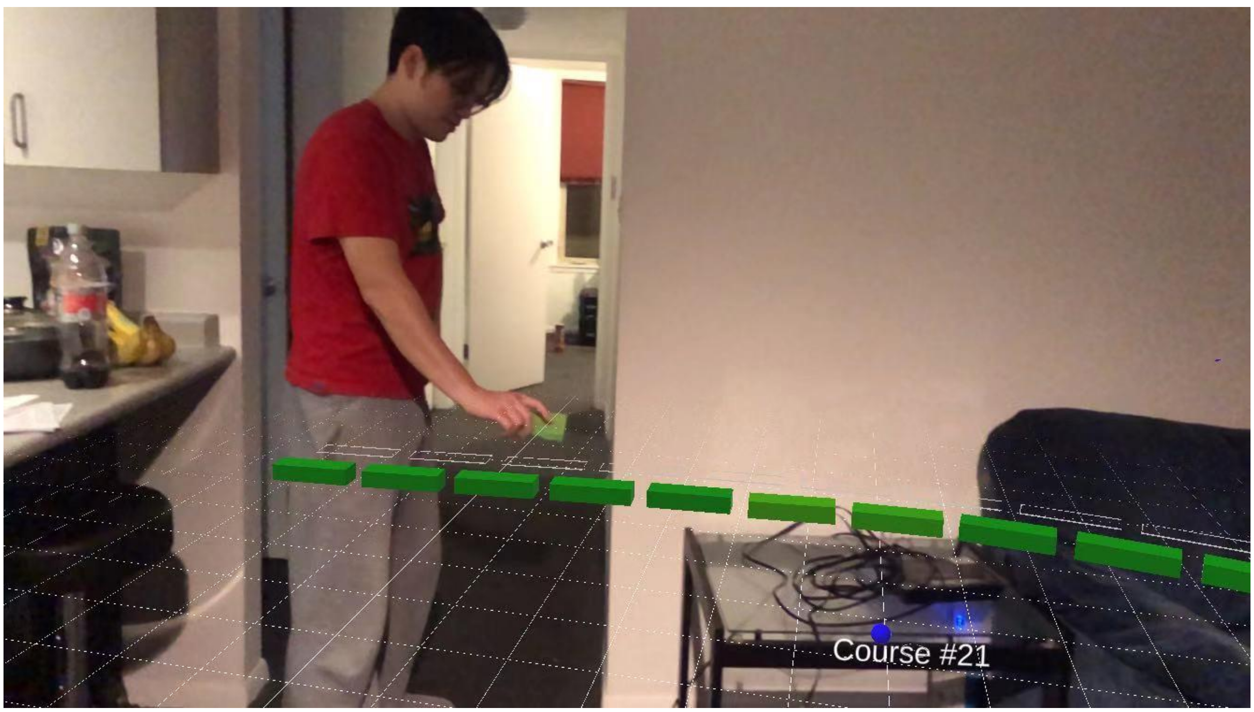

Figure 3.18: Constructors could follow the instruction provided by Fologram

The AR construction assistance's advantage is that practitioners could provide a more direct construction method to the contractors. The coordination between designer and constructer could be improved. Moreover, the Fologram Company’s claim that the software could save construction time is authentic. Directly following the three-dimensional instruction seems more efficient than repetitively checking the construction documents.

The drawback of the Fologram for construction is that the designer may need to have advanced skill in Grasshopper, which is not a required software in landscape architecture professional practice. Furthermore, the budget for the equipment is exorbitant. A Hololens priced 3500 is not affordable for small enterprises, mainstream of the current landscape architecture industry. Finally, whether Fologram is useful to all kinds of designs remains unknown. More future works need to be completed to make Fologram more reliable.

CHAPTER 4: MIXED REALITY SURVEY

Survey Objectives and Design

To address the first thesis question, which is how MR could work with the existing landscape project workflow, information was collected from professional practitioners. For collecting the opinion from practitioners, both in-person interview and questionnaires are required. The in-person interview results were summarized in Chapter 2, and they suggest that virtual reality can benefit communication among designers, clients, and contractors.

Therefore, in Chapter 4, a questionnaire is distributed to 108 Chicago-based landscape architecture firms. The landscape firms are collected from the ASLA FirmFinder system (Figure 4.1). The selected firms are located within twenty-five miles from Elk Grove Village, a town in the geometrical central in Great Chicago Area. By searching in the FirmFinder, 108 companies have been found. There are two ways to contact the companies. First, if the email can be found on the firms' website, a cover letter with the survey will be sent through email. On the hand, if the email cannot be found on the firms' website, the contact form provided on the website is used for reaching out to the companies. The email or message in the contact form especially mentioned to the firms if there is any practitioner graduated from the Department of Landscape Architecture at the University of Illinois at Urbana Champaign, please forward the message to them.

The survey questions are carefully designed and published by Survey Monkey (check Appendix B). The survey design method is introduced later in this chapter. The selections listed in each question are based on the research outcome collected from Chapter 2 and Chapter3.

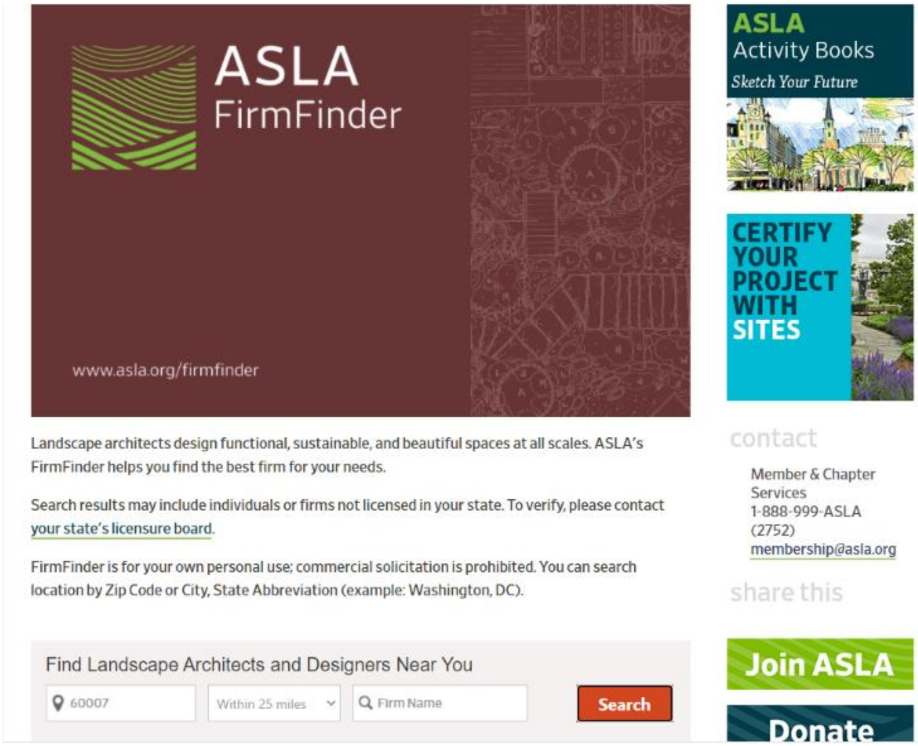

Figure 4.1: The FirmFinder from ASLA website for collecting firms in Great Chicago Area

Objectives

Three conclusions can be drawn from the survey results.

A. First, in Chapter 1, designers have already utilized virtual reality as an ideal communication tool in a project. The first conclusion could clarify the idea, either correct or false.

B. The second conclusion serves as a kind of peer-reviewing of MR software-defined potential functions in Chapter 3.

C. Finally, the third conclusion indicates the landscape architecture professional practitioners either underestimate or overestimate the potential of utilizing MR software. Moreover, the third conclusion will reflect the reason why the MR software has or has not been commonly utilized in the landscape project workflow.

Research of survey design

In 1993, Foddy Williams, in the book "Constructing Questions for Interviews and Questionnaires," has set a universal standard of design questions for either interviews or questionnaires. The most pivotal principle of organizing a questionnaire has proposed the questions only related to the core issue. Redundant questions could decrease the surveyee's willingness to finish the whole questionnaire and increase the difficulty of analyzing the survey outcome. Base on Williams's principle, the survey questions were designed and sent to the thesis committee and other scholars in the landscape architecture department, including professors and Ph.D. students, for peer-reviewing. There are six categories of questions in the survey. The six categories include the landscape architecture professional practitioners' brief personal information, the firm's information, the practitioner's experience of mixed reality, the history of utilizing mixed reality technology in a project, the practitioner's perspective of the potential contribution of the mixed reality technology in landscape architecture, and the practitioner's expectations for utilizing mixed reality technology in each stage of a landscape project. The following list elaborates purpose of the six categories.

A. The landscape architecture professional practitioners' brief personal information

Age and gender are always the indexes of how people would like to learn new technology.[47] The gender and the work experience serve as the first set of questions at the beginning of the questionnaire as a warm-up for respondents.

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[47] Elizabeth White Baker, Said S. Al-Gahtani, and Geoffrey S. Hubona, "The Effects of Gender and Age on New Technology Implementation in a Developing Country: Testing the Theory of Planned Behavior (TPB)," *Information Technology & People* 20, no. 4 (January 1, 2007): 352–75, https://doi.org/10.1108/09593840710839798.

B. The firm's information

According to Yan's graduate research, the landscape architects' experience could affect the willingness to use 3D software in the design process. Therefore, the age of a landscape firm might also affect willingness.[48] In Chapter 2, the literature review shows that the landscape project workflow slightly alters based on the genre of the project.[49] Thus, one of the questions is about the genre of the service that the firms mainly provide.

C. The practitioner's experience of mixed reality

The practitioner's experience of using mixed reality technology might reflect the variable point of view of utilizing mixed reality technology in a landscape architecture project.

D. The history of utilizing mixed reality technology in a project

As described in Chapter 1, several mid to large-sized landscape architecture firms have integrated virtual reality into the workflow. These questions aim to verify this information.

E. The practitioner's perspective of the potential contribution of the mixed reality technology in landscape architecture

The answer to the questions could prove whether the practitioners approve of MR tools' potential contribution, based on the practitioners' knowledge of MR.

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[48] Jie Yan, "An Evaluation of Current Applications of 3D Visualization Software in Landscape Architecture" (M.L.A., United States -- Utah, Utah State University, 2014), https://search.proquest.com/pqdtglobal/docview/1659779341/abstract/DF2D5B99BD844DDPQ/1.

[49] Sharky, "The Design Process and the Life of a Project."

F. The practitioner's expectations for utilizing mixed reality technology in each stage of a landscape project

The answer to the questions could prove whether the practitioners approve that MR tools are practical in practice, based on the practitioners' knowledge of MR.

Survey distribution and collection

Results from the survey could be defined as descriptive statistical data. For obtaining an effective survey outcome, 20% of the total survey recipients should answer the questionnaire[50]. For securing the most significant chance to get the answer, the survey will focus on the practitioners in the Great Chicago Area or the alumni from the University of Illinois at Urbana-Champaign. Finally, there are 40 respondents answer the survey.

[50] L. R. Gay, “Educational Research Competencies for Analysis and Application,” 1992.

Survey Results: Basic Information

Gender distribution

There are sixteen females and twenty-three males who participated in the survey (Figure 4.2).

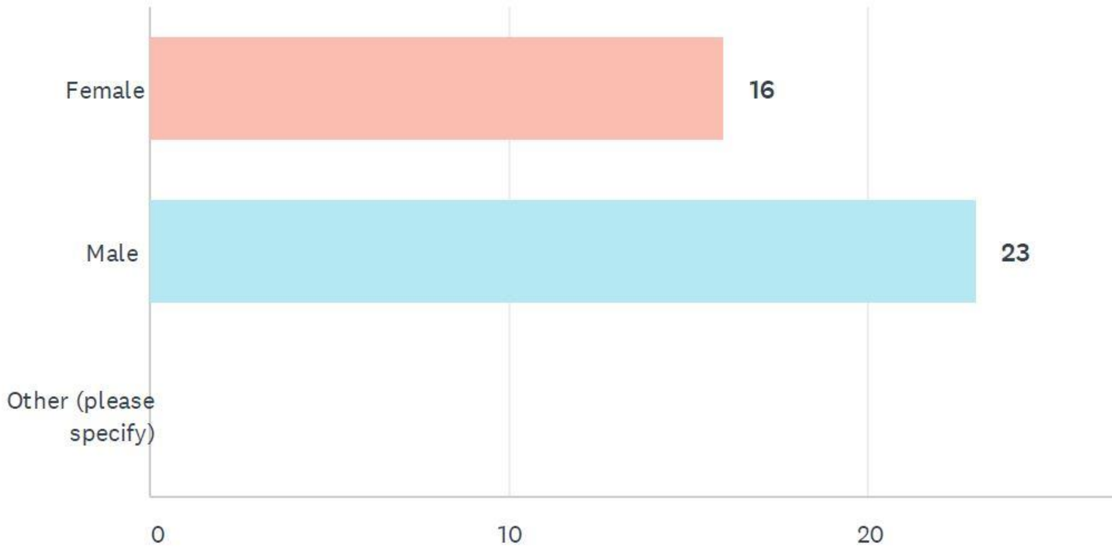

Figure 4.2: Gender distribution of the survey

Work experience distribution

70% of the respondents have worked in the landscape architecture industry for more than ten years. Only 30% of the respondents have worked less than ten years (including the tenth year).

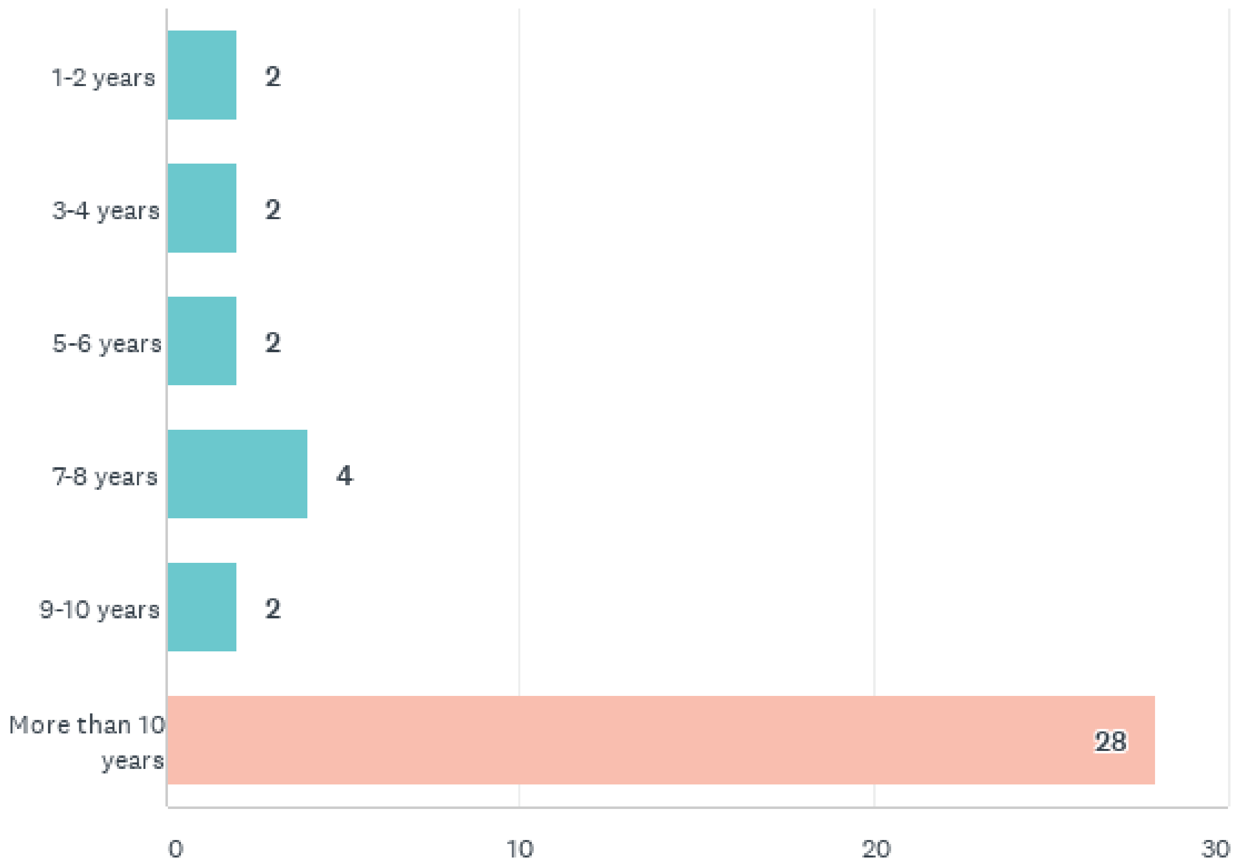

Figure 4.3: Respondents' experience distribution

Distribution of the size of respondents' firm

Seventeen respondents are from firms with one to five employees. Ten respondents are from firms with six to ten employees. Three respondents are from firms with eleven to thirty employees. Three respondents are from firms with thirty-one to fifty employees. Seven respondents are from firms with more than fifty employees.

The result (Figure 4.4) indicates that more than half of practitioners in Chicago tend to have their own business, or work in a rather small-size company.

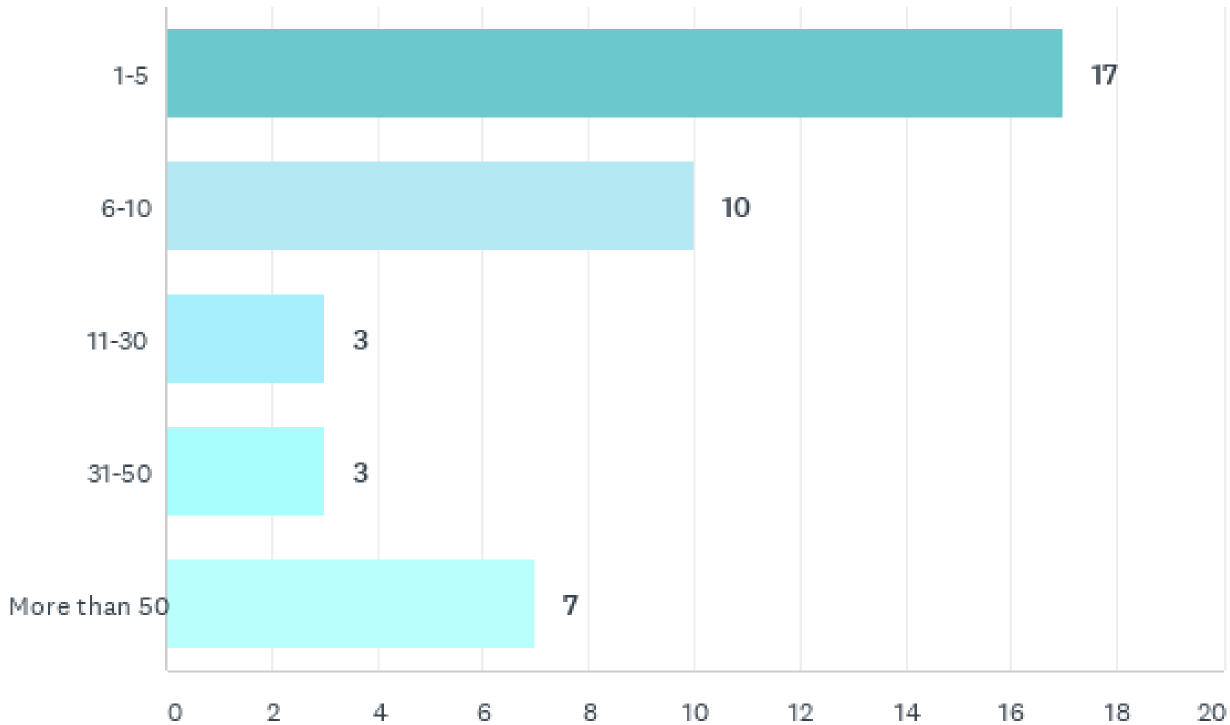

Figure 4.4: Distribution of respondents' firm size

Distribution of the time of years respondents' firm established for

Four respondents are working in a landscape architecture firm established for less than three years. Five respondents are working in a landscape architecture firm established for more than ten but less than twenty-one years. Thirty-one respondents are working in a landscape architecture firm established for more than twenty-two years.

The result (Figure 4.5) shows that experienced practitioners are more likely to answer the survey. On the other hand, the result might also mean that younger practitioners in the landscape architecture industry is relatively scarce.

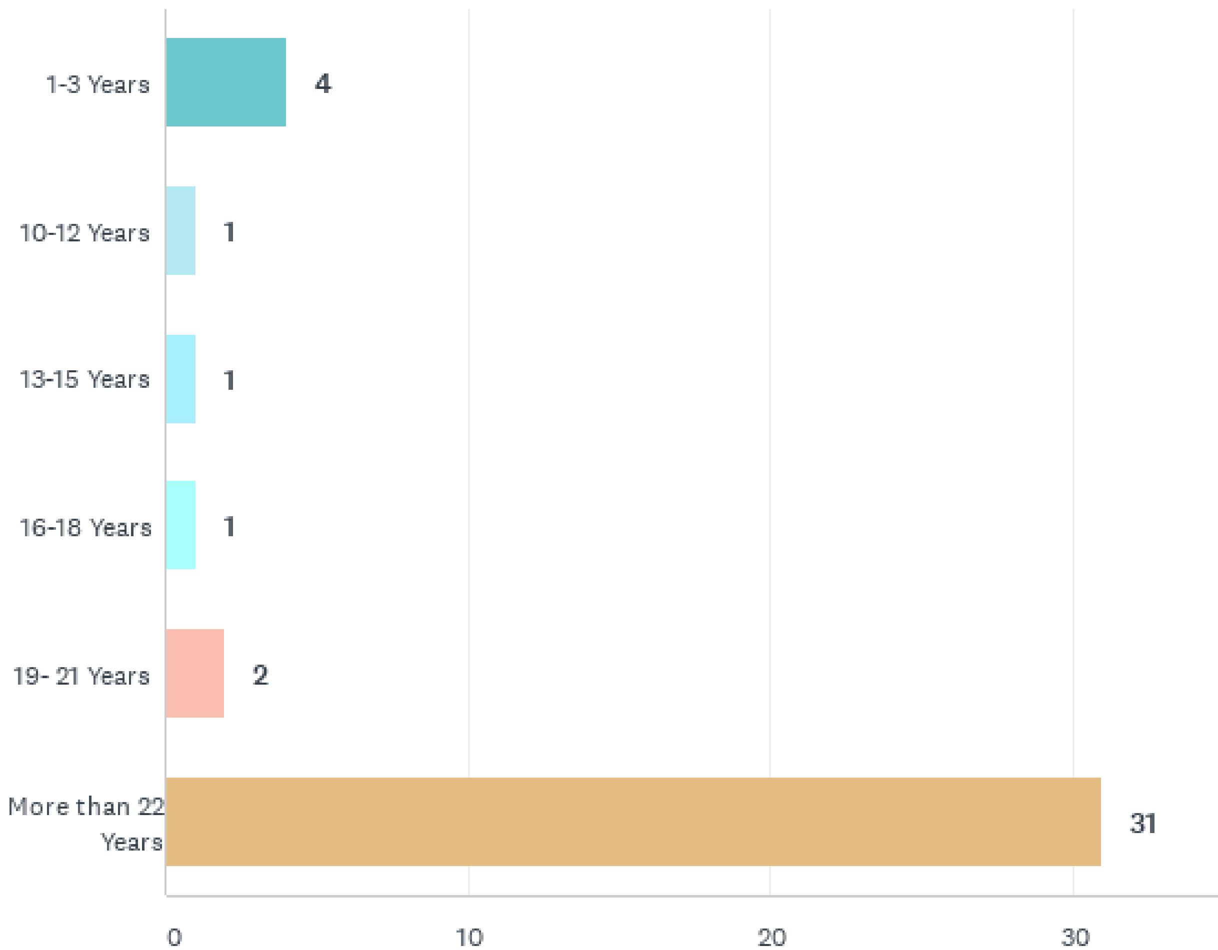

Figure 4.5: Distribution of the time of years respondents' firm established for

Survey Results and Analysis: Current Rate of use Among Practitioners

Experience with virtual reality

Nineteen respondents indicate that they use virtual reality for gaming or entertainment. Eleven respondents indicate that they use virtual reality for architecture or landscape architecture projects. One surveyee indicates that he or she uses virtual reality for primary learning. Two respondents indicated that they use virtual reality for teaching. One surveyee indicates that he or she uses virtual reality for medical training. Four respondents indicated that they use virtual reality for flight simulating. Three respondents indicated that they use virtual reality for other purposes. Fifteen respondents indicate that they have never used virtual reality. One of the respondents checked "other" but responded, "none." The popularity rate of practitioners using virtual reality is 62.5%. 44% of the practitioners using virtual reality have the experience of utilizing virtual reality technology in either landscape architecture or architecture area.

More than half of the respondents have tried virtual reality, indicates that virtual reality is not an alien technology in the landscape architecture field. Entertainment is still the most common reason why people use virtual reality. Even the respondents are designers.

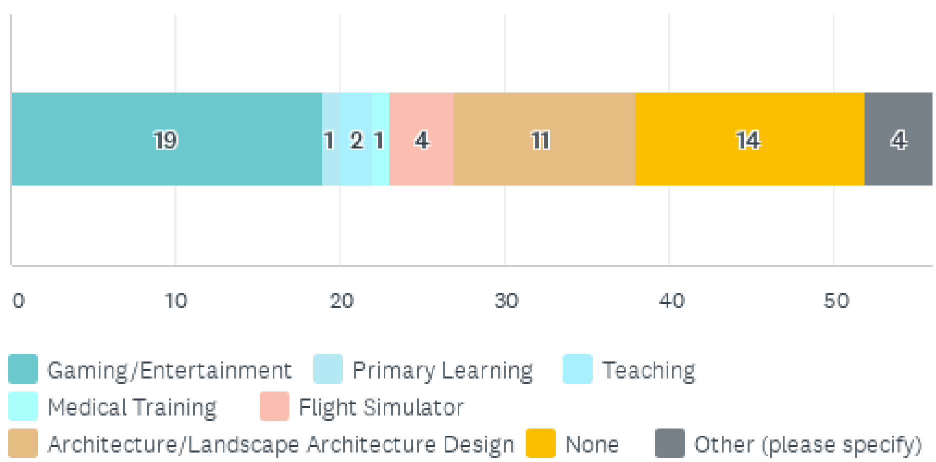

Figure 4.6: The discipline of the practitioners using virtual reality technology

Experience with virtual reality

Eleven respondents indicate that they use augmented reality for landscape architecture projects. Five respondents indicated that they use augmented reality for architecture projects. Ten respondents indicate that they use augmented reality for gaming or entertainment. One surveyee indicates that he or she uses augmented reality for industrial manufacturing. Four respondents indicated that they use augmented reality for urban planning. Eight respondents indicated that they use augmented reality for visual arts. Six respondents indicate that they use virtual reality for other purposes. Fifteen respondents indicate that they have never used augmented reality. One of the respondents skipped the question. Therefore, a total of sixteen respondents never use augmented reality technology. The popularity rate of practitioners using augmented reality is 60%. 46% of the practitioners using augmented reality have the experience of utilizing augmented reality technology in landscape architecture.

More than half of the respondents have tried augmented reality, indicating that augmented reality is not an alien technology in the landscape architecture field. Moreover, the augmented reality is slightly popular than virtual reality in landscape architecture. Comparing to virtual reality, augmented reality shows more balance between landscape design purposes and gaming.

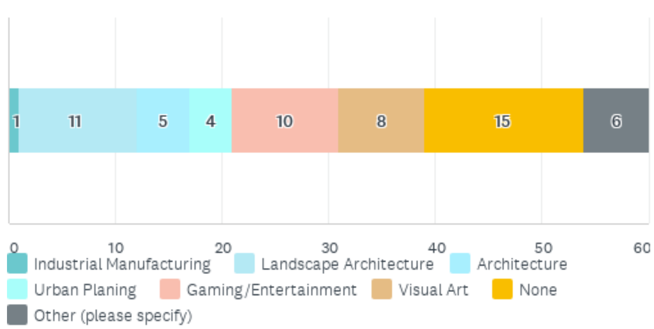

Figure 4.7: The discipline of the practitioners using augmented reality technology

Frequency

As a result (Figure 4.8), about 45% of respondents use VR for any reason less than once a month for the respondents who have ever used virtual reality for landscape or architecture projects. 9% of respondents use VR once a month. 27% of respondents use VR a few times a month. 9% of respondents use VR a few times a week. Finally, 9% of the respondents never used VR.

According to the survey completed by AR Insider, 22% of VR users experience VR less than once a month.[51] The Figure, which is nearly half of the thesis survey figure, shows that numerous landscape practitioners only use VR for works or only tried VR several times in their lives. Moreover, 78% of VR users manipulate VR at least once a month in AR Insider's statistics. The 45% of respondents who experience VR at least once a month show that the practitioners who frequently use VR are mainly for their works. On the other hand, since the defined population stands for the respondents who have utilized VR in either landscape or architecture projects, those who have never used VR could be considered an error value.

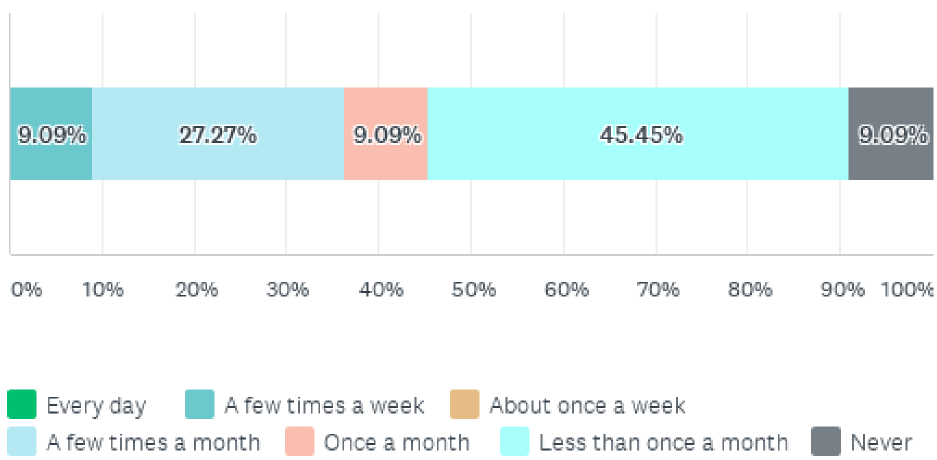

Figure 4.8: Frequency of using virtual reality technology

[51] A. R. Insider, "How Often Do VR Users Engage?," AR Insider, May 21, 2020, https://arinsider.co/2020/05/21/how-often-do-vr-users-engage/.

For the respondents who have ever used augmented reality for landscape or architecture projects in AR's result, about 54.55% of respondents use AR less than once a month. 36% of respondents use AR a few times a month. 9% of the respondents never used AR.

In AR Slider's report, more than 71% of the AR users experience AR at least once a week.[52] The result shows a similar conclusion as the VR's result. More practitioners who are experienced with AR mainly manipulate AR for their professional practices. Mentionable, the difference between the Figure of using AR less than once a month in AR Slider's report and the thesis's report is smaller than the VR's. The difference may show that more practitioners experienced with AR use the technology for other uses than VR. Finally, the same as the VR's result, those who have never used AR could be considered an error value.

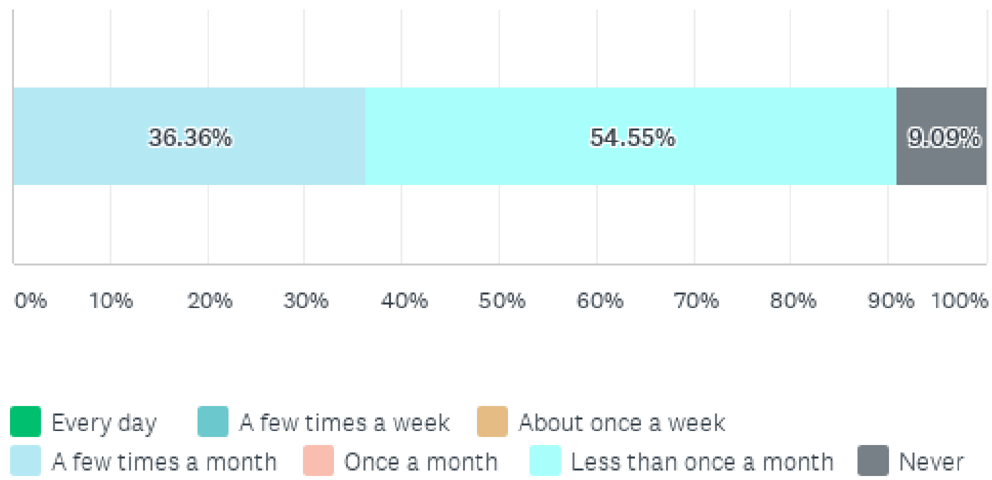

Figure 4.9: Frequency of using augmented reality technology

[52] Mike Bol, "What Types of AR Experiences Are Used Most?," AR Insider, August 13, 2020, https://arinsider.co/2020/08/13/what-types-of-ar-experiences-are-used-most/.

Years of professional practice and the use of mixed reality

The survey result (Figure 4.10) shows that 65 % of the practitioners with more than ten years of experience with landscape architecture professional practice used VR for a project. In comparison, nearly 80% of the practitioners with more than ten years of experience with landscape architecture professional practice have no experience with VR. For the same issue (Figure 4.11), 65 % of the practitioners with more than ten years of experience with landscape architecture professional practice used AR for a project. On the contrary, 63% of the practitioners with more than ten years of experience with landscape architecture professional practice have no experience with AR.

35% of the practitioners who have used VR in a landscape project have less than ten years of working experience. In comparison, 23% of practitioners who never use VR in a landscape project have less than ten years of working experience. The result reflects that practitioners with less than ten years of work experience have more enthusiasm to try using VR in landscape projects. The consequence may also conform to the fact that younger individuals have more possibility to experience VR than elders.[53] On the other hand, such a difference between the number of practitioners who have used AR for a project and practitioners who have no AR experience is insignificant. The outcome might indicate that the senior practitioners may share a similar enthusiasm for trying AR for a project as younger practitioners. To conclude, landscape architecture professional practitioners in all working times consider AR is more acceptable to be utilized in projects than VR.

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[53] Insider, “How Often Do VR Users Engage?”

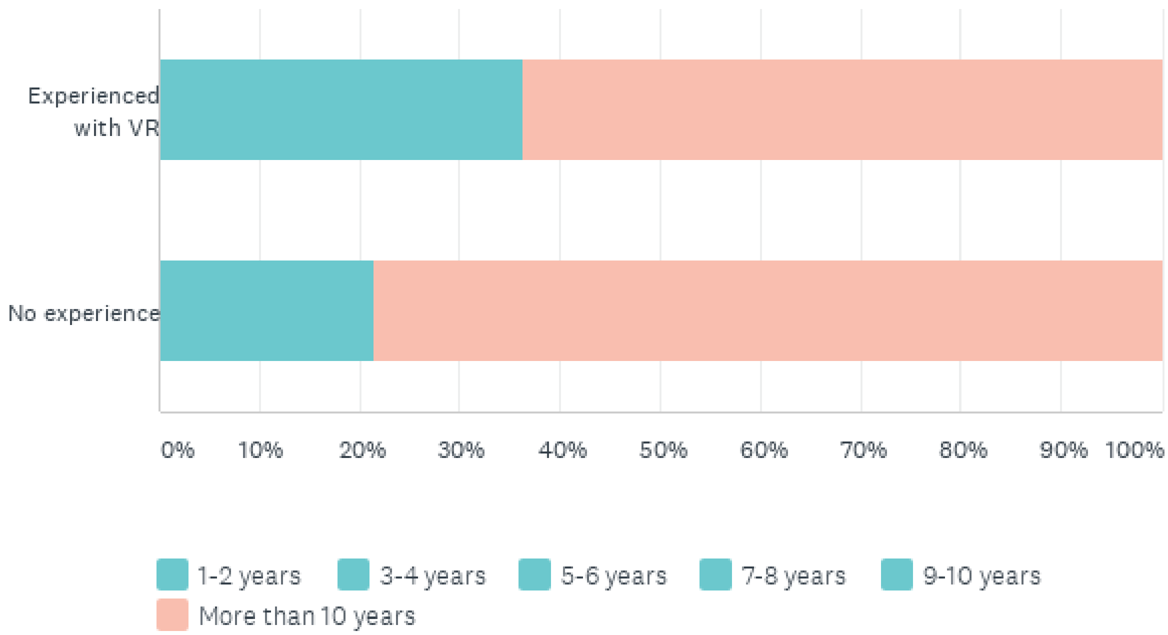

Figure 4.10: The popularity rate of using VR between practitioners work for less than ten years and practitioners work for more than ten years

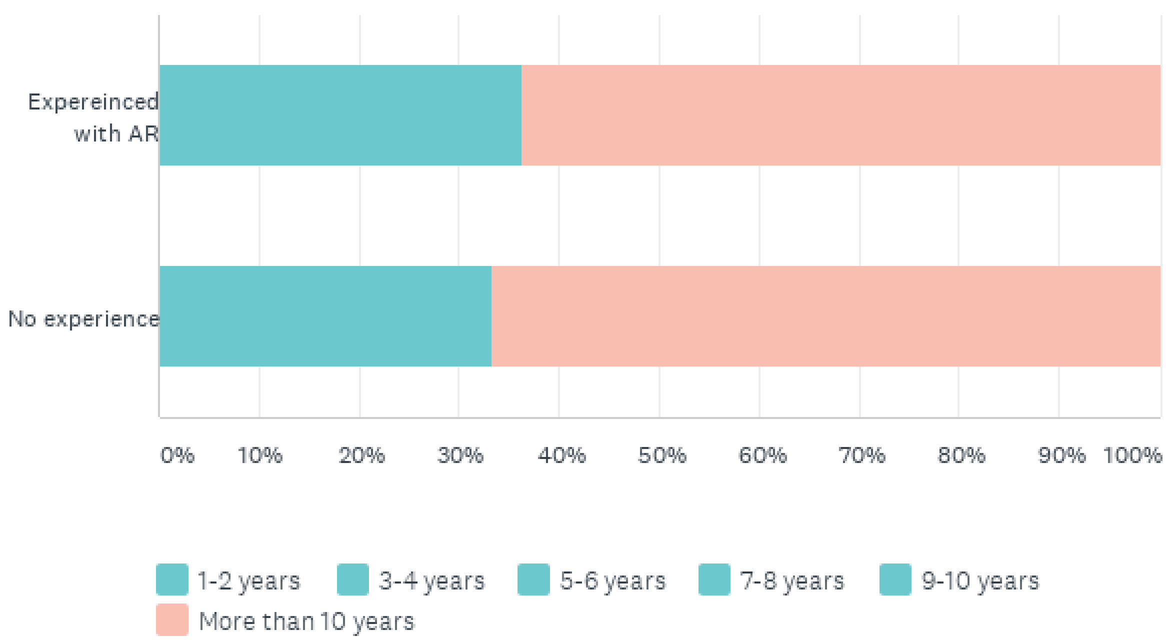

Figure 4.11: The popularity rate of using AR between practitioners work for less than ten years and practitioners work for more than ten years

Company size and the use of mixed reality

As a result (Chart 4.1), 50% of the practitioners from a firm with one to five members, 12.5% from a firm with six to ten members use VR for a project. 50 % of practitioners from a smaller medium-sized firm with 11-30 members and 100 % of the practitioners from a larger medium-sized firm with 31-50 utilize VR for a project. Finally, 75% of practitioners from a large-sized company take VR as a tool for landscape projects. For the AR's result (Chart 4.2), 54% of the practitioners from a firm with one to five members, 14% from a firm with six to ten members use AR for a project. 0% of practitioners from a smaller medium-sized firm with 11-30 members and 50 % of the practitioners from a larger medium-sized firm with 31-50 utilize AR for a project. Finally, 60% of practitioners from a large-sized company take AR as a tool for landscape projects.

The result shows that the larger the company size, the more possible to use VR or AR in landscape projects. However, since the population of each genre has limited samples, the conclusion loses authenticity.

	1-5	6-10	11-30	31-50	MORE THAN 50	TOTAL
Experienced with VR	45.45% 5	9.09% 1	9.09% 1	9.09% 1	27.27% 3	44.00% 11
No experience	35.71% 5	50.00% 7	7.14% 1	0.00% 0	7.14% 1	56.00% 14
Total Respondents	10	8	2	1	4	25

Chart 4.1: The difference popularity rate of using VR base on firm size

	1-5	6-10	11-30	31-50	MORE THAN 50	TOTAL
Experienced with AR	54.55% 6	9.09% 1	0.00% 0	9.09% 1	27.27% 3	42.31% 11
No experience	33.33% 5	40.00% 6	6.67% 1	6.67% 1	13.33% 2	57.69% 15
Total Respondents	11	7	1	2	5	26

Chart 4.2: The difference popularity rate of using AR base on firm size

Firm's Life-span and acquaintance with mixed reality

As a result (Chart 4.3), 60% of the practitioners from firms established for less than twenty -two years, 37% from a firm established for more than twenty-two years use VR for a project. On the other hand, the AR's result (Chart 4.4), 62.5% of the practitioners from firms established for less than twenty -two years, 33% from a firm established for more than twenty-two years use AR for a project.

The result shows that practitioners from the more extended the company was founded, the less tendency to use VR or AR in landscape projects. However, similar to the problem with the company size, since each genre's population has limited samples, the conclusion loses authenticity.

	1-3 YEARS	4-6 YEARS	7-9 YEARS	10-12 YEARS	13-15 YEARS	16-18 YEARS	19- 21 YEARS	MORE THAN 22 YEARS	TOTAL
Experienced with VR	18.18% 2	0.00% 0	0.00% 0	9.09% 1	0.00% 0	0.00% 0	9.09% 1	63.64% 7	44.00% 11
No experience	7.14% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7.14% 1	0.00% 0	85.71% 12	56.00% 14
Total Respondents	3	0	0	1	0	1	1	19	25

Chart 4.3: The difference popularity rate of using VR base on firm age

	1-3 YEARS	4-6 YEARS	7-9 YEARS	10-12 YEARS	13-15 YEARS	16-18 YEARS	19- 21 YEARS	MORE THAN 22 YEARS	TOTAL
Experienced with AR	18.18% 2	0.00% 0	0.00% 0	9.09% 1	9.09% 1	0.00% 0	9.09% 1	54.55% 6	42.31% 11
No experience	13.33% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6.67% 1	0.00% 0	80.00% 12	57.69% 15
Total Respondents	4	0	0	1	1	1	1	18	26

Chart 4.4: The difference popularity rate of using AR base on firm age

Survey Results and Analysis: Practitioners' Perspective of Mixed Reality

Practitioner's perspective of the potential contribution of VR in Landscape projects

To sum up (Figure 4.12, Chart 4.5), practitioners consider VR to improve showcasing the design idea and communication with the clients. However, less than 40% of practitioners think VR is efficient for the workflow, especially for small-scale projects.

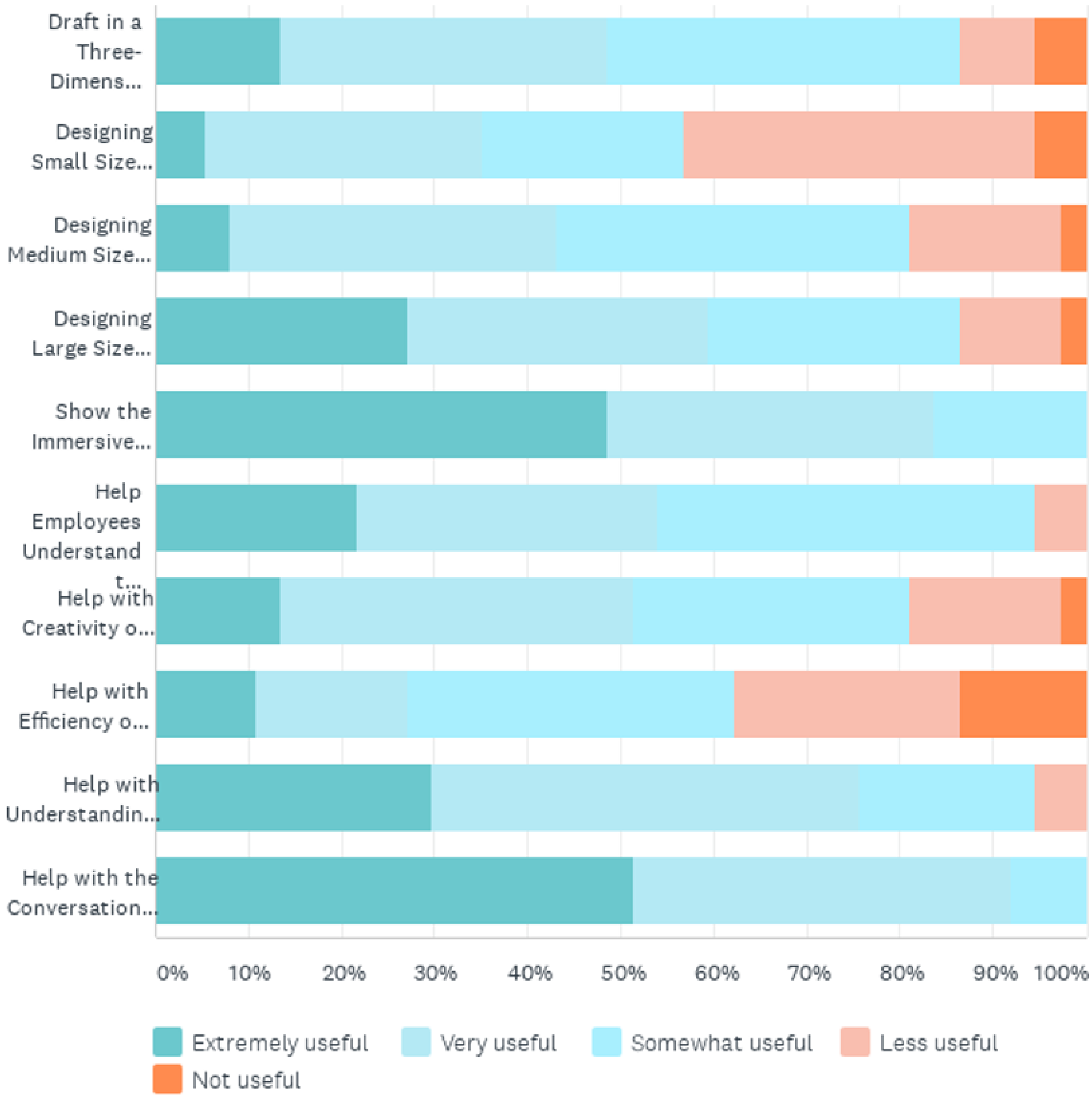

Figure 4.12: How practitioners prove the potential contribution of VR to landscape design

	EXTREMELY USEFUL	VERY USEFUL	SOMEWHAT USEFUL	LESS USEFUL	NOT USEFUL	TOTAL	WEIGHTED AVERAGE
Draft in a Three-Dimensional Space	13.51% 5	35.14% 13	37.84% 14	8.11% 3	5.41% 2	37	3.54
Designing Small Size Projects	5.41% 2	29.73% 11	21.62% 8	37.84% 14	5.41% 2	37	3.03
Designing Medium Size Projects	8.11% 3	35.14% 13	37.84% 14	16.22% 6	2.70% 1	37	3.35
Designing Large Size Projects	27.03% 10	32.43% 12	27.03% 10	10.81% 4	2.70% 1	37	3.76
Show the Immersive Experience of the Design	48.65% 18	35.14% 13	16.22% 6	0.00% 0	0.00% 0	37	4.32
Help Employees Understand the Design	21.62% 8	32.43% 12	40.54% 15	5.41% 2	0.00% 0	37	3.70
Help with Creativity of the Design	13.51% 5	37.84% 14	29.73% 11	16.22% 6	2.70% 1	37	3.49
Help with Efficiency of the Project	10.81% 4	16.22% 6	35.14% 13	24.32% 9	13.51% 5	37	3.14
Help with Understanding the site	29.73% 11	45.95% 17	18.92% 7	5.41% 2	0.00% 0	37	4.00
Help with the Conversation with Clients	51.35% 19	40.54% 15	8.11% 3	0.00% 0	0.00% 0	37	4.43

Chart 4.5: The data of how practitioners prove the potential contribution of VR to landscape design

Practitioner's perspective of the potential contribution of AR in Landscape projects

In summary (Figure 4.13, Chart 4.6), practitioners only consider AR to improve communication with the clients. On top of that, similar to the VR's survey result, less than 40% of practitioners think AR is efficient for the workflow, especially for small-scale projects.

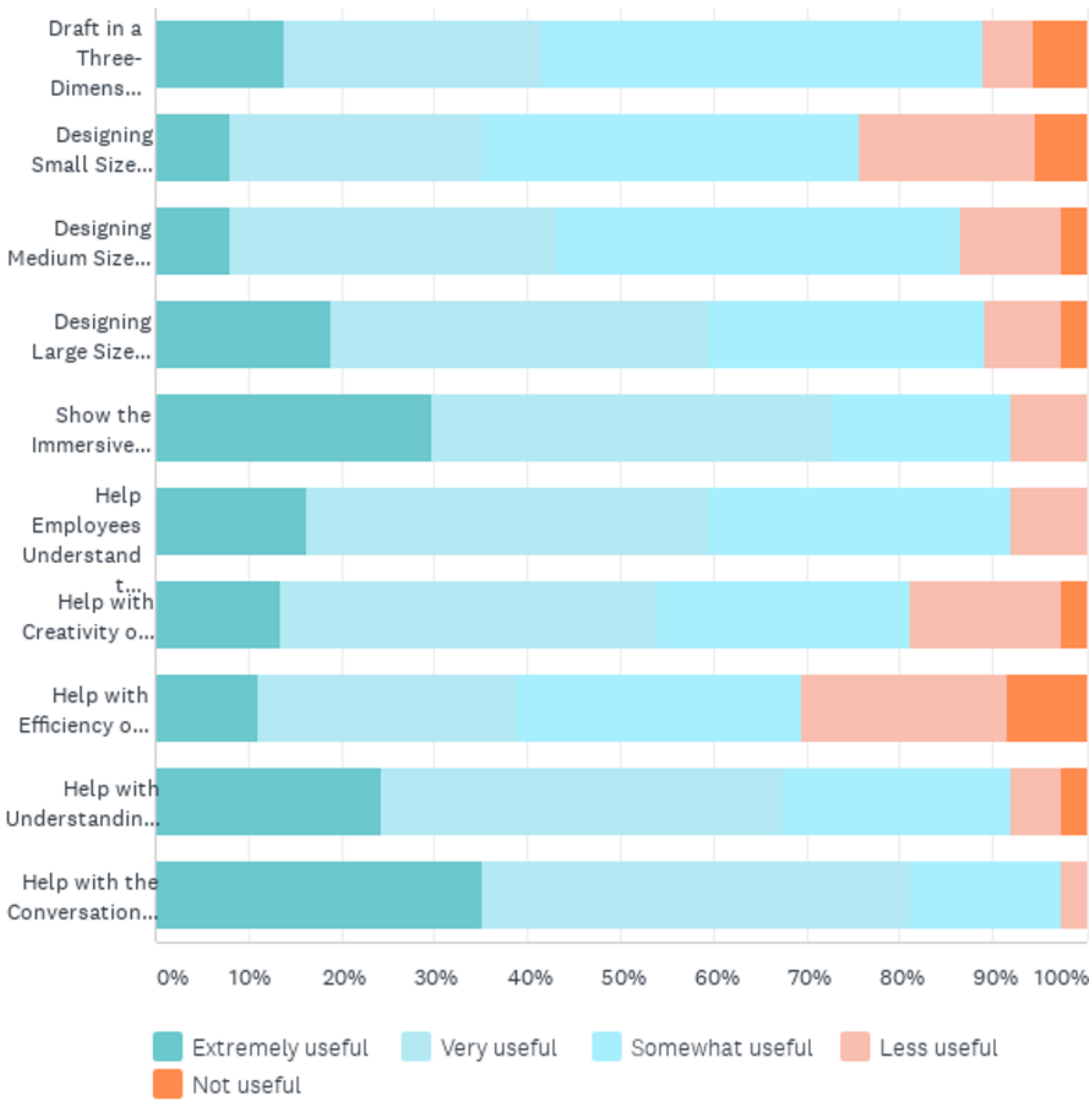

Figure 4.13: How practitioners prove the potential contribution of AR to landscape design

	EXTREMELY USEFUL	VERY USEFUL	SOMEWHAT USEFUL	LESS USEFUL	NOT USEFUL	TOTAL	WEIGHTED AVERAGE
Draft in a Three-Dimensional Space	13.89% 5	27.78% 10	47.22% 17	5.56% 2	5.56% 2	36	3.50
Designing Small Size Project	8.11% 3	27.03% 10	40.54% 15	18.92% 7	5.41% 2	37	3.24
Designing Medium Size Project	8.11% 3	35.14% 13	43.24% 16	10.81% 4	2.70% 1	37	3.41
Designing Large Size Project	18.92% 7	40.54% 15	29.73% 11	8.11% 3	2.70% 1	37	3.70
Show the Immersive Experience of the Design	29.73% 11	43.24% 16	18.92% 7	8.11% 3	0.00% 0	37	3.95
Help Employees Understand the Design	16.22% 6	43.24% 16	32.43% 12	8.11% 3	0.00% 0	37	3.68
Help with Creativity of the Design	13.51% 5	40.54% 15	27.03% 10	16.22% 6	2.70% 1	37	3.51
Help with Efficiency of the Project	11.11% 4	27.78% 10	30.56% 11	22.22% 8	8.33% 3	36	3.28
Help with Understanding the site	24.32% 9	43.24% 16	24.32% 9	5.41% 2	2.70% 1	37	3.86
Help with the Conversation with Clients	35.14% 13	45.95% 17	16.22% 6	2.70% 1	0.00% 0	37	4.14

Chart 4.6: The data of how practitioners prove the potential contribution of AR to landscape design

Three-dimensional sketching

The most critical information in the thesis is whether the mixed reality could assist practitioners by providing a medium for sketching and exploring creative ideas in a three-dimensional space instead of a traditionally two-dimensional medium, such as a paper or a computer monitor. As a result (Chart 4.5), 13.5% of the respondents strongly approve, and 35% approve that VR could provide a space for designers to draft in a three-dimensional space. Besides, 38% of the respondents have a neutral stance on such an idea. Only 13.5 % of the respondents disproved the idea. On the other hand, 13.5% of practitioners consider that VR is strongly supportive of creative thinking, and 38 % think VR is valuable for creative ideas. Nearly 30% of practitioners have a neutral stance. Around 19 % of practitioners do not agree that VR is beneficial to creativity. Practitioners who disagree VR can facilitate creative thinking is slightly higher than the one challenge VR can provide a three-dimensional drafting medium. Noticeably, more than half of the practitioners experienced with VR agree that VR could provide a three-dimensional space for drafting, facilitate creativity (Figure 4.14, Figure 4.15). For practitioners without VR experience, already 38% think that VR could provide a three-dimensional drafting space, nearly 50% stay neutral, only 7.7% do not agree with the idea. However, with VR's contribution to creativity, only 38% of practitioners without experience agree, equal to the Figure, 38% disagree.

Consequently, slightly 5.5% of practitioners think that the software features provided in virtual reality do not support creative thinking. The critical reason is that 38% of non-experienced practitioners think that VR does not benefit creativity. After experiencing VR, only 9% of the practitioner might think VR does not support creativity. To conclude, around 50% of practitioners agree with the idea that VR could potentially serve as a design tool.

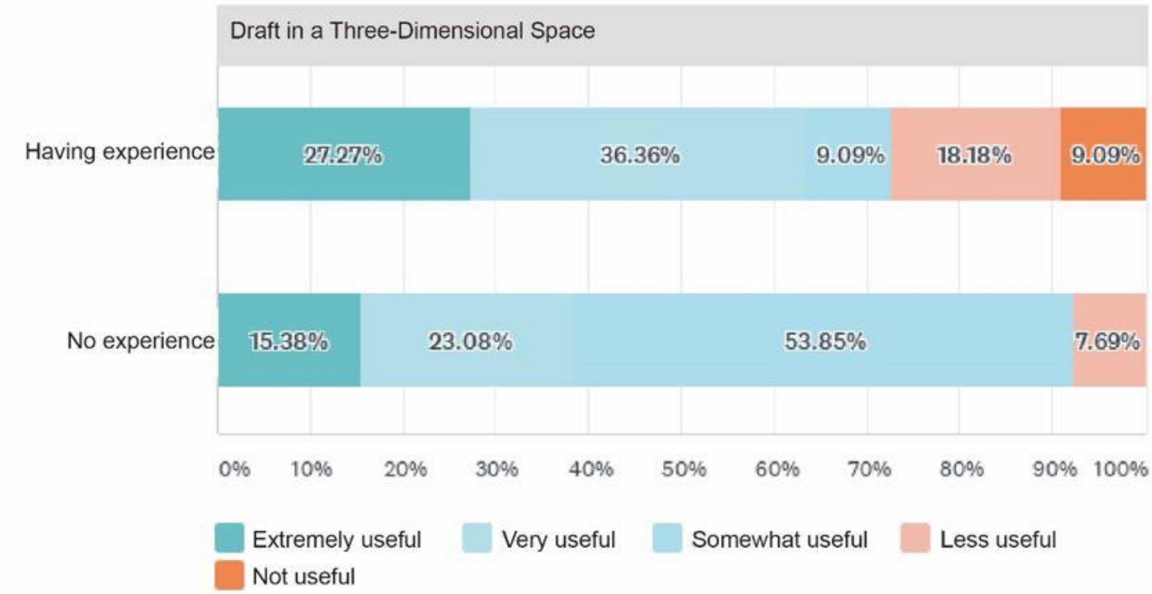

Figure 4.14: Comparison of the practitioners' perspectives of whether VR is supportive for designers to draft in a three-dimensional space, base on the experience

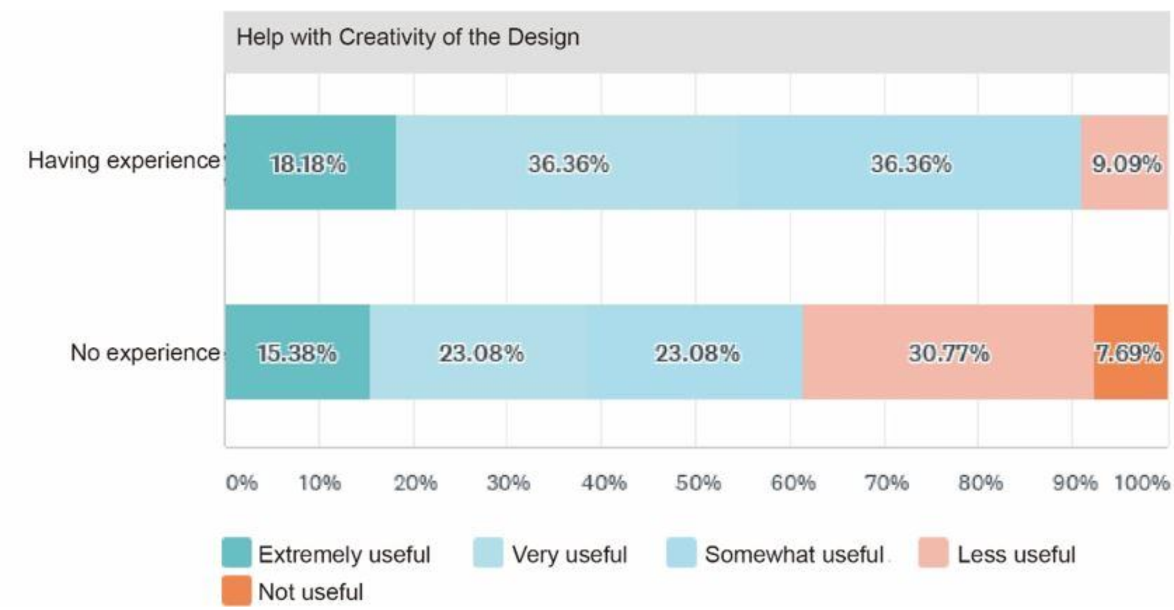

Figure 4.15: Comparison of the practitioners' perspectives of whether VR facilitates designers' creativity, based on the experience

Project scale and mixed reality

Damien, a landscape architect, mentioned in Chapter 2, enumerates that the project's scale always affects the workflow. Therefore, the role of mixed reality will also be considered influenced by the project scale.[54] According to the survey result (Figure 4.14, Figure 4.15, Chart 4.5, Chart 4.6), 35 % of practitioners approve VR or AR is supportive of the small-scale project. 43% think that VR or AR could be effectively utilized in medium-scale projects. 59% of practitioners agree that VR is beneficial for large-scale projects, while 48% consider AR also advantageous.

The result indicates that practitioners believe that mixed reality would be more significant in a large-scale project than a small-scale project. The existing data might not be able to elaborate on the reason. One research might be able to explain. According to Yan's graduate research, efficiency is based on the comparison between multiple design technics.[55] Practitioners might use hand drawing, AutoCAD, or other existing technics to finish the projects more efficiently. However, the comparison of the practitioners who do or do not experience MR (Figure 4.16, Figure 4.17) shows that the designers will slightly think MR is beneficial to the small project after utilizing MR in landscape projects. The outcome may indicate that practitioners might be more optimistic about utilizing MR in small-scale projects by having more MR experience. The same conclusion could also be applied to medium and large projects.

[54] Holmes, "PRACTICE | Stages of a Landscape Architecture Design Project."
[55] Yan, "An Evaluation of Current Applications of 3D Visualization Software in Landscape Architecture."

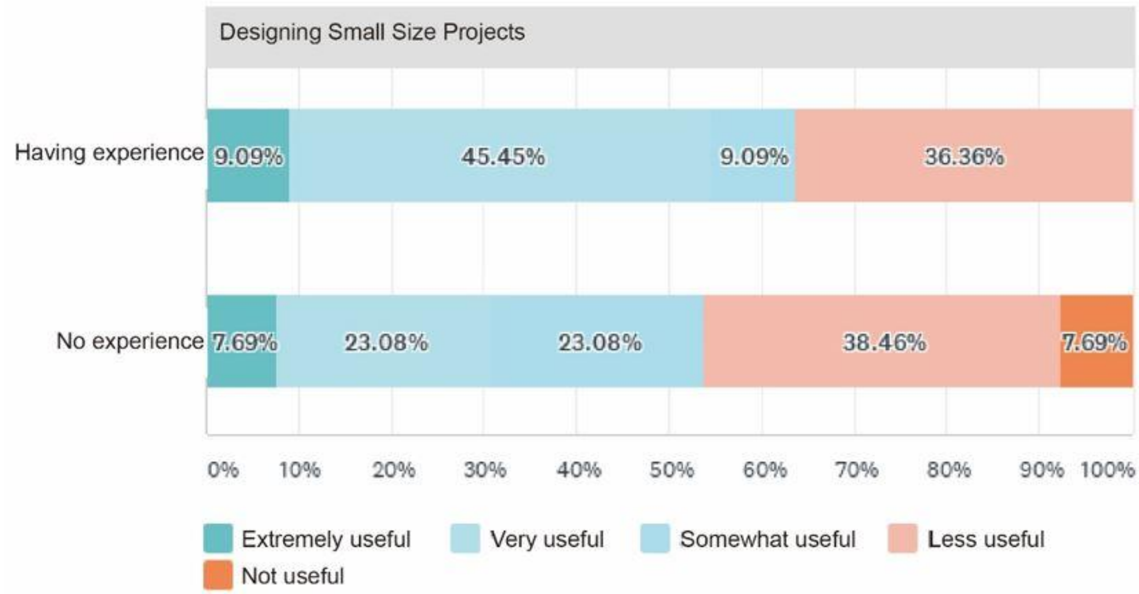

Figure 4.16: Comparison of the practitioners' perspectives of whether VR benefits small-scale projects, based on the experience

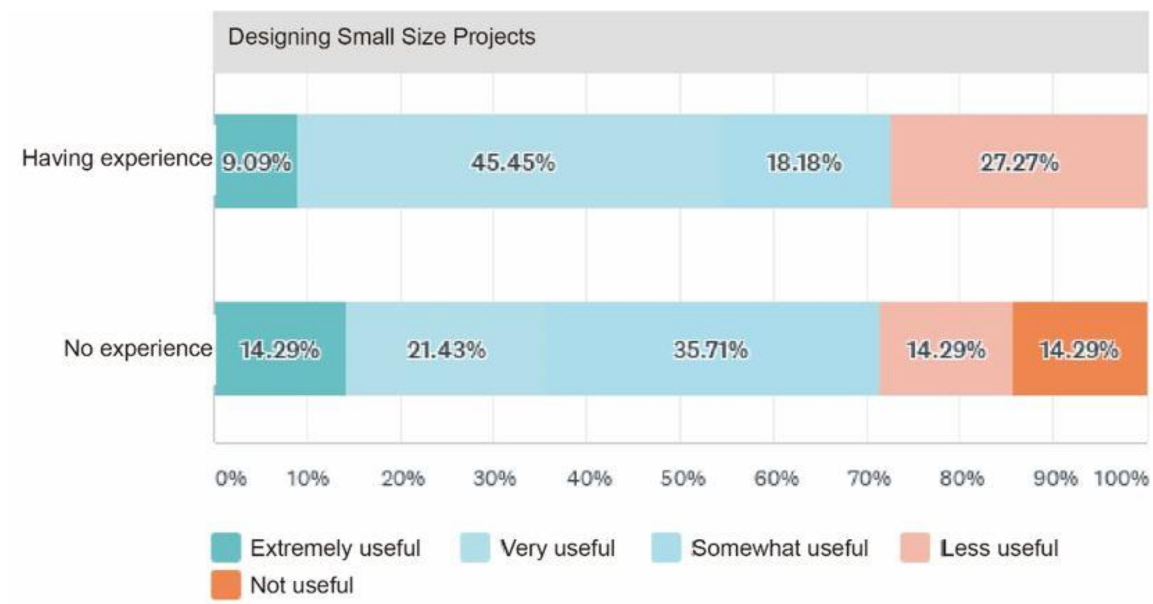

Figure 4.17: Comparison of the practitioners' perspectives of whether AR benefits small-scale projects, base on the experience

Efficiency

For telling something efficient, comparing is always a suitable approach. Song and Huang proposed that the challenge of using virtual reality to build a scene is the high demand for hardware quality and complexity of workflow. Without MR, the standard design process seems more comfortable for designers to build a scene and keep the computer's longevity.[56]

The result (Figure 4.12, Figure 4.13, Chart 4.5, Chart 4.6) shows that only 26% of respondents think VR could improve working efficiency. More than 37% of respondents disagree that VR could help work efficiently. Furthermore, only 54% of practitioners think VR could help design idea-sharing with colleagues, while 40.5% of the practitioners have no specific stance on the idea. The AR is also considered useless in this area. Only 39% of respondents think that AR could improve working efficiency. 30.5% percent of practitioners think AR is not helpful with efficiency. The only positive result in this section is that 60% of practitioners agree that the AR could help communicate with colleagues.

Consequently, from the practitioners' perspective, the MR could not effectively support the design efficiency. After comparing the practitioners with AR experience and those who do not have AR experience (Figure 4.19), the number of practitioners who think AR helps increase efficiency slightly increases. Similar to the assumption in the discussion of size, practitioners might consider AR more significant for efficiency after learning AR. However, an exciting finding (Figure 4.18) is that practitioners have become more disagree that VR could help with efficiency after experiencing VR. The finding may conclude that the VR is less efficient to the

[56] Jialu Song and Sijia Huang, "Virtual Reality (VR) Technology and Landscape Architecture," ed. G. Lee, *MATEC Web of Conferences* 227 (2018): 02005, https://doi.org/10.1051/matecconf/201822702005.

landscape project at all. For securing that the conclusion is just for the overall project but for a specific stage of a project, the thesis will test out if VR is efficient in Chapter 5.

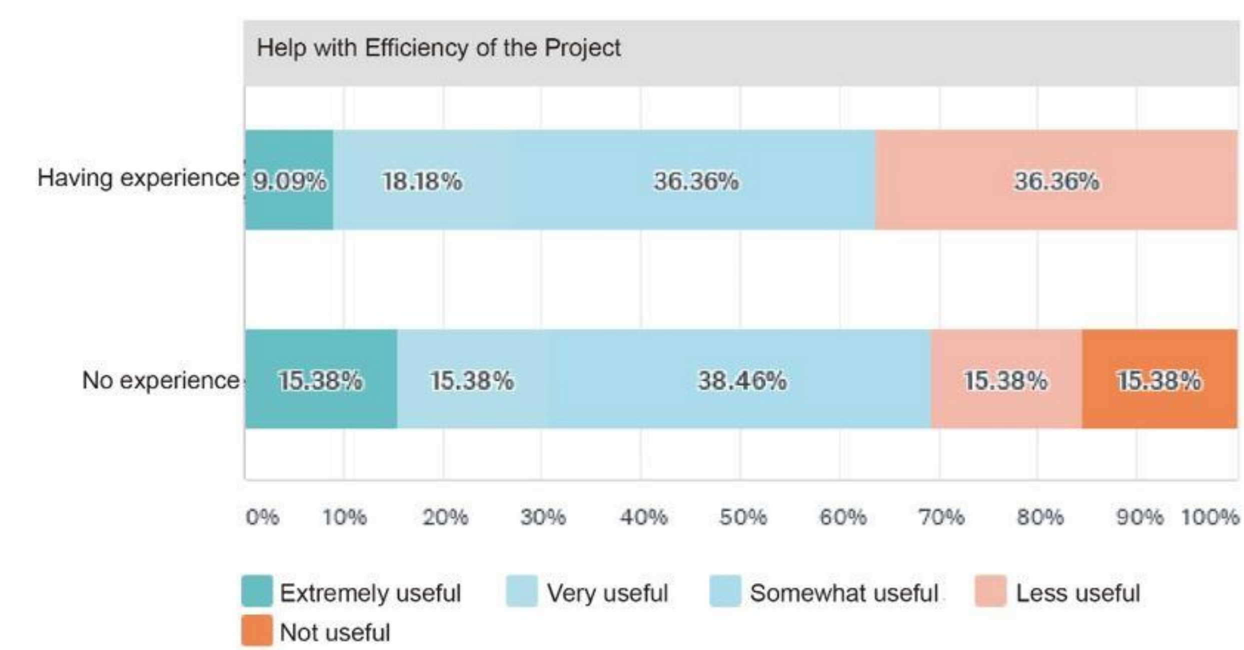

Figure 4.18: Comparison of the practitioners' perspectives of whether VR benefits efficiency

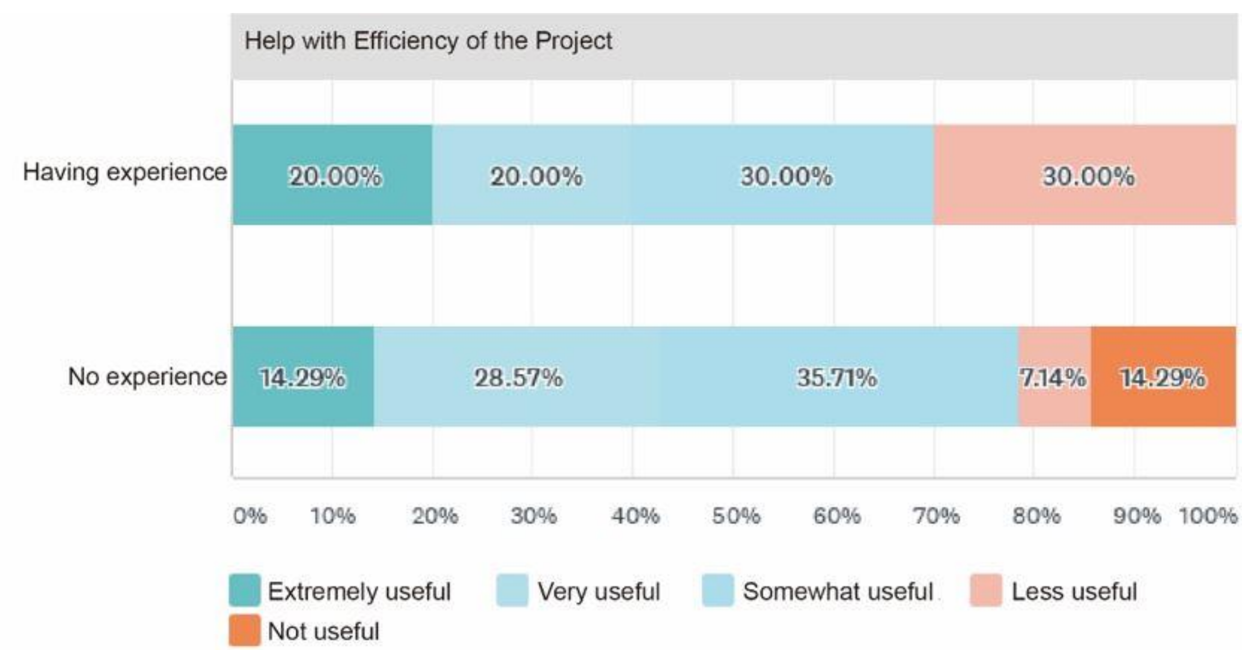

Figure 4.19: Comparison of the practitioners' perspectives of whether AR benefits efficiency

Communication with clients

The benefit of mixed reality for communicating landscape design with clients is the most agreeable contribution for practitioners.[57] The survey result (Figure 4.12, Figure 4.13, Chart 4.5, Chart 4.6) shows that 83% of practitioners agree that virtual reality could show an immersive experience of a designed environment; 91% think that virtual reality makes communication with clients more comfortable. No practitioner is against the idea. On the other hand, practitioners also have great confidence with AR for communication. The survey shows that 73% of practitioners stand for the contribution of AR to show an immersive experience of a designed environment. Moreover, 81% of practitioners believe that AR helps communicate with clients.

The unsurprising result concludes that the literature review at the beginning of the thesis is certified.

[57] Song and Huang.

Practitioner's perspective of the potential of utilizing VR in different stages of project workflows

As a result (Figure 4.20, Chart 4.7), most practitioners consider VR useful in the concept design, schematic design, and design development stage. On the other hand, practitioners think that VR is less helpful in background research, site inventory, site analysis, and the stages after "construction documents."

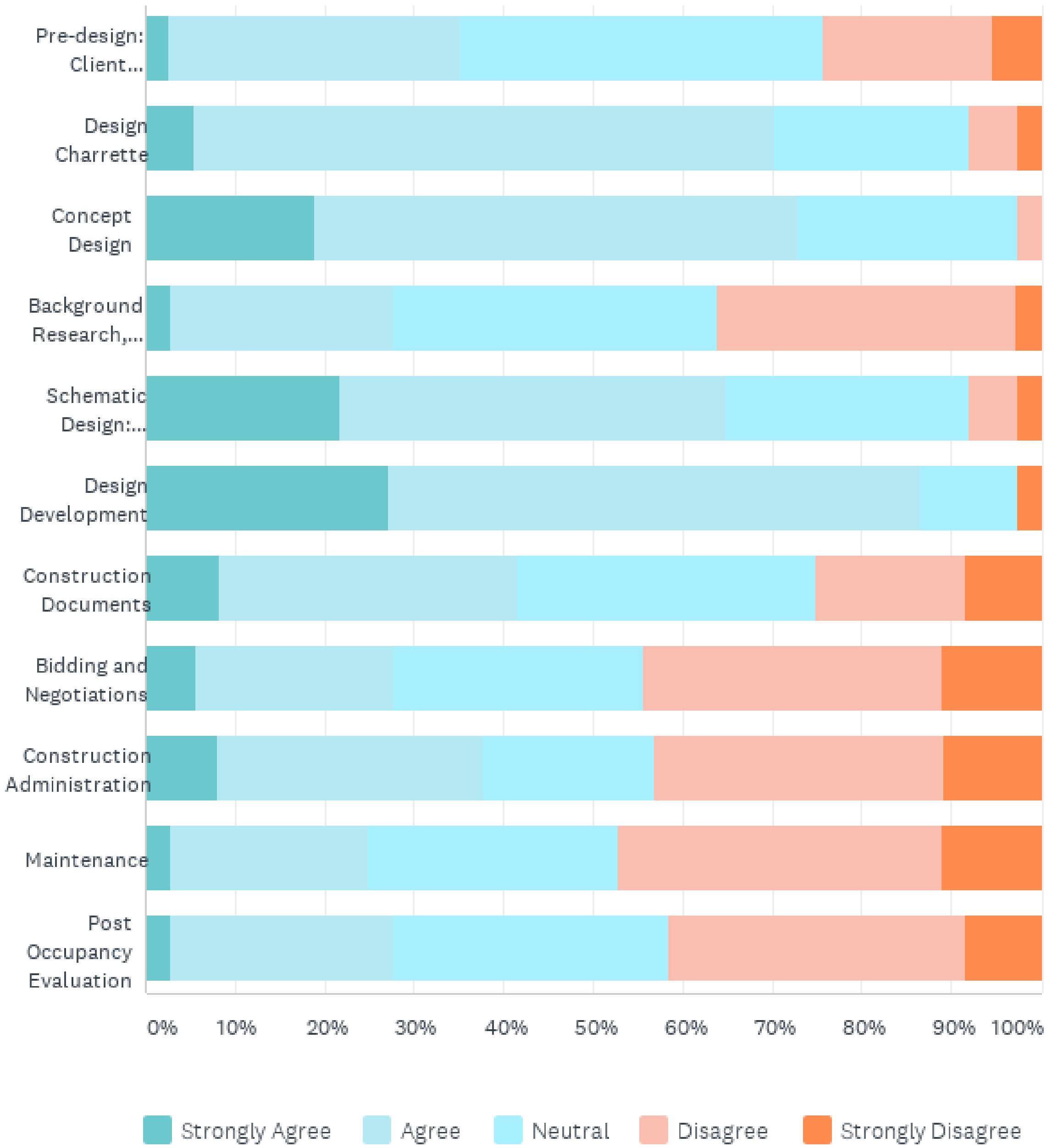

Figure 4.20: Practitioners perspective of the helpfulness to VR in landscape design projects

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
Pre-design: Client Consultation	2.70% 1	32.43% 12	40.54% 15	18.92% 7	5.41% 2	37	3.08
Design Charrette	5.41% 2	64.86% 24	21.62% 8	5.41% 2	2.70% 1	37	3.65
Concept Design	18.92% 7	54.05% 20	24.32% 9	2.70% 1	0.00% 0	37	3.89
Background Research, Inventory, and Analysis	2.78% 1	25.00% 9	36.11% 13	33.33% 12	2.78% 1	36	2.92
Schematic Design: Establishing Design Intent	21.62% 8	43.24% 16	27.03% 10	5.41% 2	2.70% 1	37	3.76
Design Development	27.03% 10	59.46% 22	10.81% 4	0.00% 0	2.70% 1	37	4.08
Construction Documents	8.33% 3	33.33% 12	33.33% 12	16.67% 6	8.33% 3	36	3.17
Bidding and Negotiations:	5.56% 2	22.22% 8	27.78% 10	33.33% 12	11.11% 4	36	2.78
Construction Administration	8.11% 3	29.73% 11	18.92% 7	32.43% 12	10.81% 4	37	2.92
Maintenance	2.78% 1	22.22% 8	27.78% 10	36.11% 13	11.11% 4	36	2.69
Post Occupancy Evaluation	2.78% 1	25.00% 9	30.56% 11	33.33% 12	8.33% 3	36	2.81

Chart 4.7: The data of practitioners’ perspective of the helpfulness to VR in landscape design projects

Practitioner's perspective of the potential of utilizing AR in different stages of project workflows

The result (Figure 4.21, Chart. 4.8) shows that most practitioners agree that AR could be useful in the concept design stage. *Like the result in VR, landscape architecture professional practitioners believe that the stages after "construction documents" are less helpful in landscape projects.*

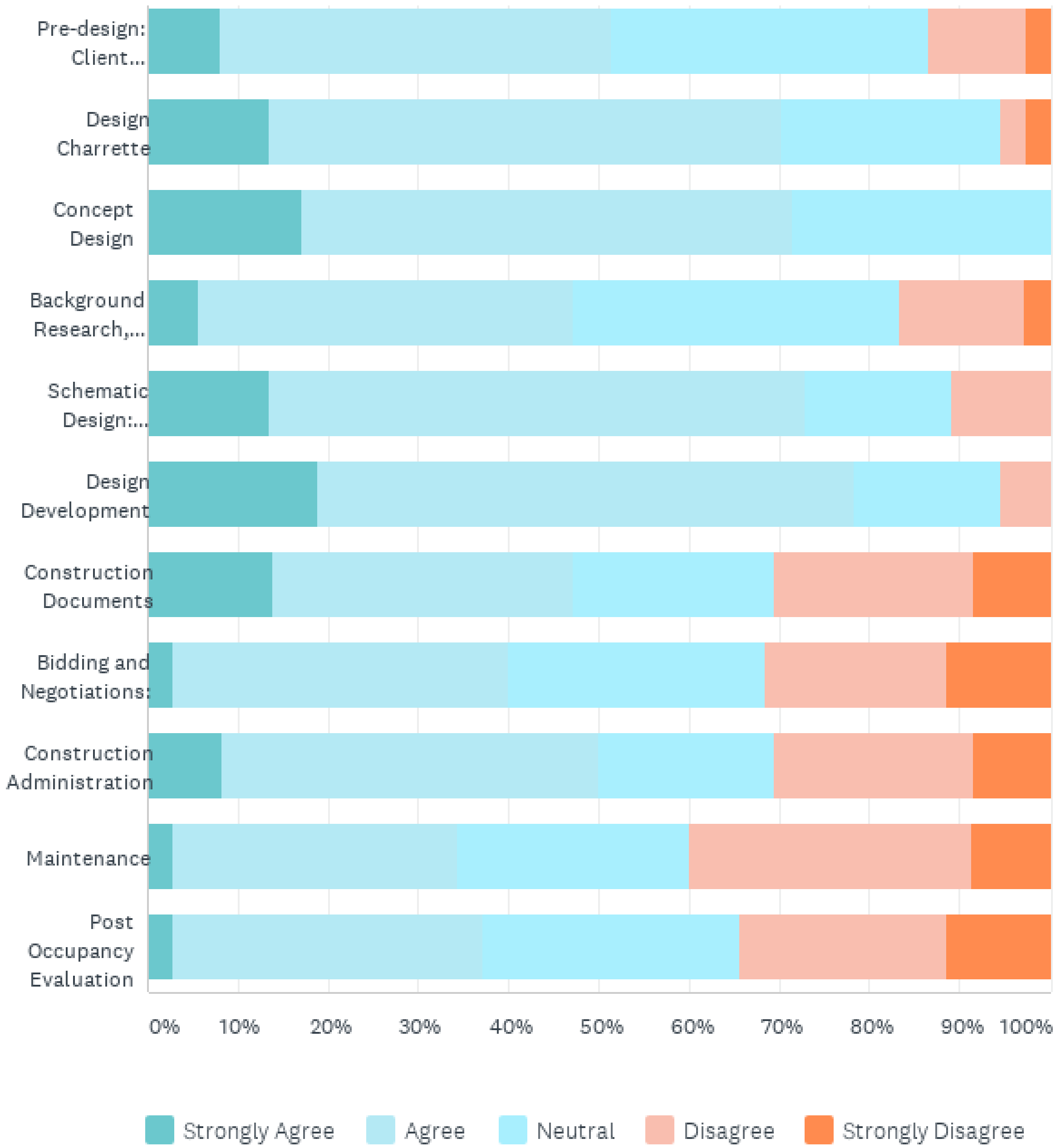

Figure 4.21: Practitioners perspective of the helpfulness to AR in landscape design projects

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
Pre-design: Client Consultation	8.11% 3	43.24% 16	35.14% 13	10.81% 4	2.70% 1	37	3.43
Design Charrette	13.51% 5	56.76% 21	24.32% 9	2.70% 1	2.70% 1	37	3.76
Concept Design	17.14% 6	54.29% 19	28.57% 10	0.00% 0	0.00% 0	35	3.89
Background Research, Inventory, and Analysis	5.56% 2	41.67% 15	36.11% 13	13.89% 5	2.78% 1	36	3.33
Schematic Design: Establishing Design Intent	13.51% 5	59.46% 22	16.22% 6	10.81% 4	0.00% 0	37	3.76
Design Development	18.92% 7	59.46% 22	16.22% 6	5.41% 2	0.00% 0	37	3.92
Construction Documents	13.89% 5	33.33% 12	22.22% 8	22.22% 8	8.33% 3	36	3.22
Bidding and Negotiations:	2.86% 1	37.14% 13	28.57% 10	20.00% 7	11.43% 4	35	3.00
Construction Administration	8.33% 3	41.67% 15	19.44% 7	22.22% 8	8.33% 3	36	3.19
Maintenance	2.86% 1	31.43% 11	25.71% 9	31.43% 11	8.57% 3	35	2.89
Post Occupancy Evaluation	2.86% 1	34.29% 12	28.57% 10	22.86% 8	11.43% 4	35	2.94

Chart 4.8: The data of practitioner's perspective of the helpfulness to AR in landscape design projects

Discussion

At the beginning of this chapter, three survey conclusions were assumed to be obtained. For the first conclusion, 44% of the practitioners using virtual reality can utilize virtual reality technology in either landscape architecture or architecture area. Only one surveyee uses virtual reality technology for landscape or architecture projects once a week (Figure 4.5). On the other hand, 46% of respondents use augmented reality for landscape projects. However, none of the respondents use augmented reality for landscape projects daily or weekly (Figure 4.6). To conclude, the outcome shows that MR is not yet an ideal software for landscape projects.

In Chapter 3, the literature review draws out seven categories of the potential functions that MR could be applied to the landscape projects. For the three-dimensional sketching function, half of the practitioners believe that MR is helpful (Chart 4.5, Chart 4.6). The number slightly conforms to the perspective proposed in Chapter 3 that MR can provide designers a space to sketch three-dimensionally. For communication, most of the practitioners agree that MR could make communicating (Chart 4.5, Chart 4.6) with clients more comfortable. The result strongly accords to the perspective proposed in Chapter 3. On the other hand, there are around 49% of the respondents think that AR could be helpful to the construction(Chart4.7, Chart 4.8). The idea also moderately corresponds to the idea that AR could help with the construction phase. To conclude, the respondents' perspective does not coincide with the potential functions listed in Chapter 3. Therefore, more research on the listed potential functions should be done in the future.

Finally, while some of the functions listed in Chapter 3 are not firmly accepted by the landscape architecture professional practitioners, the practitioners may underestimate MR's potential. The best explanation of the situation is that the potential is always approved while the sample narrowed down to only practitioners who experienced MR (Chart 4.5, Chart 4.6). However, time is limited, and one person only tests the software. After more tests for the MR software, the conclusion that practitioners underestimate the MR could be confirmed.

CHAPTER 5: MIXED REALITY LANDSCAPE DESIGN EXPERIENCE

Objectives

In Chapter three, seven categories of mixed reality tools are listed. The first thesis question proposed in Chapter one has been discussed. However, the second thesis question remains questionable. To further clarify each MR software's evaluation and explore the answer to the thesis's second question, a landscape project will be executed using mixed reality tools. For testing out as much software as possible in the project, rather than focusing on a simple residential project, the project's topic will be more "issue-oriented." Since the Google Tilt Brush seems to have the potential to produce an environment effectively, an issue based on an extreme environment typically not easily accessible, such as the surface of Mars or the deep sea, is considered. Noticeably, such two places are beyond people's imagination. The second rate decision will be somewhere remote to human's recognition, such as Antarctica or the middle of the South Pacific Ocean. Thus, the site chosen for testing out the MR software is the Pacific Ocean.

The frontier of human's life circle

The location would be one reason to choose the middle of the South Pacific Ocean as the site. When discussing Oceania Countries, most people might immediately consider Australia or New Zealand. However, there are fourteen countries[58] and nine dependencies or territories in Oceania.[59] Most of the Oceania countries are suffering from the disasters brought by climate

[58] "How Many Countries Are in Oceania?," WorldAtlas, accessed November 29, 2020, https://www.worldatlas.com/articles/how-many-countries-are-in-oceania.html.
[59] "How Many Countries in Oceania? - Worldometer," accessed November 29, 2020, https://www.worldometers.info/geography/how-many-countries-in-oceania/.

change.[60] Kiribati, one of the most undeveloped countries in the world, is the site for the issue of the design project. The highest point of Kiribati's capital, Tarawa, is only 20 feet in height. Multiple pieces of research have pointed out that the sea level rising due to climate change is gradually submerging the land of Tarawa.[61] More than 50 thousand Tarawa citizens are in danger. The adaption to encounter the sea level rising should be put in the priority.

Less challenge

There are two challenging difficulties while determining an atoll in the middle of the South Pacific Ocean as the site. First, there is a lack of data about obscure countries in google street view. Therefore, site visiting, which is a fundamental process in the schematic design stage, would be difficult to be carried out. However, the author of the thesis paper has had lived in Tarawa for a year. Since Tarawa is a small atoll, the author has already visited any part of Tarawa. The site visiting, thus, is not a challenge in this case. The second challenge is collecting rather confidential data. However, since the author participated in an international architectural design competition related to the climate issue in Tarawa, a comprehensive CAD file for the atoll has been obtained.

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[60] Anthony McMichael, Australia, and Department of Health and Ageing, *Human Health and Climate Change in Oceania: A Risk Assessment* (Canberra: Commonwealth Department of Health and Ageing, 2003).

[61] Heather Summers, "INVESTIGATING THE ABILITY OF CORAL REEFS TO PROTECT SHORELINES IN THE REPUBLIC OF KIRIBATI," n.d., 87.

Potential outputs

There are two categories of outputs that are supposed to be present at the end of the mixed reality landscape architecture design. First, the mixed reality landscape design process is based on the typical method. Therefore, the outputs should be in typical drawings as below.

1. Site analysis mappings, sections, isometric diagrams, and infographics
2. Project goals infographics
3. Problem and approach infographics, mappings, isometric diagrams, sections, perspectives, and photo collages
4. Proposal masterplans, sections, section perspective, isometric/axonometric diagrams, aerial view graphics, and perspectives
5. Strategy diagrams or icons
6. Programing diagrams, mappings, and charts
7. Plant design mappings, graphics
8. Site tour animation

The other category of outputs is any kind of suitable communication method generated by mixed reality technologies. Since the mixed reality for landscape design is a relatively avant-garde approach for landscape projects, the outputs remain unclarified.

Virtual Reality Landscape Design Method

Testing out utilizing mixed reality tools in the design stages is the most direct approach to evaluate the software. While designing in virtual reality, the second question could probably be answered. The design process mainly focuses on the designing stage that could be done in an academic setting. Thus, the proposed process in the thesis research will start from the concept to detail development. The discussion processes, including part of the concept stage and Charrette stage, are switched from discussing with clients to discussing with Professor O'Shea, the Chair Advisor of the thesis. Moreover, only virtual reality is tried out since the augmented reality software seems difficult to be utilized in the processes.

On the other hand, since the research is about using mixed reality technology in the landscape architecture professional practice, the project's scope should always be compatible with the professional workflow. Therefore, the outputs are based on typical drawings, such as sections, perspectives, or masterplans. For testing out the software, I used Innovation Studio (Figure 5.1), a Lab for VR research, with an Oculus Rift and an Oculus Quest 2 (Figure 5.2) from Professor O’Shea’s Landscape Strategies Lab. These tools are the most popular and accessible VR tools available to consumers and professionals.

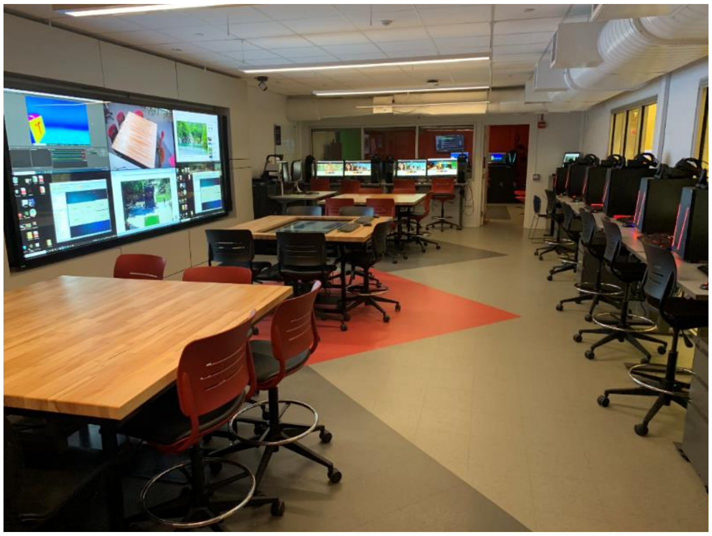

Figure 5.1: Innovative Studio in Armory, University of Illinois at Urbana-Champaign

Figure 5.2: Oculus Quest 2

The first draft of the virtual reality landscape architecture design process

In the beginning, Danny Bittman's "Becoming a virtual artist" tutorial series served as the pivotal reference for establishing the design process. Since Danny's workflow is based on an artist and game-making knowledge, the initial process (Figure 5.3) is mostly composited from the virtual reality technology and the gaming compatible rendering tools. This workflow is:

A. Data gathering and defining the goals, issues, and challenges

In the beginning, as usual, designers should clarify an issue or a goal. Next, designers should move on to the literature online or in paper to define the issue's cause and effect. Since the site is in Tarawa, Kiribati, the geospatial data is hard to be collected. Therefore, the technology on the contribution of virtual reality in such an early step is scarce.

B. Site modeling

In Chapter 3, the Google Tilt Brush is considered suitable for quick sketching. Base on Danny's tutorial, the Tilt Brush provides the ability to the environment sketching. Afterward, the Tilt Brush model could be exported to Unity for further editing.[62]

C. Concept design

After creating a rough background, a draft design will be sketched through Google Tilt Brush in virtual reality. In Drew's research, sketching rough design ideas in virtual reality helped understand the design-environment relationship and improve communication with co-workers.[63] Therefore, the rough sketching strategy will be applied before moving forward to the detailed modeling step.

D. Detailed modeling

The AB and C stages conform to the Concept stage of the universal workflow defined in Chapter 2. The detailed modeling stage will be part of the schematic design. In this stage, the rough model created through the Google Tilt Brush will be imported into Gravity Sketch. According to Chapter 3, the Gravity Sketch provides more features compatible with designers than artists. Afterward, the model created through Gravity Sketch will be exported to Blender, which is modeling software for industrial designers, artists, or game designers. The Blender also provides an excellent rendering feature. The output images, such as sections or perspectives, will be extracted from the rendered model.

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[62] Danny Bittman, *How to Create a Massive Tilt Brush Environment in 10 Minutes // Becoming a VR Artist Ep. 6*, 2019, https://www.youtube.com/watch?v=tFSAZvQTZBE&ab_channel=DannyBittman.

[63] Hill, "HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE DESIGN PROCESS AT VARIOUS SCALES."

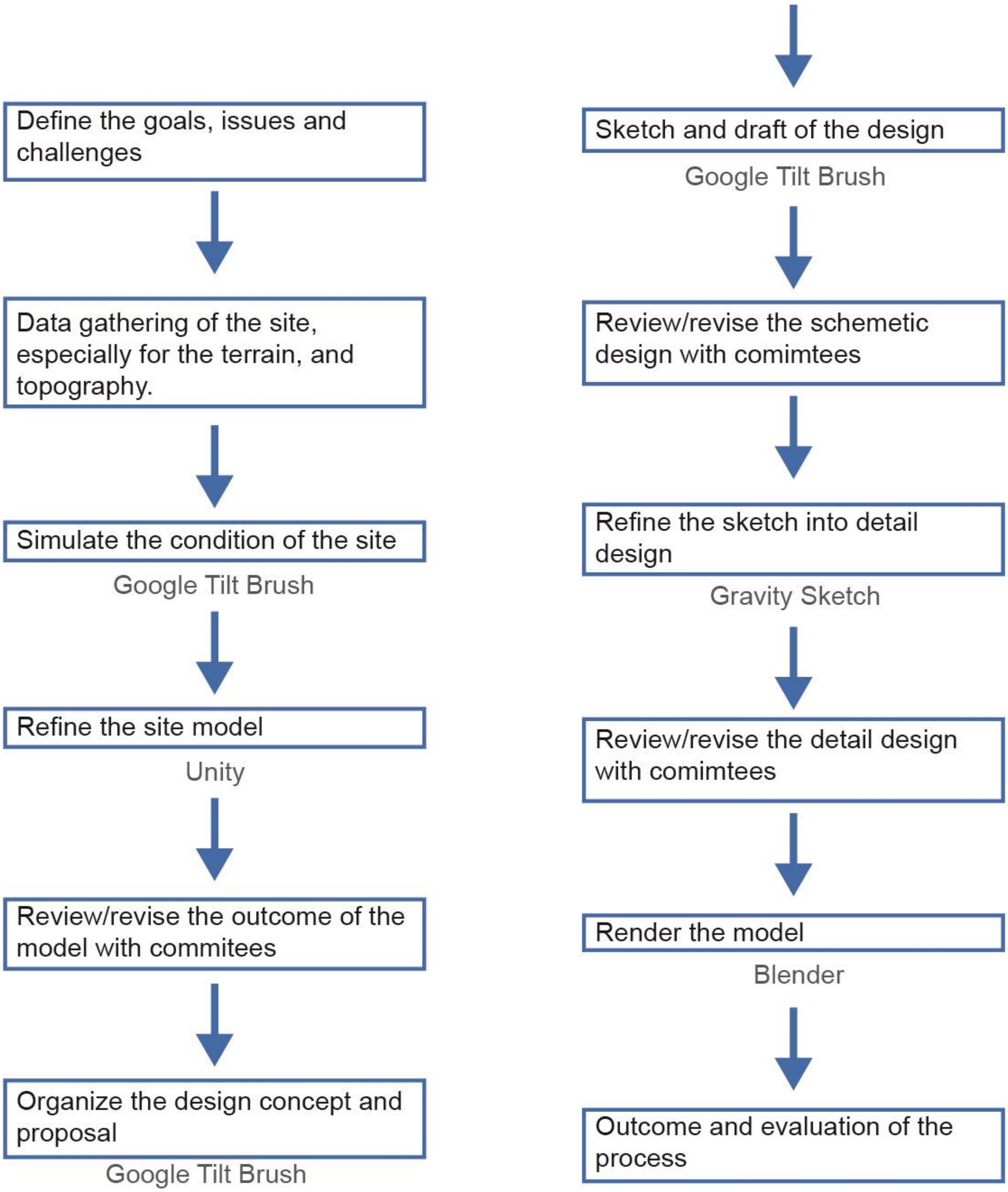

Figure 5.3: The first draft of the virtual reality landscape architecture design process

Discussion for the first draft

While organizing the design process, the typical output was ignored. Therefore, two flaws appeared in the middle of the process. The first flaw is that the first draft is not suitable for landscape architects. One of the thesis project advisors pointed out that software such as Unity and Blender is irrelevant to the current professional practice workflow. Moreover, except for perspectives, the proposed design process seems inefficient for creating the usual design visualization drawings such as masterplans or sections.

The second flaw is that the file format of the model built through Google Tilt Brush is incompatible with Gravity Sketch. There are only two brushes that could be successfully imported into the Gravity Sketch. Neither could the model refined in Unity. Therefore, the designers could not move the site model and the rough design model into Gravity Sketch. The designers might consider the second draft of the design process.

The improved draft of the virtual reality landscape architecture design process

To improve the initial process, the designers should consider utilizing more current digital aids in the professional workflow. The first draft seems unreasonable is because of lacking clear outputs and technics described in the design process. Without describing what techniques to use and outputs to show, the design process might be obscure to read the process picture. More software and outputs will be clearly enumerated in the improved design process (Figure 5.4). The landscape architect-familiar software will participate in the improved design process.

1. Google Map, Google Earth
2. GIS

3. AutoCAD
4. Adobe Photoshop
5. Adobe Illustrator
6. Lumion

The main idea of each design process remains similar. The site analysis derives from the "Data gathering and defining the goals, issues, and challenges" stage. The concept design and site analysis are combined in the improved design process, and the order between concept design and site modeling changed. The site modeling is now in the same hierarchy as the concept design process, which has been combined with site analysis. The detailed modeling progress is considered as part of the "design visualization" stage, which will be defined in the improved design process. Besides, for evaluating the virtual reality software's effectiveness, some of the output will be produced through both popular software and virtual reality software. Indeed, the process could always alter and interchangeable.[64] For example, designers could only build a model for a specific part of the design to produce perspectives and use AutoCAD or Adobe Photoshop to complete masterplans or sections. However, the thesis just decides one of the standard processes for testing out the virtual reality design process.

A. Data gathering and defining the goals, issues, and challenges

The content of the process is the same as the one in the first draft.

B. Site modeling

Both the virtual reality technology and Rhino would be utilized in the process.

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[64] Carl Steinitz, "Landscape Architecture into the 21st Century – Methods for Digital Techniques," n.d., 25.

C. Site analysis and concept design

For communicating the outcome of the analysis, the infographic diagrams, spatial mappings, and sections are still required. The usual software, including Adobe Photoshop, Adobe Illustrator, and AutoCAD, might be more suitable for drawings. On the other hand, based on Drew's research, virtual reality might create a unique style of output, three-dimensional site analysis.[65]

D. Design visualization

The content in the design visualization stage is similar to the schematic design stage in Chapter 2. Before moving on to the variable visualization output drawings, the detailed design model will be built. The designers could produce the rest of the drawings, including sections, room axon diagrams, masterplans, perspectives, and other drawings, from the detailed model.

[65] Hill, "HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE DESIGN PROCESS AT VARIOUS SCALES."

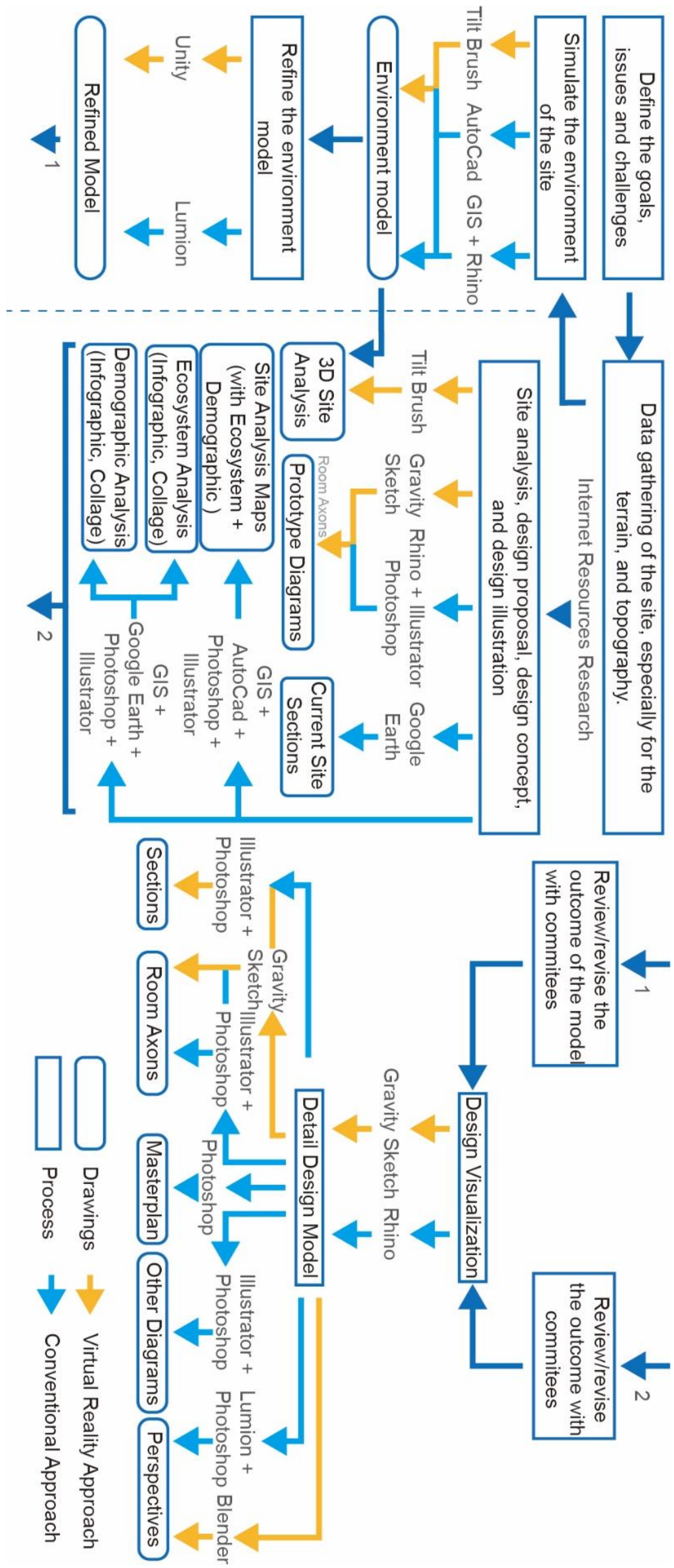

Figure 5.4: The improved draft of the virtual reality landscape architecture design process

Discussion of the improved draft

The overall design process of the improved draft does not contain a critical flaw. The improved draft problem is that the description diagram does not elaborate nor make the design process more comfortable to read. Therefore, with a more precise diagram, the final draft will be produced at a more optimizing level.

The final draft of the virtual reality landscape architecture design process

In the final draft, the overall process remains the same as the improved draft. The only part that has been changed is the design of the design process diagram (Figure 5.5). Each process has been arranged to the left of the outputs and applied software.

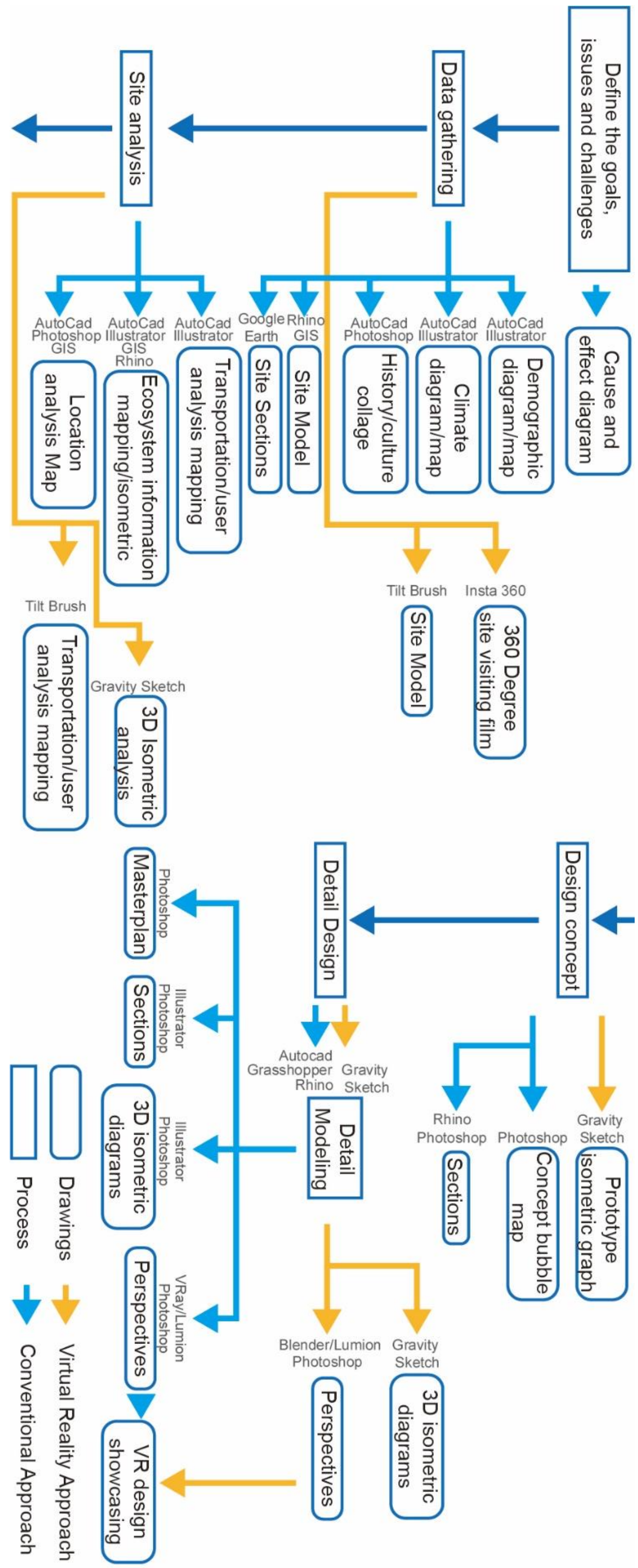

Figure 5.5: The final draft of the virtual reality landscape architecture design process

Discussion of the final draft

The outcome obtained from the virtual reality landscape design process's final draft will serve as the standard to evaluate how the virtual reality tool could participate in the landscape architecture professional workflow. Moreover, the time spent on experiencing virtual reality design software is supportive of answering the second thesis question.

Results and Discussion: Concept

Data gathering and defining the goals, issues, and challenges

To start a landscape project, the designers always need to gather information and set up the issues and goals. In this case, there is no client in the project. Therefore, the designers need to find out the problems through news, academic journals, and the country's policies. Next, based on the obtained information, designers need to figure out the cause and effect of the issue rather than set up a design goal or proposal.

Since the defined site, Tarawa, Kiribati, is too far to be visited during the semester. Therefore, 360-degree filming may not be able to be utilized. The stage's visualization will all be limited in a typical method, including infographics, photo collages, or treemaps (Figure 5.6).

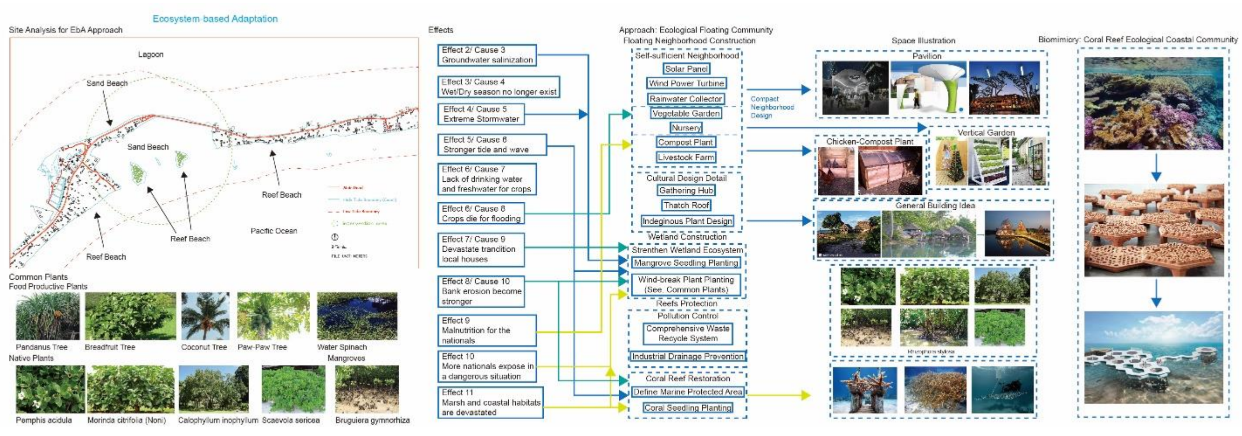

Figure 5.6: The data, issues, goals, and primary design concept visualizations

To conclude, the MR tools seem challenging to support the project since only site visiting could help. However, such a remote place blocked MR's only chance to be useful in the initial stage.

Site modeling

An environment model is always a helpful tool for landscape architects to develop design ideas or even site analysis in a landscape project's initial stage.[66] The GIS data of a site located in the State is always available for any parties. However, topography data of a remote place is challenging to find. VR modeling software seems to have the potential to solve the problem roughly.

A CAD file without contours was exported as a PDF file and imported to Google Tilt Brush. Next, use the VR hand tracker to depict each land boundary outline (Figure 5.7). The site photos are also imported to the VR for reference (Figure 5.8). Some details, including rocks, reefs (Figure 5.9), or vegetation (Figure 5.10), could be created by referring to the photos. Finally, a rough model with topography and vegetation could be created in VR.

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[66] H. Mitasova et al., “Real-Time Landscape Model Interaction Using a Tangible Geospatial Modeling Environment,” *IEEE Computer Graphics and Applications* 26, no. 4 (July 2006): 55–63, https://doi.org/10.1109/MCG.2006.87.

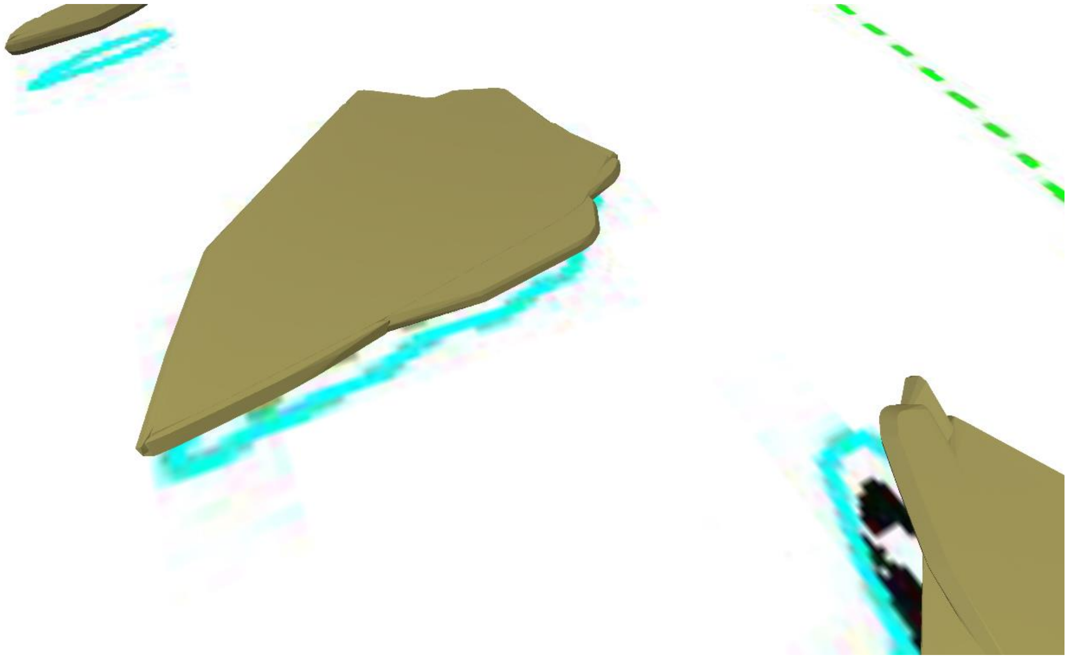


Figure 5.7: Create the Topography by depicting the land boundary

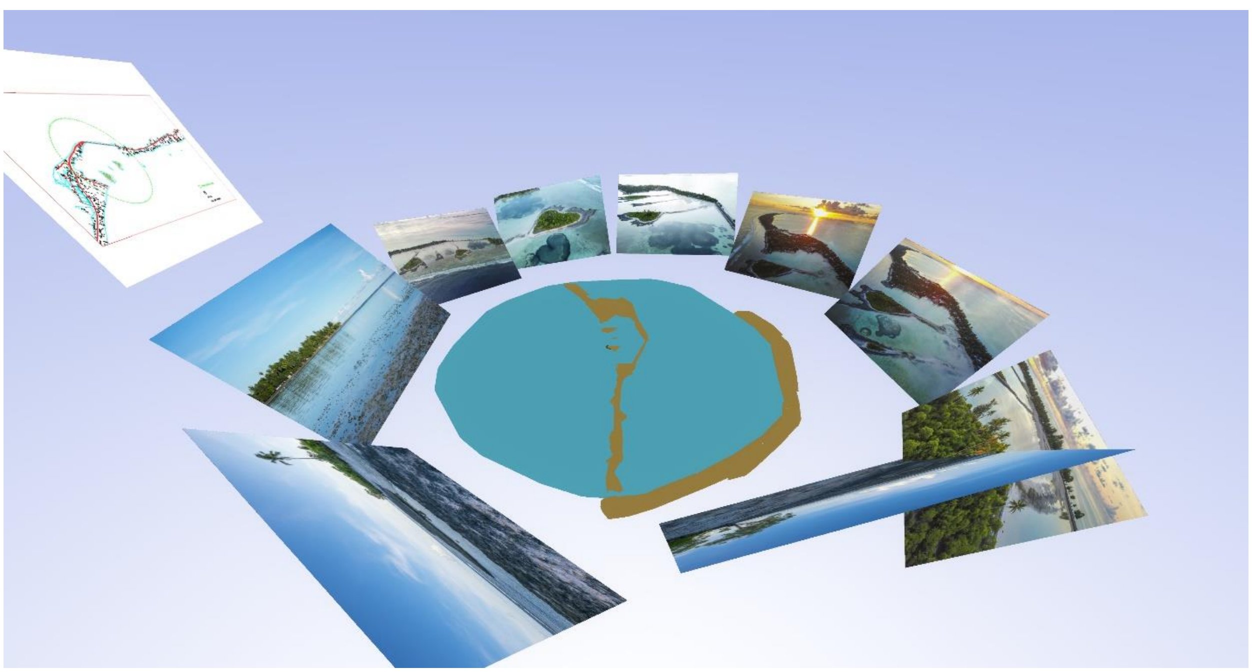


Figure 5.8: Import the site photos to VR for reference

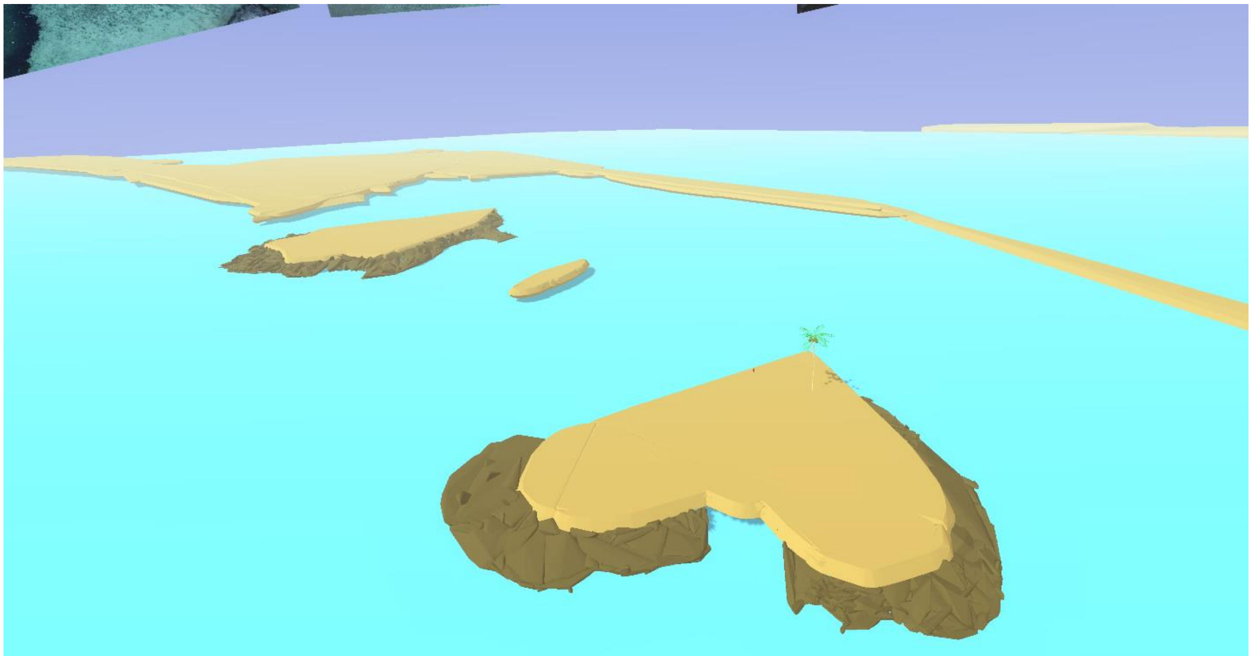


Figure 5.9: Add the rocks and reef-like topography in the model

Figure 5.10: Create a coconut tree in VR

The Google Tilt Brush is suitable for building a site model in the early stage of a project. The process takes only a short time. Moreover, designers can have further communication with each other in the VR.

However, there are also numerous disadvantages with Google Tilt Brush. First, the essential features in a landscape modeling software, such as point snapping or model alignment, are not available. The drawback makes the model less precise and reduces efficiency. Furthermore, the large-scale model causes a tremendous lagging in VR. A lagging VR could cause virtual reality dizziness. At the same time, by copying more trees in the model, the VR software collapse quickly. Finally, the model could not be exported to any typical landscape architecture software. The model only could be exported to Unity, which is an excellent tool for producing a VR experience but not a typical tool for landscape architects. To conclude, the drawback is all caused by the software's flaws. The VR still serves as an excellent tool for modeling a site that the contour map is hardly found.

Results and Discussion: Schematic Design

Site analysis

The contribution of VR in the site analysis process has been enumerated in Chapter 3. In this case, the site analysis is suitable to be completed in Google Tilt Brush. However, the model will crash with more vegetation. The model without vegetation seems not suitable to serve as a drawing in a professional document (Figure 5.11).

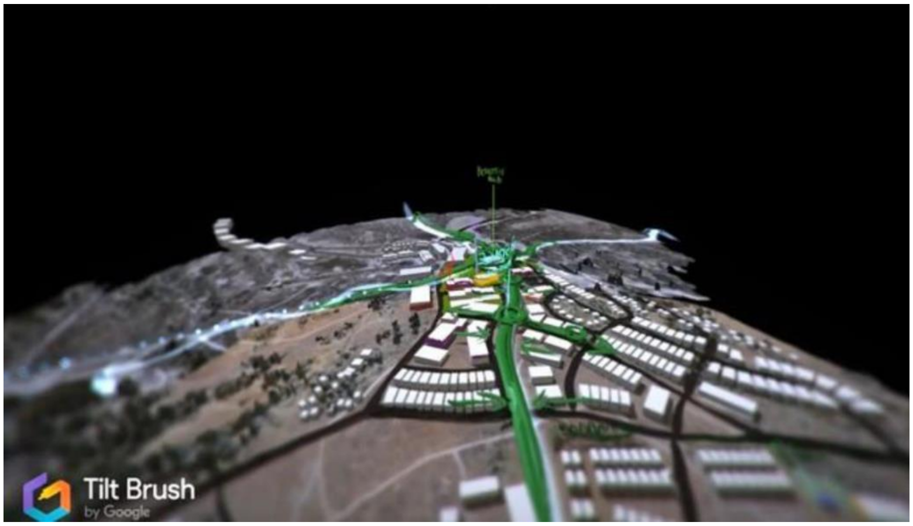


Figure 5.11: The site analysis visualized in VR

Thus, due to MR's limited contribution, the site analysis visualization (Figure 5.12, Figure 5.13, Figure 5.14) has still been done by standard software, including Adobe Photoshop, Adobe illustrator, and GIS.

Figure 5.12: Visualization of site analysis in Ambo, South Tarawa produced by standard software

Figure 5.13: Visualization of site analysis in Ambo, South Tarawa produced by standard software

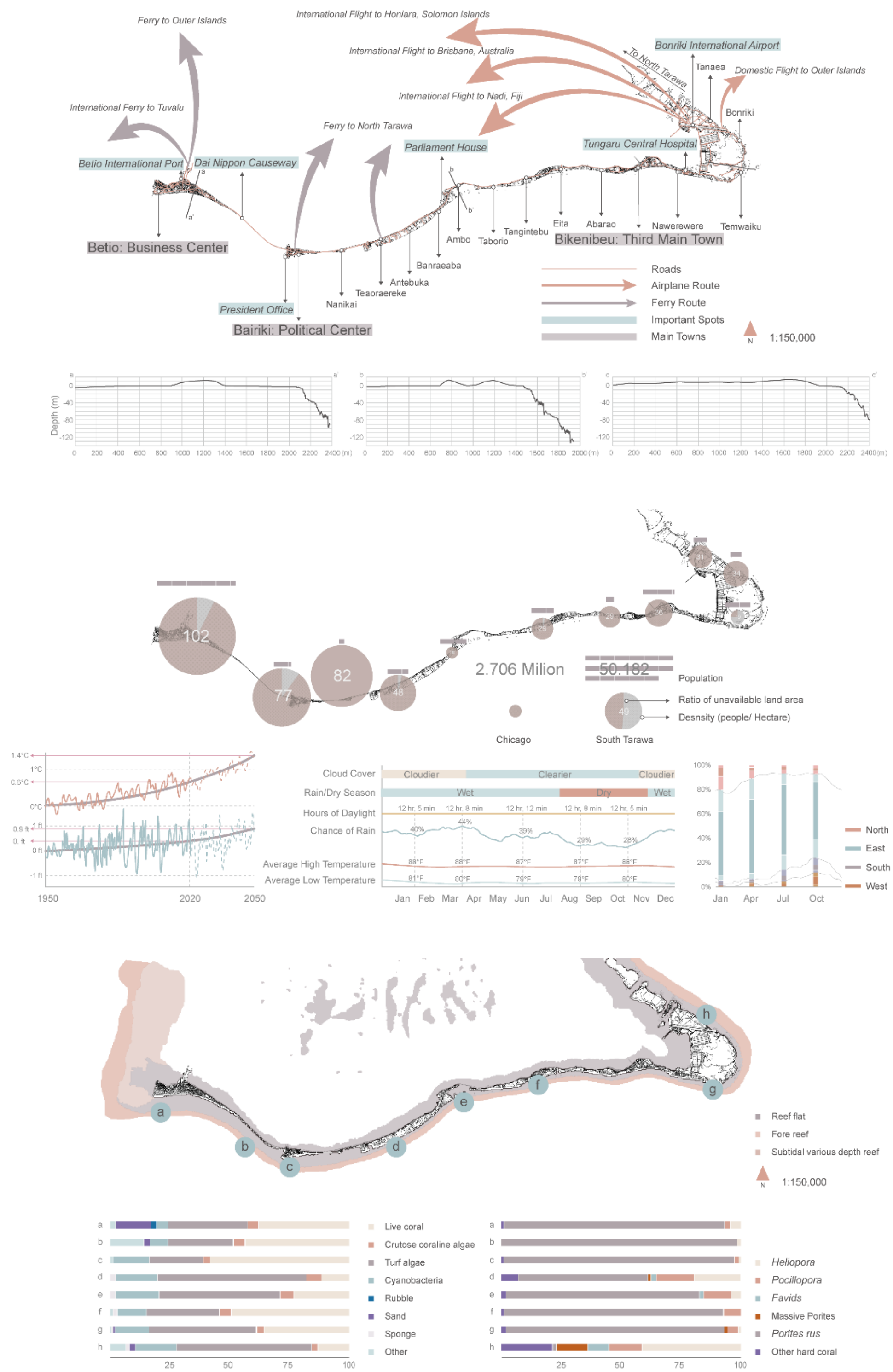


Figure 5.14: Visualization of site analysis of South Tarawa, Kiribati, produced by standard software

Concept design

In the concept design stage, designers organize outcomes from the site analysis and provide proposals. The drawings in this stage should indicate the idea of design and the solution for the issues.

The concept design stage provides an excellent chance for the thesis to explore the second thesis question's answer. Gravity Sketch, a VR modeling tool created for industrial designers, seems to provide several features suitable for landscape architects. While in the concept design stage, a correct scale of the design serves as a significant role. Comparing to Google Tilt Brush, the Gravity Sketch has a snapping, alignment, and precise scale functions (Figure 5.15). The features make Gravity Sketch suitable for exploring design ideas and in VR. Thus, whether designing in VR could facilitate creativity will be discovered.

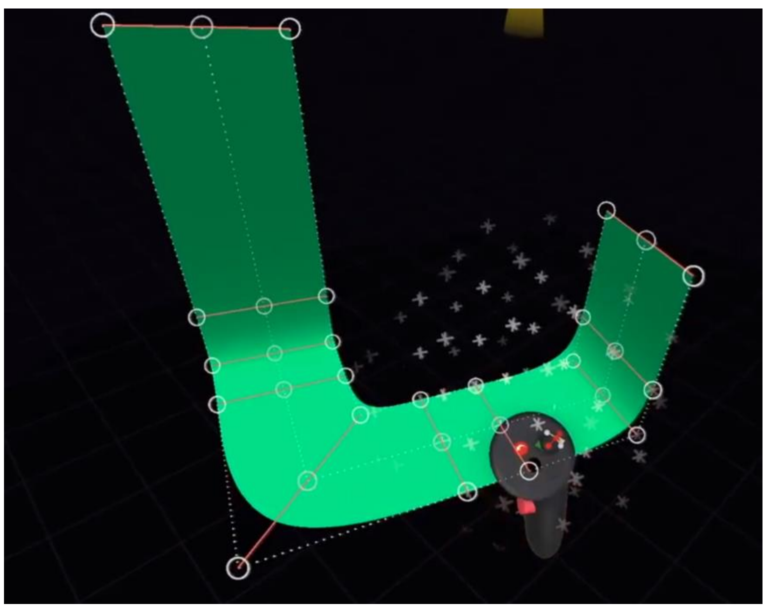


Figure 5.15: Grid function for a more precise drawing[67]

The Gravity Sketch concept design workflow is proposed as the following processes.

[67] ebemto, *Gravity Sketch VR Grid & Smartmove*, 2018, https://www.youtube.com/watch?v=hVnZuohoSuc&ab_channel=ebemto.

1. Create the background model in Rhino (Figure 5.16)
2. Export the model in Obj format and import the model to Gravity Sketch
3. Sketch in-scale concept design in virtual reality

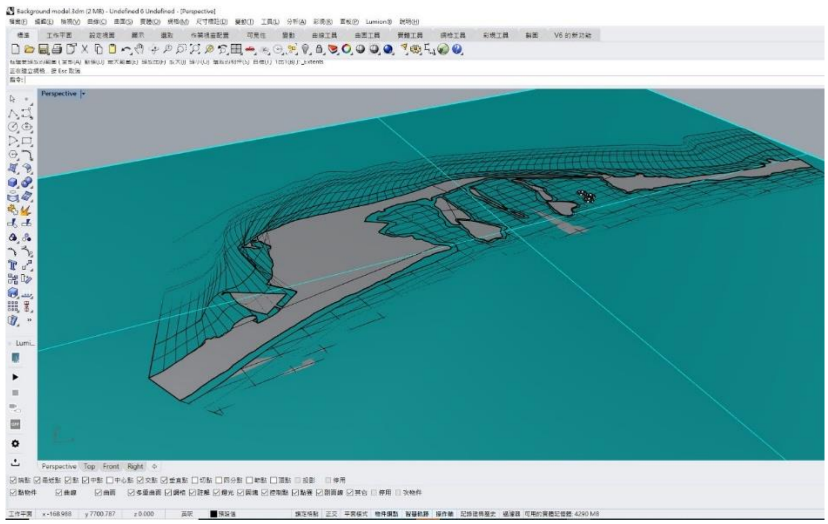


Figure 5.16: Background model made by Rhino

After testing out, the process just stuck in the first step (Figure 5.17). The background model collapse in the Gravity sketch. The problem blocks the chance to explore the second thesis question. Consequently, the concept design stage can only be completed by the standard software. The stage's standard output includes concept plans (Figure 5.18), isometric diagrams (Figure 5.19), sections (Figure 5.20), or rough perspectives.

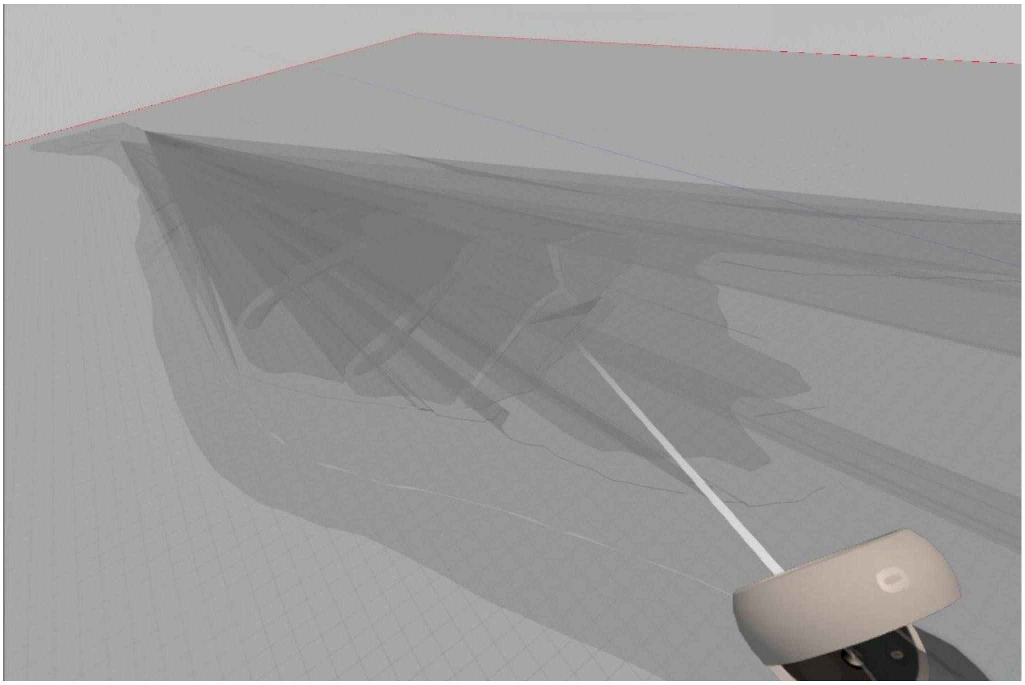


Figure 5.17: Background model collapses while importing to Gravity Sketch

Figure 5.18: Concept plan created by Adobe Photoshop and AutoCAD

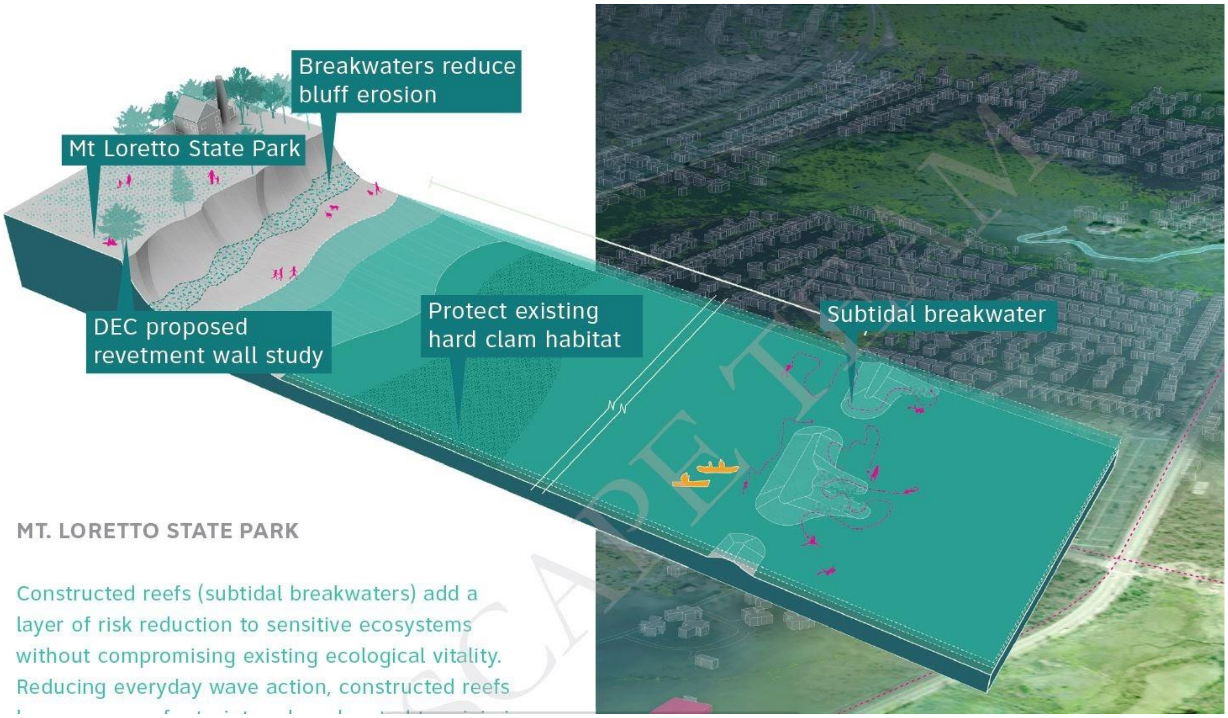


Figure 5.19: Isometric diagram, created by Adobe Photoshop, for the visualization of the breakwater system as the proposal (Scape, Living Breakwaters) [68]

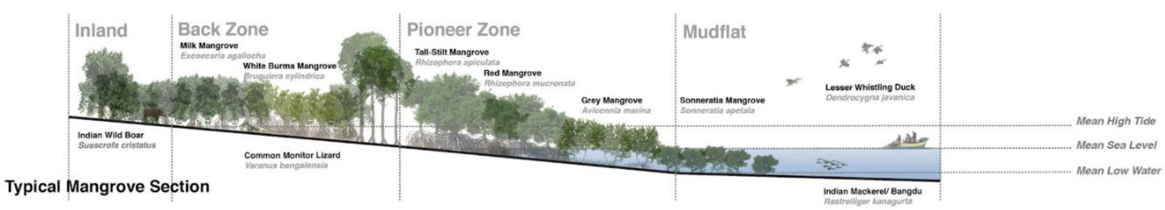


Figure 5.20: Cultivating mangrove habitat as the proposal (Hinterland Urbanism and Landscape, "Mangrove Metropolis")[69]

[68] "Living Breakwaters Design and Implementation - SCAPE," accessed May 7, 2019, https://www.scapestudio.com/projects/living-breakwaters-design-implementation/.
[69] Aneesha Dharwadker and Conor O'Shea, "Mangrove Metropolis," HINTERLANDS, accessed December 7, 2020, http://www.hinterlands-ul.net/mangrove-metropolis-1.

Design Visualization

Before this stage, all the supposed contribution of the MR fails to support the project effectively. The critical reason is not the MR is not helpful for the project but lacks the software customized for a landscape architecture project. However, the MR still has enormous potential to be applicable in this stage.

At the end of the schematic stage, practitioners express the design contents to the clients. Typically, designers submit the drawings, including masterplans, sections, isometric diagrams, infographics diagrams, and perspectives. The mentioned drawings are not a rule of what should be included in documents, but how designers express any design ideas to the audience, clients, or co-workers. The ideas usually expressed to the audience include grading plans, proposed elevation, plant design, stormwater management strategies, or human-water relationships. In this stage, the MR should serve as an innovative tool for designers to coordinate with standard drawings and explore a new way of expressing ideas.

The MR software, in the detail visualization stage, is used for detailed modeling. Gravity Sketch has been chosen as the tool for detail modeling. The purpose, conforming to the subject "Immersive and design modeling" for testing out, is to evaluate if modeling in virtual reality is beneficial for a landscape architecture project.

The workflow in this stage is listed below.

1. Follow the concept plan (Figure 5.18) and confirm the function of a space
2. Base on the space, start creating the model to fulfill the needs
3. Use Gravity Sketch to build a model as much as possible (Figure 5.21), and use other modeling tools to finish the part that Gravity Sketch cannot support

4. Combine the model in Rhino through Gravity Sketch Rhino plugin (Figure 5.22), or transfer the model made by Gravity Sketch to Blender

5. For an innovative workflow that practitioners scarcely utilize, the rendering could be completed in Blender. For aa more typical workflow, practitioners could import the combined model to popular rendering software, such as Lumion or Enscape, for further rendering

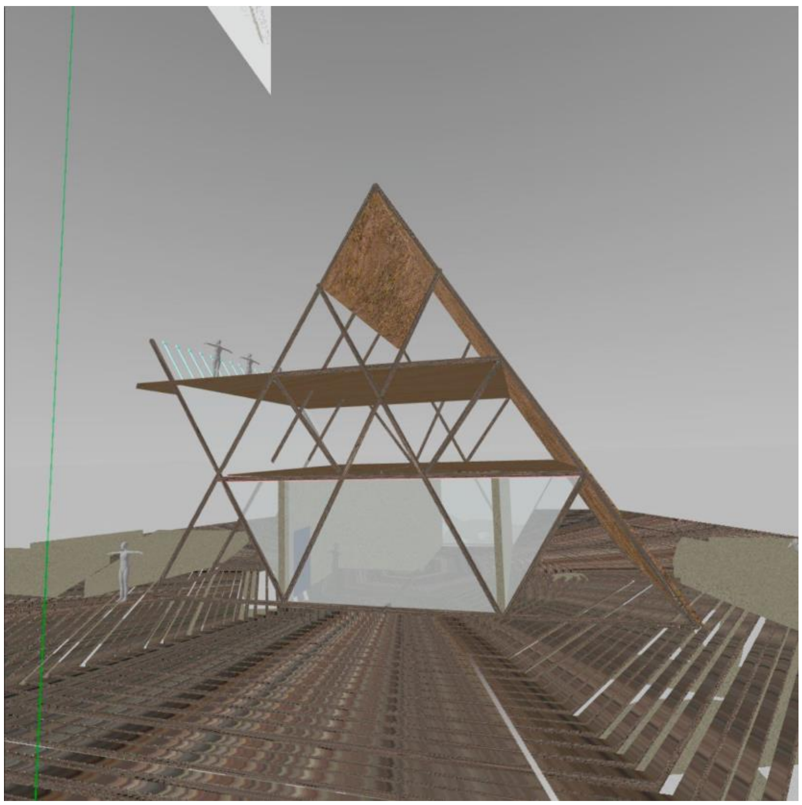


Figure 5.21: Detailed model building Gravity Sketch

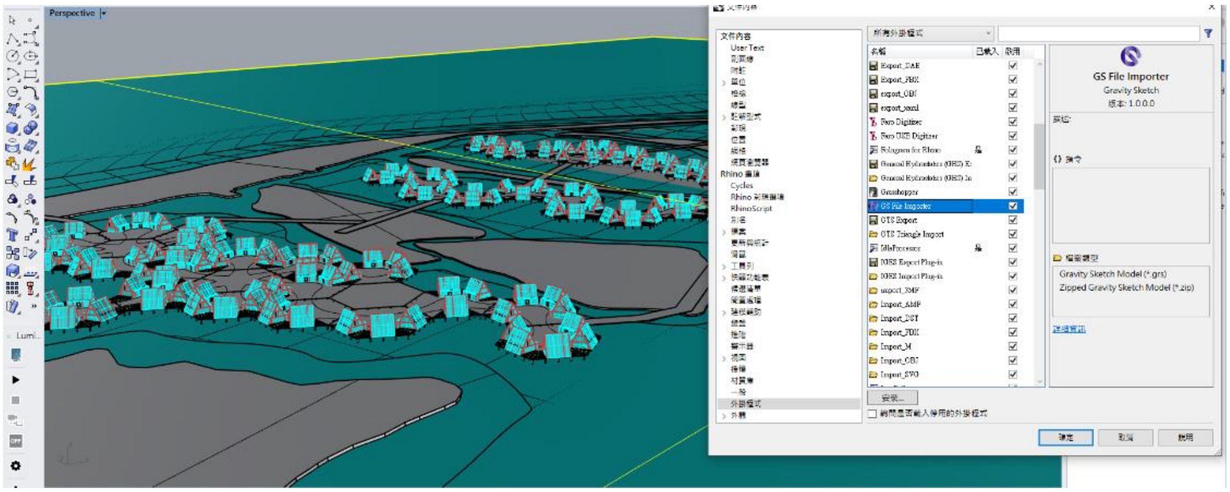


Figure 5.22: Combine the models through Gravity Sketch plugin

After experiencing the process, the conclusion has been figured out. The advantage of developing a detailed design model is that compared with traditional modeling tools, designing a model in Gravity Sketch provides designers more opportunity to create organic shapes. For example, biomimicry, a term developed in 1996, has been applied to multiple disciplines. Recently, landscape architects also started to consider biomimicry as a proposal or concept of the design.[70] However, any software, such as Rhino or Grasshopper, even Sketchup, with functions for modeling curves, meshes, and irregular surfaces, does not provide a medium for practitioners to model an organic shape as flexible as possible. In this case, the proposal is to create an organic structure that mimics the mangroves' complex structure to provide a residential area with an intertidal ecosystem for wild lives. Gravity Sketch provides a suitable medium for designers to create a detailed model efficiently.

Gravity Sketch also benefits the production of some typical drawings, such as isometric diagrams (Figure 5.23) or eye-level perspectives for further renderings (Figure 5.24).

[70] Sigurd Carl Sandzén, "BIOMIMICRY AS DESIGN LENS FOR LANDSCAPE ARCHITECTURE," n.d., 86.

However, some features that benefit large-scale modeling, such as components, are not available in Gravity Sketch. Gravity also lacks plant materials. Designers need to place plants in other software. Moreover, Gravity Sketch easily collapses while the model becomes large. Therefore, for overall project efficiency, Gravity Sketch is more suitable for small-scale modeling. For a large or medium-scale project, the Gravity Sketch could serve as a role while some specific area needs an organic model shape. After modeling the small, detailed models, the Gravity Sketch model is still better combined with the Rhino model for other rendering or other use for visualization (Figure 5.25).

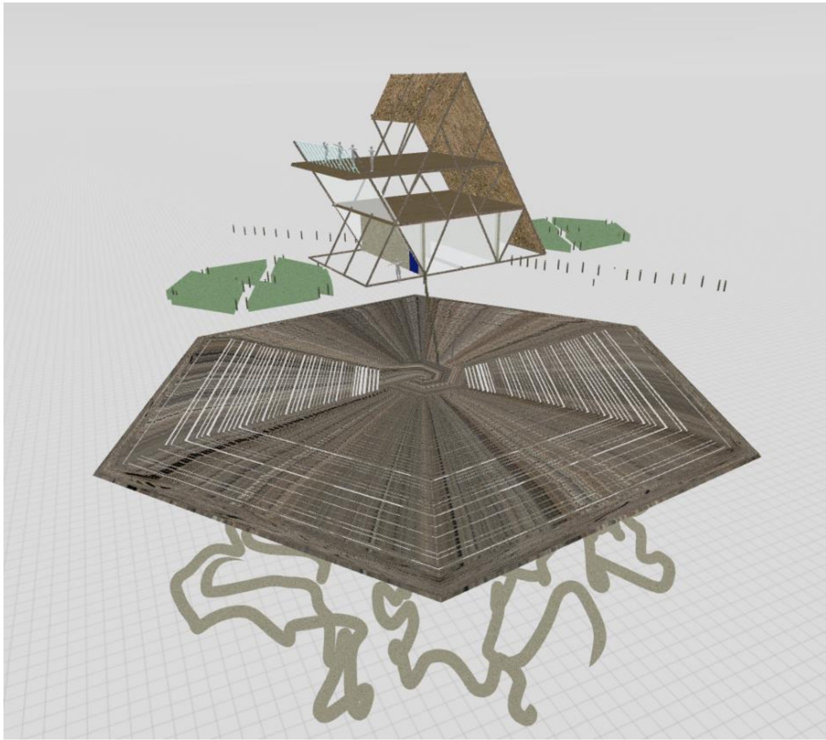


Figure 5.23: An example of how Gravity Sketch could provide isometric drawings

Figure 5.24: Rendered perspective made by Lumion

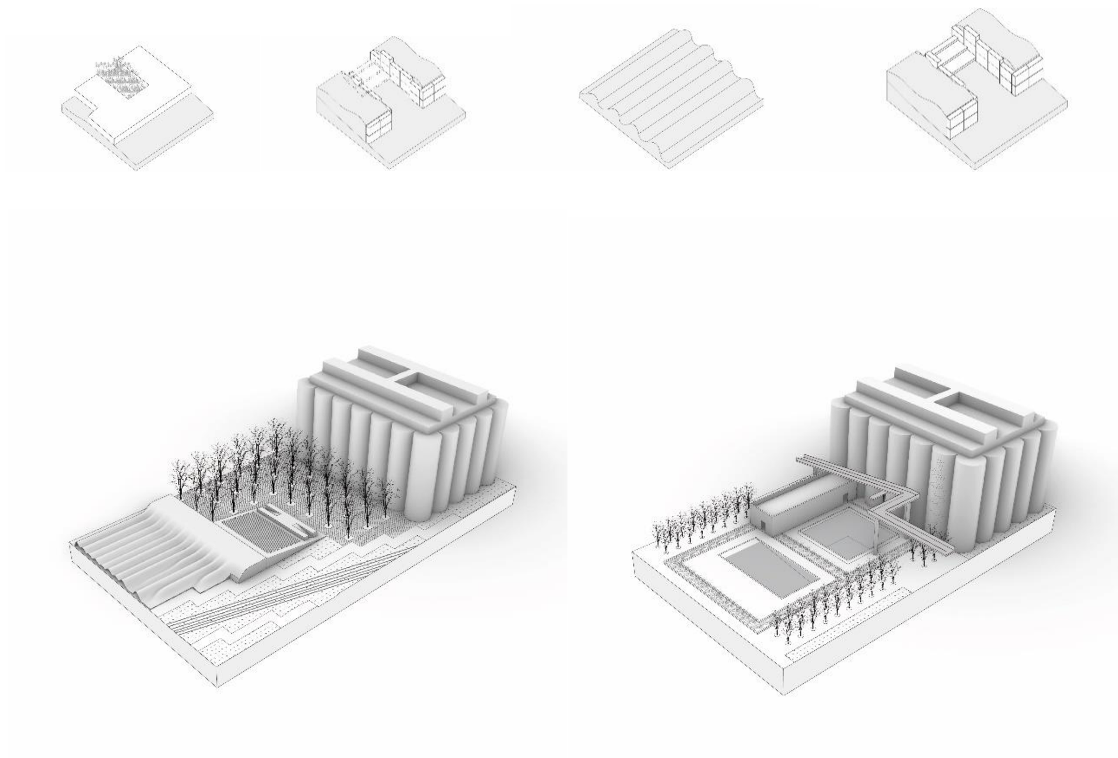


Figure 5.25: Common drawings as outputs in the schematic design stage (Chung-Chiang Chen, LA 537: Landscape Planning & Design Studio)

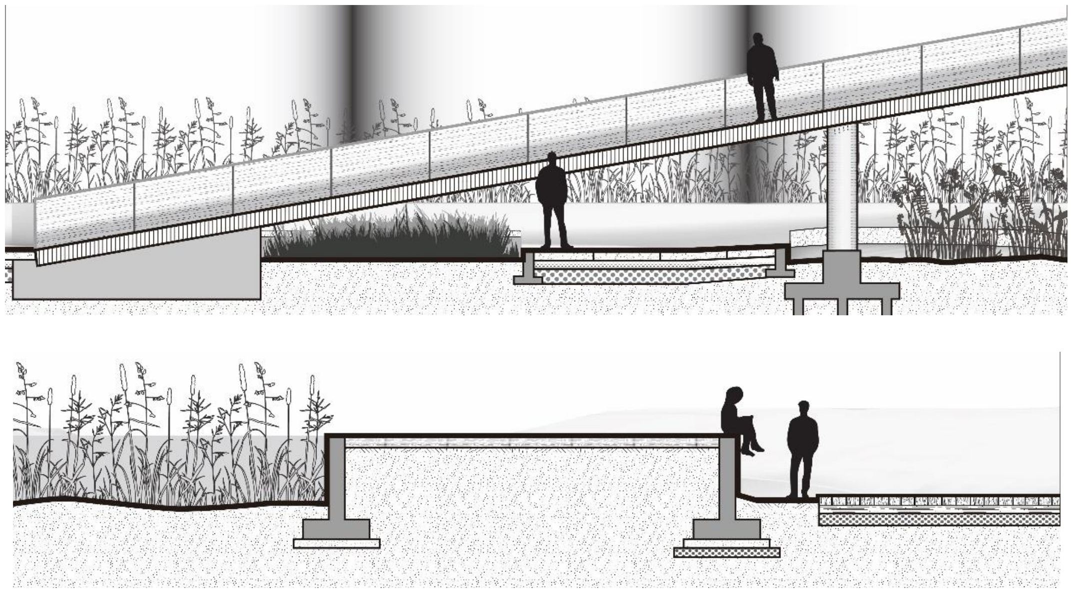


Figure 5.25: (cont.)

CHAPTER 6: EVALUATION OF THE MIXED REALITY SOFTWARE

Evaluation of Mixed Reality Software for Landscape Architecture

In Chapter 3, seven categories of the mixed reality software could potentially participate in the landscape architecture professional workflow. The operation record of mixed reality software, including Insta 360-degree Filming software, Google Tilt brush, iScape, and Fologram, has been collected later in Chapter 3. In Chapter 5, the Google Tilt Brush and Gravity Sketch also serve a pivotal role in the virtual reality design process. The output of the mentioned MR software is in Chapter 3 and Chapter 5.

Chapter 6 will define the seven professional practice-related criteria for finding out the answer to the first thesis question.

The criterion for evaluating the mixed reality software

Fourteen criteria are listed base on the result obtained from Chapter 3 to Chapter 5. In the second part of Chapter 3, several MR tools have been tested. The endeavor for learning and applying MR tools is defined. On the other hand, some tested MR tools in Chapter 3 provided virtual reality for users to explore the site and design. The capacity of such a function is rated. Next, one of the thesis's pivotal ideas is whether MR tools could provide virtual reality for designers to improve creativity. The feature is also be evaluated in Chapter 5. The list of the tested MR software is in the following list.

1. Google Tilt Brush
2. Gravity Sketch
3. 360-degree filming
4. IScape

5. Fologram

For the construction stage, according to the result (Figure 4.20) in Chapter 4, 50% of the professional practitioners believe that AR could support the construction administration stage in a project workflow. The feature also has been tested out in Chapter 3. Therefore, the related criteria would be discussed. Finally, according to the survey result extracted from Chapter 4, efficiency is considered the least possible contribution that MR could provide. To summary, the fragrance of the evaluation criterion mentioned in the former chapter is organized in Figure 6.1.

1. Easy to use
2. Easy to learn
3. Understanding the site
4. Site analysis visualization
5. Improving creativity
6. Sketching conceptual design
7. Designing buildable structures
8. Communicating with clients
9. Helping with construction
10. Efficient for small-scale projects
11. Efficient for medium-scale projects
12. Efficient for large-scale projects
13. Providing an immersive experience of the design
14. Coordinating with other software

	Tilt Brush	Gravity Sketch	360-degree Filming	Iscape	Fologram
Easy to use	●	▲	●	●	✕
Easy to learn	●	▲	●	●	✕
Understanding the site	●	▲	●	✕	✕
Site analysis visualization	▲	●	✕	✕	✕
Improve creativity	●	●	✕	●	●
Sketching concept design	●	●	✕	●	▲
Design buildable structure	▲	●	✕	▲	●
Communication with clients	●	●	✕	●	●
Help with construction	✕	▲	✕	▲	●
Efficient for small-scale projects	▲	●	●	●	●
Efficient for medium-scale projects	▲	▲	●	✕	▲
Efficient for large-scale projects	✕	✕	▲	✕	▲
Providing immersive experience of the design	●	●	✕	✕	✕
Coordination with other software	✕	●	✕	✕	▲

● Very Useful ▲ Somehow useful ✕ Not really

Figure 6.1: The summary of the contribution of tested MR software in former chapters

Mixed Reality and Current Professional Workflow

The universal workflow defined in Chapter 3 supports the summary of evaluating the potential of MR. Based on the universal workflow, some of the stages are complex, including more than one kind of work. Therefore, the MR's evaluation is not classified by the eight stages in the universal workflow, but practitioners' actual activities need to do in each stage. Furthermore, to evaluate a technique's quality, a comparison with standard methods is a straightforward approach to express the outcome. Therefore, the typical methods in each activity serve as an example to be compared with MR. The thesis classifies eight kinds of activities that are applied for evaluating the MR software (Figure 6.2).

1. Site information collecting and analysis: under "concept" in universal workflow
2. Defining main issue, goal, and concept: under "concept" in universal workflow
3. Discussion with clients or other project participants: under "concept, charrette, schematic design, design development, construction documents, bidding and negotiations" in universal workflow
4. Creating a design model: under "schematic design, design development" in universal workflow
5. Model rendering: under "schematic design" in universal workflow
6. Design visualizations: under "schematic design, design development" in universal workflow
7. Construction drawings: under "construction documents" in universal workflow
8. Construction instructions: under "construction administrations" in universal workflow

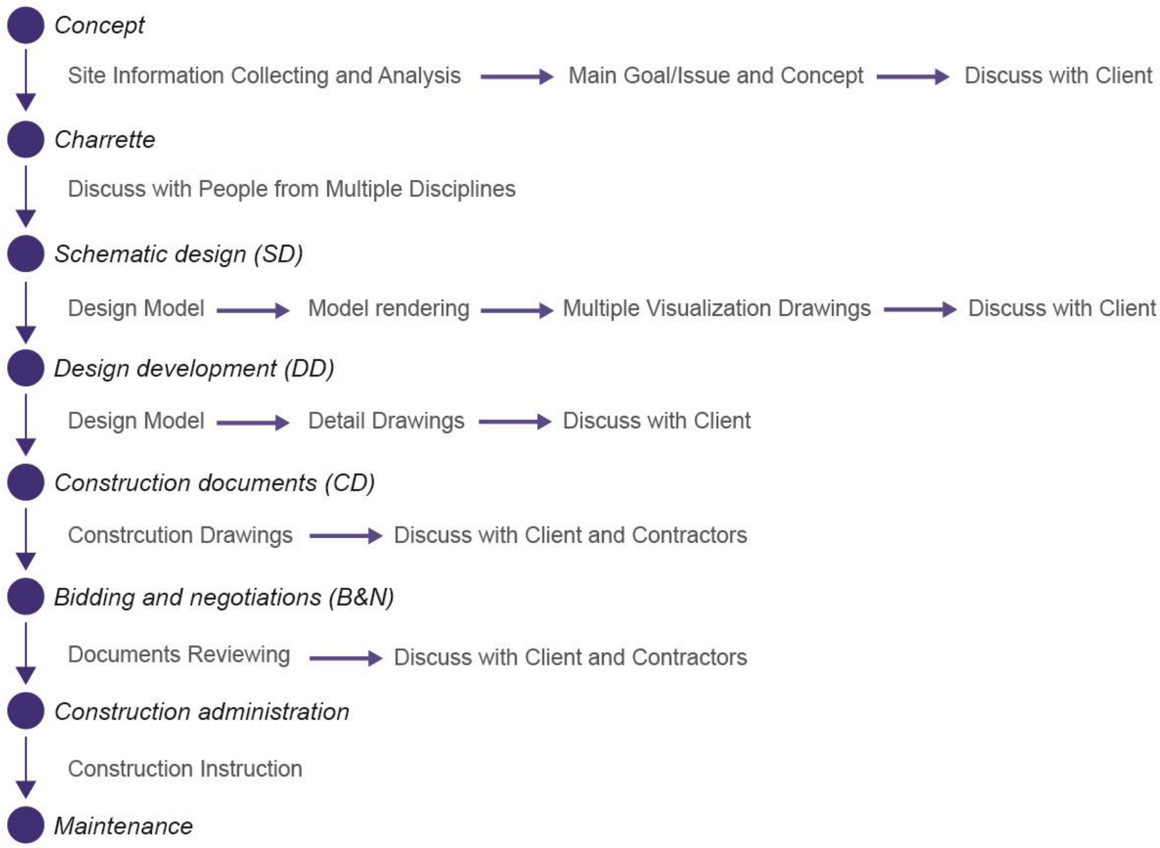


Figure 6.2: The activities and universal workflow

Site information collecting and analysis

The methods of how practitioners applied in this stage are the most dynamic one in the universal workflow. Seven typical software is listed for evaluating the MR. The common objectives that practitioners might work on are searching the site's information, understating the site, and visualizing the findings. The result (Figure .6.3) of the evaluation indicates that the MR is beneficial for modeling a site and visualize spatial analysis.

Figure 6.3: The evaluation of MR in site information collecting and analysis

Defining main issue, goal, and concept

Since the way to define the issue, goal, and concept are based on the style and personality of a practitioner, many techniques will be applied to this activity. To enumerate the thinking, designers always need to visualize the works in whatever methods, rather than merely speak the ideas. The typical objectives of this activity include brainstorming and visualizing. The result (Figure 6.4) of the evaluation indicates that the MR is beneficial to create isometric diagrams and brainstorming.

Strategy brainstorming	✕	●	✕	▲
Project goals infographics	✕	▲	✕	✕
Problem/Approach/Concept infographic diagrams	▲	●	▲	✕
Problem/Approach/Concept mappings	●	✕	●	●
Problem/Approach/Concept isometric Diagrams	▲	✕	●	●
Problem/Approach/Concept sections	▲	✕	●	●
Problem/Approach/Concept perspectives	▲	✕	▲	●
Problem/Approach/Concept photo collages	✕	✕	✕	✕

	Ai	Ps	MR
Strategy brainstorming	✕	●	●
Project goals infographics	●	●	▲
Problem/Approach/Concept infographic diagrams	●	●	▲
Problem/Approach/Concept mappings	●	●	▲
Problem/Approach/Concept isometric Diagrams	●	●	●
Problem/Approach/Concept sections	▲	●	▲
Problem/Approach/Concept perspectives	▲	●	✕
Problem/Approach/Concept photo collages	▲	●	✕

● Works great in the workflow ▲ Potentially useful in the workflow ✕ Not really works in the workflow

Figure 6.4: The evaluation of MR in defining main issue, goal, and concept

Discussion with clients or other project participants

The ways how designers communicate with the audience could be classified into visual information and acoustic information. The visual information includes any information received by eyes, including words, pictures, or videos. On the other hand, acoustic information means the information received by the ears.[71] Three typical techniques would be compared to MR for evaluation. The result (Figure 6.5) of the evaluation indicates that the MR is beneficial to variable communication methods, except for the documentation.

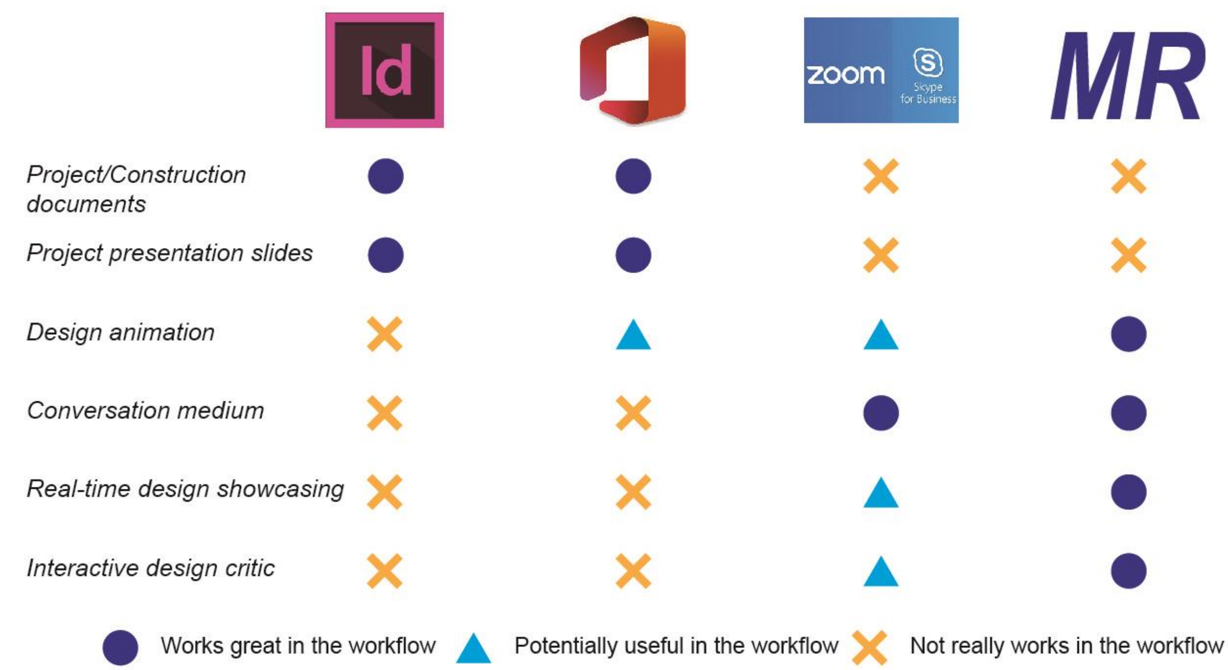


Figure 6.5: The evaluation of MR in discussion with clients or other project participants

[71] Peter J. Rentfrow, Lewis R. Goldberg, and Ran Zilca, "Listening, Watching, and Reading: The Structure and Correlates of Entertainment Preferences," *Journal of Personality* 79, no. 2 (April 2011): 223–58, https://doi.org/10.1111/j.1467-6494.2010.00662.x.

Creating a design model

A design model is essential for any developed design project. Many drawings could be extracted from a model. In this activity, the evaluation criteria are mainly about how the software could provide a handy way to build any shape or structure that designers imagined and its efficiency. The result (Figure 6.6) of the evaluation indicates that the MR is handy for designers to draw organic structures or curvy shapes. However, efficiency is not as good as typical software.

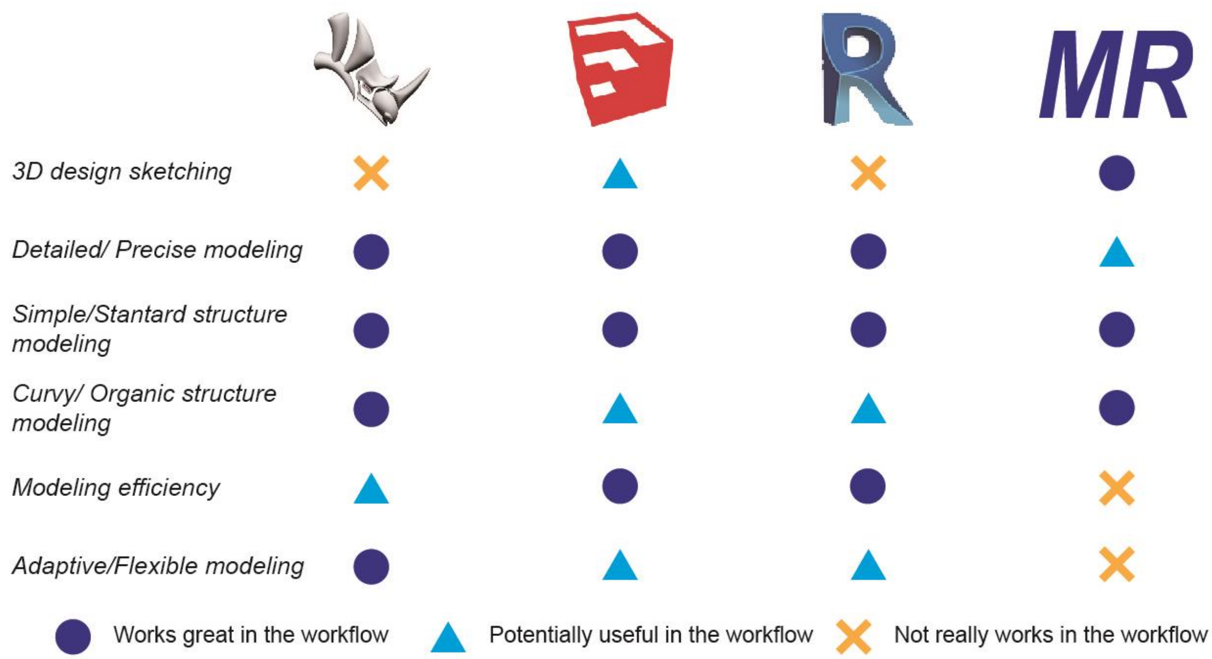


Figure 6.6: The evaluation of MR in discussion with creating a design model

Model rendering

A rendered model could be more comfortable for designers to communicate the ideas to people who do not have relevant knowledge. The rendering software is also improved tremendously in recent years. The result (Figure 6.7) shows that MR may have no contribution to the rendering activity in any criteria.

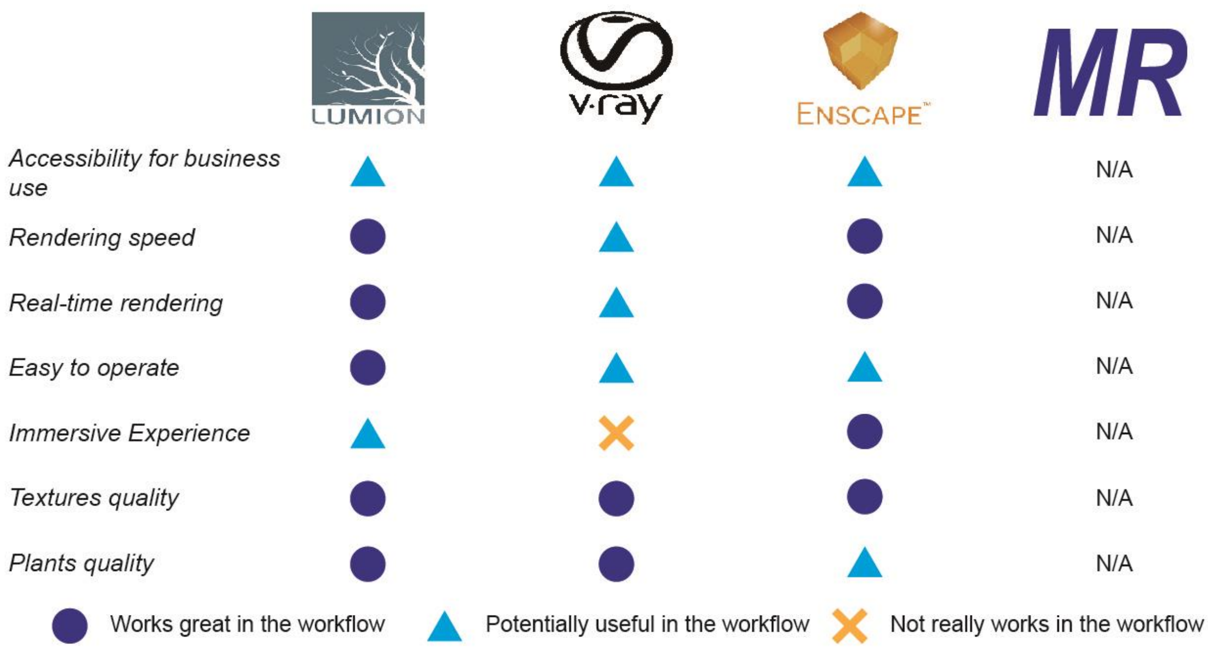


Figure 6.7: The evaluation of MR in model rendering

Design visualizations

Except for the perspective, some design ideas, such as energy circulation, water recycling, or self-efficient strategies, which sections, icons, or vector images are more suitable for expressing these ideas, is also common to be applied for communication. Therefore, four specific technics are considered for comparing with MR. The result (Figure 6.8) shows that MR benefit most of the visualization except for plans, or sections, which are expected to be a 2D diagram.

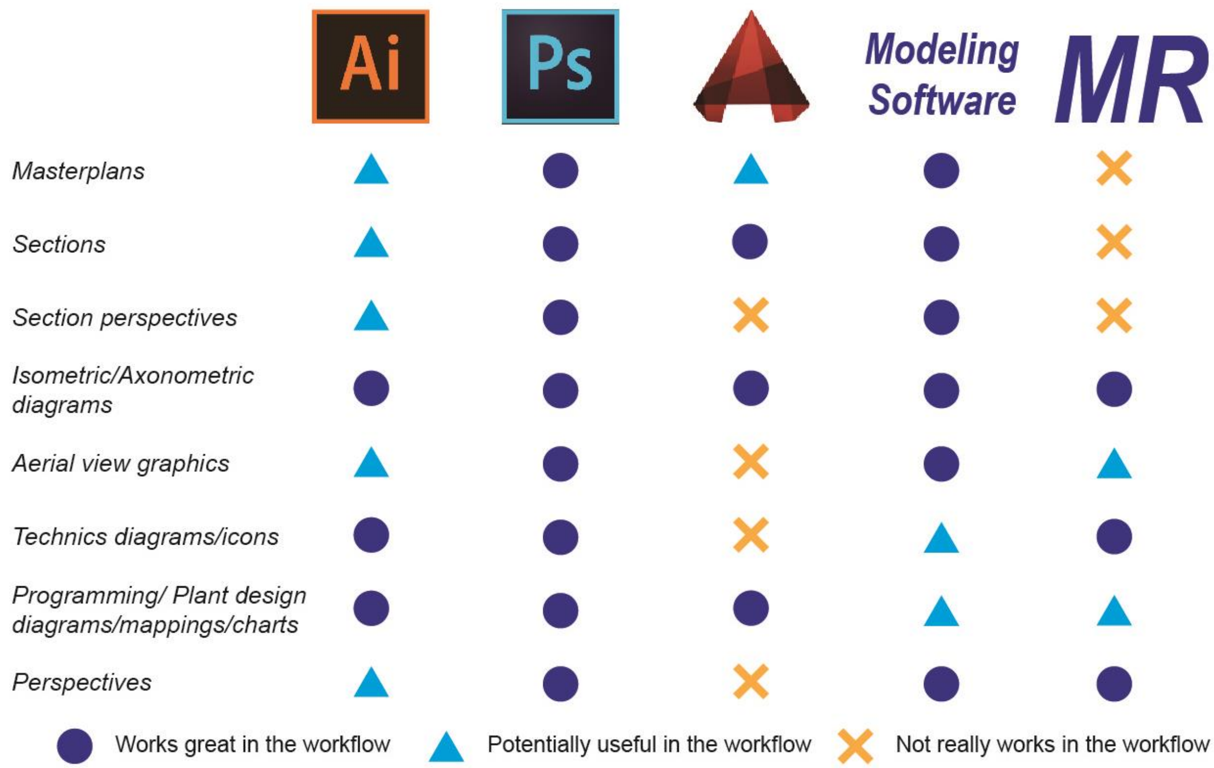


Figure 6.8: The evaluation of MR in design visualizations

Construction drawings

The construction drawings are the official documentation that landscape architects submit to the contractor to build the project. Therefore, the documentation drawings should be in a specific pattern that all participants in a project could recognize. Moreover, the drawings are highly restricted to local regulations. In this case, MR seems not supportive in any part of this action (Figure 6.9).

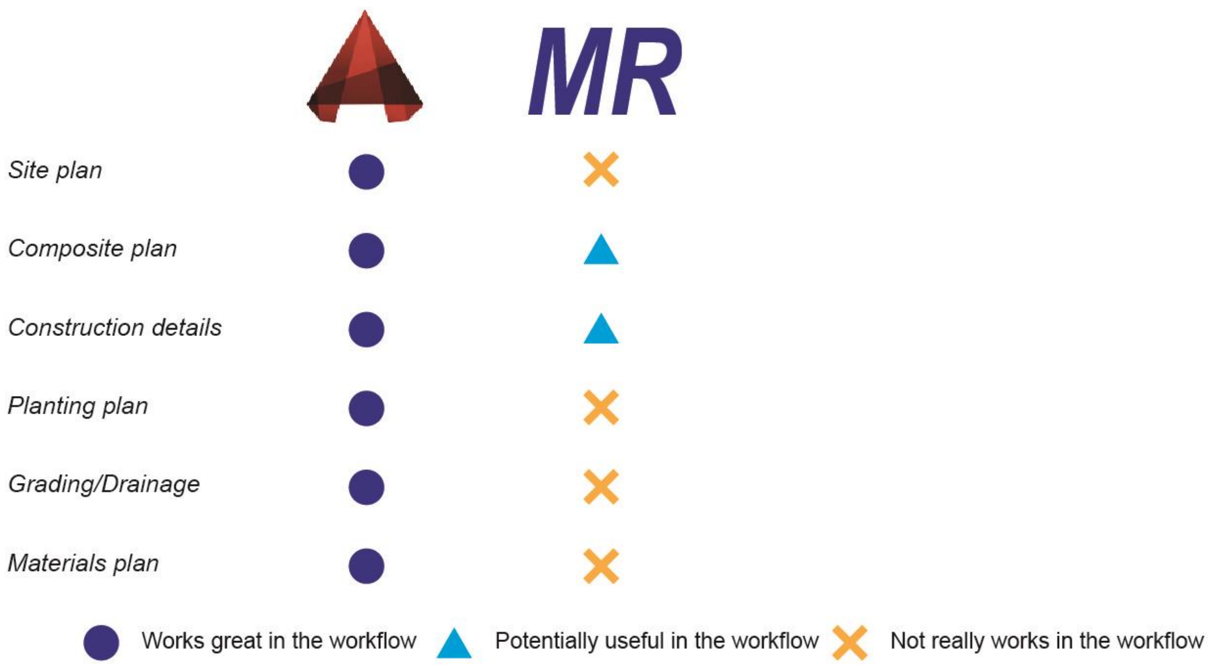


Figure 6.9: The evaluation of MR in construction drawings

Construction instructions

Finally, construction management is the last stage in a universal workflow that MR software could provide support. In chapter 3, the Fologram showed out how AR could help with construction in multiple aspects. Although in the result (Figure 6.10), the MR receives many positive comments, the MR's limitation, including the demanding skill and unknown capability to all kinds of design, still make it less reliable.

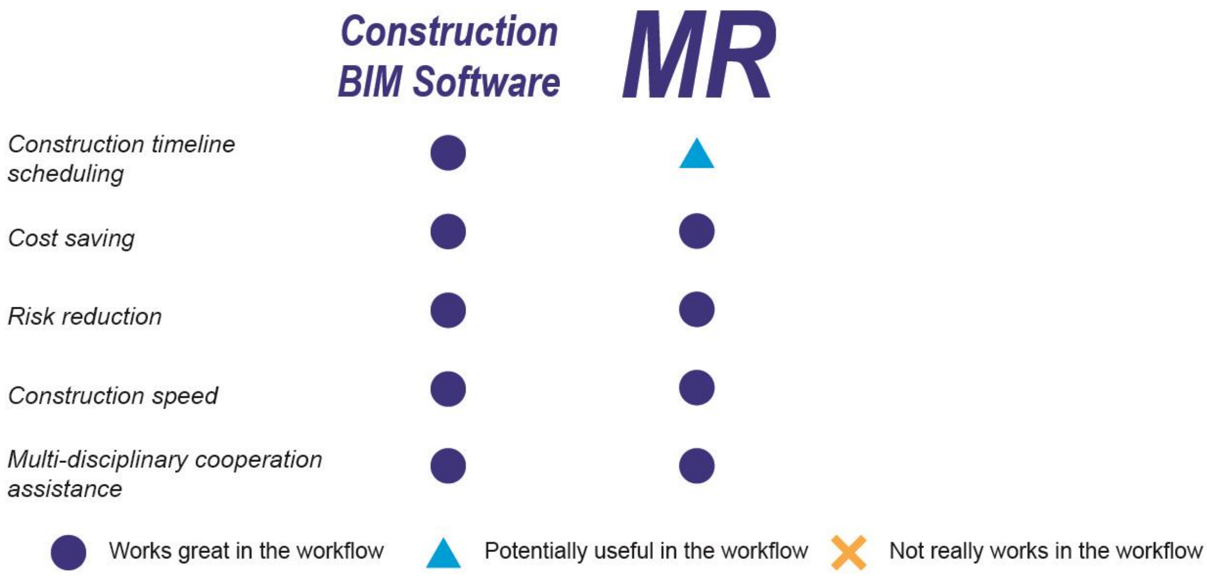


Figure 6.10: The evaluation of MR in construction instructions

Summary of the Potential of Mixed Reality for Landscape Architecture

To conclude the evaluation, a scale for calculating an "effectiveness score" for evaluation has been defined. An effectiveness score is defined by how many circles, crosses, and triangles received in the evaluation charts—a circle count one point, a triangle counts zero points five, and a cross count zero point. The total score of each stage in the universal workflow will be the sum of all the circles that could be obtained in activities.

	Conventional Software	MR
Concept	20/21 (95%)	11.5/21 (55%)
Site Information Collecting and Analysis	7/7 (100%)	3.5/7 (50%)
Main Goal/Issue and Concept	8/8 (100%)	4/8 (50%)
Discuss with Client	5/6 (83%)	4/6 (67%)
Charrette	5/6 (83%)	4/6 (67%)
Discuss with People from Multiple Disciplines	5/6 (83%)	4/6 (67%)
Schematic design (SD)	25/27 (93%)	11.5/20 (58%)
Design Model	6/6 (100%)	3.5/6 (58%)
Model rendering	6/7 (85%)	N/A
Multiple Visualization Drawings	8/8 (100%)	4/8 (50%)
Discuss with Client	5/6 (183%)	4/6 (67%)
Design development (DD)	19/20 (95%)	11.5/20 (58%)
Design Model	6/6 (100%)	3.5/6 (58%)
Detail Drawings	8/8 (100%)	4/8 (50%)
Discuss with Client	5/6 (83%)	4/6 (67%)
Construction documents (CD)	11/12 (92%)	5/12 (41%)
Constrcution Drawings	6/6 (100%)	1/6 (58%)
Discuss with Client and Contractors	5/6 (83%)	4/6 (67%)
Bidding and negotiations (B&N)	N/A	N/A
Construction administration	6/6 (100%)	5/6 (67%)
Maintenance	N/A	N/A

Chart 6.1: The effectiveness score of conventional software an MR in each stage

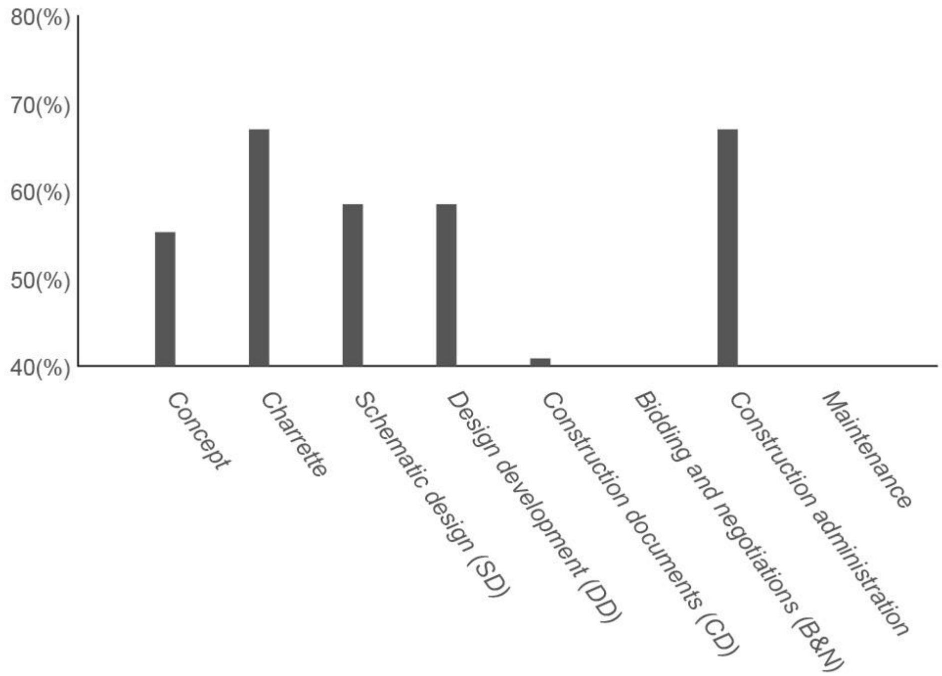


Figure 6.11: The summary bar chart of the contribution of MR in each stage

The final score shows that MR is potentially helpful for the concept, charrette. Schematic design, design development, and construction administration in the universal workflow. The scores indicated that MR could only serve as one of the design tools. However, the MR shows strong potential in any discussion stage and the construction administration.

CHAPTER 7: CONCLUSION

The thesis's inspiration is that multiple industries have used mixed reality technology to support their works in variable ways. However, in the landscape architecture discipline, few practitioners are utilizing mixed reality for the works. For exploring the accessibility of mixed reality in a landscape architecture project, the thesis focuses on two questions. First, the thesis discusses how mixed reality technology could participate in a landscape architecture professional project. Next, the thesis figures out if mixed reality could facilitate designers' creative ideas.

The thesis's first challenge is that multiple workflows could differ depending on project types, firm styles, or the designer's personality. Therefore, by organizing the literature reviews and the interview with a landscape architect, a standard workflow has been proposed as a universal workflow. The universal workflow stages include concept, charrette, schematic design, design development, construction documents, bidding, construction management, and post-construction maintenance.

Afterward, the thesis collects numerous mixed reality software potentially helpful for landscape projects and classified the software into seven categories. The first category provides virtual reality as a medium for practitioners to sketch in a three-dimensional space. Next, the second category is software that could create a comprehensive virtual reality environment, and users can experience the VR through headsets. The third category is that the 360-degree filming software could serve as an alternative for site visiting. A fourth category is a group of AR software that provides landscape designers with a quick sketching function for discussing with clients. The fifth category is the communicating function of mixed reality. The sixth category provides designers a virtual reality to work and design together. The final category is that AR software could support the construction administration. Google Tilt Brush, Insta 360 X, iScape, and Fologram have been tested out and approved with the functions.

The survey outcome proves that nearly half of the practitioners have tried to utilize MR in their projects. Moreover, most of the practitioners use MR for communicating with the project participants through the virtual tour or AR design sketching. The result also shows that most of the practitioners agree with the potential MR functions that support landscape architect projects. However, some of the contribution proposed in Chapter 2 was mostly disapproved by practitioners. For example, the contribution of AR in the construction administration stage. The practitioners may underestimate such contribution because of lacking the experience with AR. An analysis shows that most of the practitioners agree with the potentials of MR after experiencing MR. Therefore, by disseminating MR to more practitioners, the MR could be more supportive in the landscape architecture profession in the future.

A virtual reality landscape design workflow is proposed and tried out in the thesis. The VR shows not helpful in the data collecting, goal defining stage, and most of the typical drawings that the practitioners widely accepted, such as section and masterplans. However, VR provides excellent potential to help with modelings, such as site modeling and detailed modeling. Due to the fact that there is no VR sketching software designed for landscape projects, efficiency is still unsatisfactory.

Finally, the research summary shows that mixed reality could be somewhat helpful in concept, charrette, schematic design, design development, and construction administration stages in the universal workflow. However, the MR still cannot work as a leading role in each stage. The combination of typical software still provides a more substantial contribution to each stage.

Next Steps

The future works of accessing MR in the landscape architecture professional practice could be clarified into three subjects. First, create a virtual reality software suitable for landscape architecture. Next, explore more approaches that could be applied in the AR construction assistance tool. Finally, disseminate MR knowledge to more practitioners.

VR software for landscape architecture

In Chapter 3 and Chapter 5, the thesis summarizes all the potential contribution that MR could bring to landscape architecture projects. However, none of the user's interface in the mentioned software is friendly to landscape architects. For example, although Google Tilt Brush provides a flexible VR for users to draw. Nevertheless, landscape architects sometimes need to draw on a precise scale; even the design may not be detailed. Popular software such as AutoCAD, SketchUp, and Rhino, is comfortable for landscape architects because of a precise snapping and alignment function. Therefore, landscape architecture-oriented software is future work for either landscape practitioners or computer engineers.

Exploring more approach to make AR construction assistance compatible

In Chapter 3, the Fologram shows many potentials of how AR could contribute to landscape architecture. The challenge is how to express the instruction in AR glasses in a comfortable format for all the landscape architecture projects. For example, how to create a Grasshopper parameter to instruct a landscape fountain made of concrete? After more templates or examples are explored, AR could be a robust tool for the construction administration stage.

Disseminating MR knowledge

The survey result in Chapter 4 indicates that landscape architecture practitioners are optimistic about MR in many stages. Moreover, the multiple comparisons between practitioners with and without MR experience prove that practitioners usually approve of the contribution of MR to landscape architecture projects. Therefore, more potential of MR could be explored while more practitioners start learning MR technology.

References

Ahmad, Ahmad Mohammad, and Abdullahi Adamu Aliyu. “The Need for Landscape Information Modelling (LIM) in Landscape Architecture,” 531–40. Anhalt University of Applied Science, University in Köthen, Germany, 2012.

“ASLA Virtual Reality | Asla.Org.” Accessed November 27, 2020. https://www.asla.org/vr.aspx.

Baranowski, Tom. “Pokémon Go, Go, Go, Gone?” *Games for Health Journal* 5, no. 5 (October 2016): 293–94. https://doi.org/10.1089/g4h.2016.01055.tbp.

Batty, Michael. “Defining Geodesign (= GIS + Design?).” *Environment and Planning B: Planning and Design* 40, no. 1 (February 2013): 1–2. https://doi.org/10.1068/b4001ed.

Bol, Mike. “What Types of AR Experiences Are Used Most?” AR Insider, August 13, 2020. https://arinsider.co/2020/08/13/what-types-of-ar-experiences-are-used-most/.

Calvert, Sandra L., and Siu-Lan Tan. “Impact of Virtual Reality on Young Adults’ Physiological Arousal and Aggressive Thoughts: Interaction versus Observation.” *Journal of Applied Developmental Psychology* 15, no. 1 (January 1994): 125–39. https://doi.org/10.1016/0193-3973(94)90009-4.

Chittenden, Tara. “Tilt Brush Painting: Chronotopic Adventures in a Physical-Virtual Threshold.” *Journal of Contemporary Painting* 4, no. 2 (October 1, 2018): 381–403. https://doi.org/10.1386/jcp.4.2.381_1.

CSS_mainAdmin. “The Stages of a Landscape Architecture Project.” Creative Shade Solutions, August 7, 2020. https://www.creativeshadesolutions.com/the-stages-of-a-landscape-architecture-project/.

Danny Bittman. *How to Create a Massive Tilt Brush Environment in 10 Minutes // Becoming a VR Artist Ep. 6*, 2019. https://www.youtube.com/watch?v=tFSAZvQTZBE&ab_channel=DannyBittman.

Dharwadker, Aneesha, and Conor Conor. “Mangrove Metropolis.” HINTERLANDS. Accessed December 7, 2020. http://www.hinterlands-ul.net/mangrove-metropolis-1.

ebemto. *Gravity Sketch VR Grid & Smartmove*, 2018. https://www.youtube.com/watch?v=hVnZuohoSuc&ab_channel=ebemto.

“Enable a Smooth Decision-Making and Positive Landscaping Experience.” Accessed December 5, 2020. https://www.iscapeit.com/blog/enable-a-smooth-decision-making-and-positive-landscaping-experience.

Fabos, Julius Gy. “Paperless Landscape Architecture: Future Prospects?” *Landscape Journal* 2, no. 1 (1983): 13–18. https://doi.org/10.3368/lj.2.1.13.

Fazel, Alireza, and Abbasali Izadi. “An Interactive Augmented Reality Tool for Constructing Free-Form Modular Surfaces.” *Automation in Construction* 85 (January 2018): 135–45. https://doi.org/10.1016/j.autcon.2017.10.015.

“Fologram.” Accessed November 29, 2020. https://fologram.com/.

Francis, Mark. “A Case Study Method For Landscape Architecture,” n.d., 15.

Gay, L. R. “Educational Research Competencies for Analysis and Application,” 1992.

“Get Ready to Hear a Lot More About ‘XR.’” *Wired*. Accessed November 27, 2020. https://www.wired.com/story/what-is-xr/.

Gong, Liang, Henrik Söderlund, Leonard Bogojevic, Xiaoxia Chen, Anton Berce, Åsa Fast-Berglund, and Björn Johansson. “Interaction Design for Multi-User Virtual Reality Systems: An Automotive Case Study.” *Procedia CIRP* 93 (2020): 1259–64. https://doi.org/10.1016/j.procir.2020.04.036.

Gottfredson, John A. “Design Process in Landscape Architecture: Developing a Learning Guide for the Design Workshop Archives at Utah State University,” 2014, 99.
Gram Garden. *Augmented Reality Landscape*, 2017. https://www.youtube.com/watch?v=oRWJdyNGRgc&ab_channel=GramGarden.
Hall, Temple Buell, and E Lorado Taft Drive. “David L. Hays, Professor and Brenton H. and Jean B. Wadsworth Head Lori Davis, Academic Affairs Coordinator,” n.d., 10.
Hill, Drew. “HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE DESIGN PROCESS AT VARIOUS SCALES,” 2019.
Holmberg, Trine Theresa, Tanja Lilly Eriksen, Rasmus Petersen, Nicklas Nørgård Frederiksen, Ulla Damgaard-Sørensen, and Mia Beck Lichtenstein. “Social Anxiety Can Be Triggered by 360-Degree Videos in Virtual Reality: A Pilot Study Exploring Fear of Shopping.” *Cyberpsychology, Behavior, and Social Networking* 23, no. 7 (July 1, 2020): 495–99. https://doi.org/10.1089/cyber.2019.0295.
Holmes, Damian. “PRACTICE | Stages of a Landscape Architecture Design Project.” *World Landscape Architecture* (blog), August 6, 2017. https://worldlandscapearchitect.com/practice-stages-of-a-landscape-architecture-design-project/.
DesignWanted. “How Fologram Sees the World and Then Builds in It,” January 21, 2020. https://designwanted.com/tech/fologram/.
WorldAtlas. “How Many Countries Are in Oceania?” Accessed November 29, 2020. https://www.worldatlas.com/articles/how-many-countries-are-in-oceania.html.
“How Many Countries in Oceania? - Worldometer.” Accessed November 29, 2020. https://www.worldometers.info/geography/how-many-countries-in-oceania/.
Hu, Nan. Landscape Architecture and Mixed Reality: An Interview, March 20, 2020.
Hughes, C.E., C.B. Stapleton, D.E. Hughes, and E.M. Smith. “Mixed Reality in Education, Entertainment, and Training.” *IEEE Computer Graphics and Applications* 25, no. 6 (November 2005): 24–30. https://doi.org/10.1109/MCG.2005.139.
Insider, A. R. “How Often Do VR Users Engage?” AR Insider, May 21, 2020. https://arinsider.co/2020/05/21/how-often-do-vr-users-engage/.
jacksepticeye. *NEXT GEN STARTS NOW | Spider-Man Miles Morales - Part 1 (PS5)*, 2020. https://www.youtube.com/watch?v=oR5Z7bE9LU8&ab_channel=jacksepticeye.
Jones, Sarah. “Disrupting the Narrative: Immersive Journalism in Virtual Reality.” *Journal of Media Practice* 18, no. 2–3 (September 2, 2017): 171–85. https://doi.org/10.1080/14682753.2017.1374677.
Kishino, Fumio. “Http://Vered.Rose.Utoronto.ca/People/Paul_dir/IEICE94/Ieice.Htm,” n.d., 15.
Koch, Brian. “Landscape Architecture.” Terra Ferma Landscapes, 2020. https://tflandscapes.com/what-we-do/our-process/process-landscape-architecture/.
Kovach, Leah. “How This Landscape Architecture Firm Uses VR To Communicate Design Intent.” Accessed April 24, 2019. https://blog.irisvr.com/how-this-landscape-architecture-firm-uses-vr-to-communicate-design-intent.
Kumar, Satish. “How Does Augmented Reality Work?,” November 26, 2017, 4.
“Living Breakwaters Design and Implementation - SCAPE.” Accessed May 7, 2019. https://www.scapestudio.com/projects/living-breakwaters-design-implementation/.
McMichael, Anthony, Australia, and Department of Health and Ageing. *Human Health and Climate Change in Oceania: A Risk Assessment*. Canberra: Commonwealth Department of Health and Ageing, 2003.

Mitasova, H., L. Mitas, C. Ratti, H. Ishii, J. Alonso, and R.S. Harmon. "Real-Time Landscape Model Interaction Using a Tangible Geospatial Modeling Environment." *IEEE Computer Graphics and Applications* 26, no. 4 (July 2006): 55–63. https://doi.org/10.1109/MCG.2006.87.

Nicholson, Daren T, Colin Chalk, W Robert J Funnell, and Sam J Daniel. "Can Virtual Reality Improve Anatomy Education? A Randomised Controlled Study of a Computer-Generated Three-Dimensional Anatomical Ear Model." *Medical Education* 40, no. 11 (November 2006): 1081–87. https://doi.org/10.1111/j.1365-2929.2006.02611.x.

Ozturkcan, Selcen. "Service Innovation: Using Augmented Reality in the IKEA Place App." *Journal of Information Technology Teaching Cases*, August 13, 2020, 2043886920947110. https://doi.org/10.1177/2043886920947110.

Pope, Vanessa C., Robert Dawes, Florian Schweiger, and Alia Sheikh. "The Geometry of Storytelling: Theatrical Use of Space for 360-Degree Videos and Virtual Reality." In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 4468–78. Denver Colorado USA: ACM, 2017. https://doi.org/10.1145/3025453.3025581.

Portman, M.E., A. Natapov, and D. Fisher-Gewirtzman. "To Go Where No Man Has Gone before: Virtual Reality in Architecture, Landscape Architecture and Environmental Planning." *Computers, Environment and Urban Systems* 54 (November 2015): 376–84. https://doi.org/10.1016/j.compenvurbsys.2015.05.001.

Reed, Brandon. "DEVELOPERS: KNOW THE 4 DESIGN PHASES OF A SUCCESSFUL LANDSCAPE PROJECT IN UTAH." *LoftSixFour* (blog). Accessed November 28, 2020. https://loftsixfour.com/blog/developers-know-the-4-design-phases-of-a-successful-landscape-project-in-utah/.

Rentfrow, Peter J., Lewis R. Goldberg, and Ran Zilca. "Listening, Watching, and Reading: The Structure and Correlates of Entertainment Preferences." *Journal of Personality* 79, no. 2 (April 2011): 223–58. https://doi.org/10.1111/j.1467-6494.2010.00662.x.

Rohr, Fabian. "Comparison of Best VR Headsets: Morpheus vs. Rift vs. Vive," August 14, 2015. https://web.archive.org/web/20150820001906/http://data-reality.com/comparison-of-best-vr-headsets-morpheus-vs-rift-vs-vive/.

Sandzén, Sigurd Carl. "BIOMIMICRY AS DESIGN LENS FOR LANDSCAPE ARCHITECTURE," n.d., 86.

Sharky, Bruce. "The Design Process and the Life of a Project." In *Thinking About Landscape Architecture*, 45–64, 2016.

Shushan, Yossi, Juval Portugali, and Efrat Blumenfeld-Lieberthal. "Using Virtual Reality Environments to Unveil the Imageability of the City in Homogenous and Heterogeneous Environments." *Computers, Environment and Urban Systems* 58 (July 2016): 29–38. https://doi.org/10.1016/j.compenvurbsys.2016.02.008.

Song, Jialu, and Sijia Huang. "Virtual Reality (VR) Technology and Landscape Architecture." Edited by G. Lee. *MATEC Web of Conferences* 227 (2018): 02005. https://doi.org/10.1051/matecconf/201822702005.

Steinitz, Carl. "Landscape Architecture into the 21st Century – Methods for Digital Techniques," n.d., 25.

Studios, Structure. "YARD - Augmented Reality Designer - From Structure Studios." Accessed November 29, 2020. https://www.structurestudios.com/yard.

Summers, Heather. "INVESTIGATING THE ABILITY OF CORAL REEFS TO PROTECT SHORELINES IN THE REPUBLIC OF KIRIBATI," n.d., 87.

Tai, L. “Assessing the Impact of Computer Use on Landscape Architecture Professional Practice: Efficiency, Effectiveness, and Design Creativity.” *Landscape Journal* 22, no. 2 (January 1, 2003): 113–25. https://doi.org/10.3368/lj.22.2.113.

“This Is How a Complex Brick Wall Is Built Using Augmented Reality | The Strength of Architecture | From 1998.” Accessed December 5, 2020. https://www.metalocus.es/en/news/how-a-complex-brick-wall-built-using-augmented-reality#.

“This Pokémon Go Update Is Showing Us Why ARCore Is Great.” Accessed December 5, 2020. https://www.androidauthority.com/pokemon-go-arcore-update-913547/.

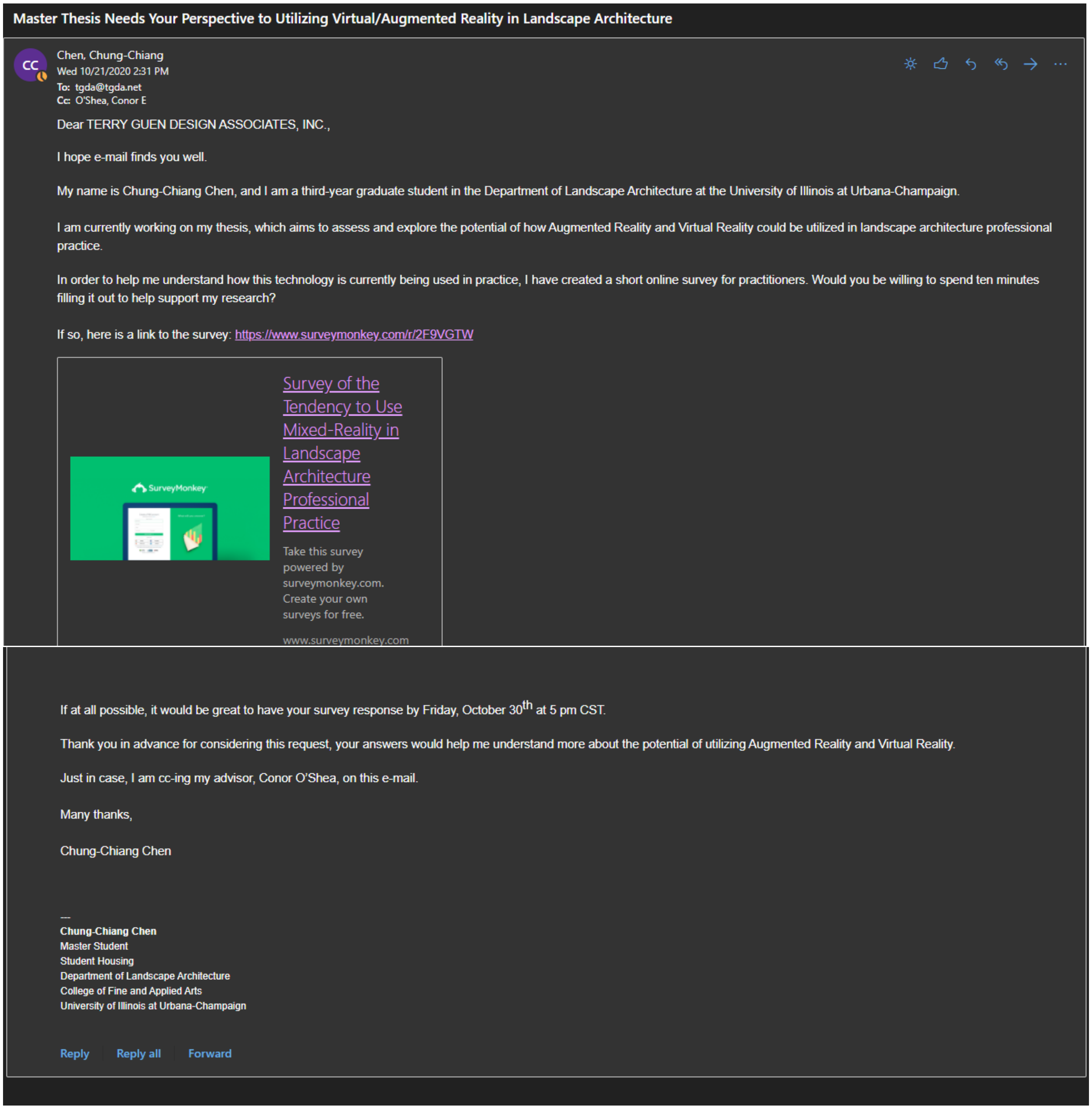
Wei, Zhuo, Ningning Xie, and Wenna Feng. “Modern Landscape Design Based on VR Technology and Wireless Internet of Things System.” *Microprocessors and Microsystems*, November 2020, 103516. https://doi.org/10.1016/j.micpro.2020.103516.

White Baker, Elizabeth, Said S. Al-Gahtani, and Geoffrey S. Hubona. “The Effects of Gender and Age on New Technology Implementation in a Developing Country: Testing the Theory of Planned Behavior (TPB).” *Information Technology & People* 20, no. 4 (January 1, 2007): 352–75. https://doi.org/10.1108/09593840710839798.

Yan, Jie. “An Evaluation of Current Applications of 3D Visualization Software in Landscape Architecture.” M.L.A., Utah State University, 2014. https://search.proquest.com/pqdtglobal/docview/1659779341/abstract/DF2D5B99BD844DDPQ/1.

Yung, Ryan, and Catheryn Khoo-Lattimore. “New Realities: A Systematic Literature Review on Virtual Reality and Augmented Reality in Tourism Research.” *Current Issues in Tourism* 22, no. 17 (October 21, 2019): 2056–81. https://doi.org/10.1080/13683500.2017.1417359.

Appendix A: Cover Letter Example



Master Thesis Needs Your Perspective to Utilizing Virtual/Augmented Reality in Landscape Architecture

CC Chen, Chung-Chiang
Wed 10/21/2020 2:31 PM
To: tgda@tgda.net
Cc: O'Shea, Conor E

Dear TERRY GUEN DESIGN ASSOCIATES, INC.,

I hope e-mail finds you well.

My name is Chung-Chiang Chen, and I am a third-year graduate student in the Department of Landscape Architecture at the University of Illinois at Urbana-Champaign.

I am currently working on my thesis, which aims to assess and explore the potential of how Augmented Reality and Virtual Reality could be utilized in landscape architecture professional practice.

In order to help me understand how this technology is currently being used in practice, I have created a short online survey for practitioners. Would you be willing to spend ten minutes filling it out to help support my research?

If so, here is a link to the survey: https://www.surveymonkey.com/r/2F9VGTW

SurveyMonkey

Survey of the Tendency to Use Mixed-Reality in Landscape Architecture Professional Practice

Take this survey powered by surveymonkey.com. Create your own surveys for free.

www.surveymonkey.com

If at all possible, it would be great to have your survey response by Friday, October 30th at 5 pm CST.

Thank you in advance for considering this request, your answers would help me understand more about the potential of utilizing Augmented Reality and Virtual Reality.

Just in case, I am cc-ing my advisor, Conor O'Shea, on this e-mail.

Many thanks,

Chung-Chiang Chen

--
Chung-Chiang Chen
Master Student
Student Housing
Department of Landscape Architecture
College of Fine and Applied Arts
University of Illinois at Urbana-Champaign

Reply | Reply all | Forward

Figure A.1: Sample of the cover letter

Appendix B: Content of the Questionnaire

Survey of the Tendency to Use Mixed-Reality in Landscape Architecture Professional Practice

Definition of Virtual Reality and Augmented Reality

Mixed-Reality is a circumstance that blends physical and digital worlds. This circumstance could be made by a computer, a headset, or an Ipad. Generally, the mixed reality usually includes augmented reality and virtual reality.

Virtual Reality: the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.- *from Oxford Dictionary*

Augmented Reality: a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.- *from Oxford Dictionary*

Survey of the Tendency to Use Mixed-Reality in Landscape Architecture Professional Practice

Basic Information

1. What is your gender?

- ◯ Female
- ◯ Male
- ◯ Other (please specify)

* 2. How long have you been professionally working as a landscape architect, or employed by a landscape architecture/design office?

- ◯ 1-2 years
- ◯ 3-4 years
- ◯ 5-6 years
- ◯ 7-8 years
- ◯ 9-10 years
- ◯ More than 10 years

Figure B.1: The list of questions in the survey

Firm Information

* 3. How many staff in your firm. If your company is an integrated enterprise, how many staff in the landscape department?

- ◯ 1-5
- ◯ 6-10
- ◯ 11-30
- ◯ 31-50
- ◯ More than 50

* 4. How long has your firm been established for?

- ◯ 1-3 Years
- ◯ 4-6 Years
- ◯ 7-9 Years
- ◯ 10-12 Years
- ◯ 13-15 Years
- ◯ 16-18 Years
- ◯ 19- 21 Years
- ◯ More than 22 Years

* 5. What types of services does your firm provide? (choose all that apply)

- ☐ Residential Landscape
- ☐ Commercial
- ☐ Landscape- Land Use Planning
- ☐ Community Design
- ☐ Ecology and Restoration
- ☐ Campus Planning and Design
- ☐ Children's Outdoor Environment
- ☐ Parks and Recreation
- ☐ Sustainable Design and Development
- ☐ Transportation Design
- ☐ Therapeutic Gardens
- ☐ Historic Preservation
- ☐ Design-Build

Figure B.1 (cont.)

Knowledge of Virtual/Augmented Reality

* 6. What is your experience with virtual reality?

- [ ] Gaming/Entertainment
- [ ] Primary Learning
- [ ] Teaching
- [ ] Medical Training
- [ ] Military Training
- [ ] Flight Simulator
- [ ] Architecture/Landscape Architecture Design
- [ ] Drive Training
- [ ] None
- [ ] Other (please specify)

* 7. What is your experience with augmented reality?

- [ ] Archaeology
- [ ] Industrial Manufacturing
- [ ] Landscape Architecture
- [ ] Architecture
- [ ] Urban Planing
- [ ] Gaming/Entertainment
- [ ] Literature
- [ ] Visual Art
- [ ] None
- [ ] Other (please specify)

Figure B.1 (cont.)

* 8. How frequently do you use virtual/augmented reality, in any situation (entertainments or professional settings)?

- ◯ Every day
- ◯ A few times a week
- ◯ About once a week
- ◯ A few times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ Never

* 9. What about others in your firm, do they utilize virtual/augmented reality tools

- ◯ Yes
- ◯ No

10. If yes, how do you or your firm apply virtual/augmented reality tools, and what kind of software and equipment is used?

Potential Functions of Virtual/Augmented Reality

* 11. How useful do you think that the potential functions brought by virtual reality are?

	Extremely useful	Very useful	Somewhat useful	Less useful	Not useful
Draft in a Three-Dimensional Space	◯	◯	◯	◯	◯
Designing Small Size Projects	◯	◯	◯	◯	◯
Designing Medium Size Projects	◯	◯	◯	◯	◯
Designing Large Size Projects	◯	◯	◯	◯	◯
Show the Immersive Experience of the Design	◯	◯	◯	◯	◯
Help Employees Understand the Design	◯	◯	◯	◯	◯

Figure B.1 (cont.)

Draft in a Three-Dimensional Space	○	○	○	○	○
Designing Small Size Projects	○	○	○	○	○
Designing Medium Size Projects	○	○	○	○	○
Designing Large Size Projects	○	○	○	○	○
Show the Immersive Experience of the Design	○	○	○	○	○
Help Employees Understand the Design	○	○	○	○	○
Help with Creativity of the Design	○	○	○	○	○
Help with Efficiency of the Project	○	○	○	○	○
Help with Understanding the site	○	○	○	○	○
Help with the Conversation with Clients	○	○	○	○	○

If you think that the virtual reality can do more, please specify.

* 12. How useful do you think that the potential functions brought by augmented reality are?

	Extremely useful	Very useful	Somewhat useful	Less useful	Not useful
Draft in a Three-Dimensional Space	○	○	○	○	○
Designing Small Size Project	○	○	○	○	○
Designing Medium Size Project	○	○	○	○	○
Designing Large Size Project	○	○	○	○	○
Show the Immersive Experience of the Design	○	○	○	○	○
Help Employees Understand the Design	○	○	○	○	○
Help with Creativity of the Design	○	○	○	○	○

Figure B.1 (cont.)

Help with Efficiency of the Project	○	○	○	○	○
Help with Understanding the site	○	○	○	○	○
Help with the Conversation with Clients	○	○	○	○	○

If you think that the virtual reality can do more, please specify.

* 13. Do you think the virtual reality can work with any of the following stages of a landscape architecture project?

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Pre-design: Client Consultation	○	○	○	○	○
Design Charrette	○	○	○	○	○
Concept Design	○	○	○	○	○
Background Research, Inventory, and Analysis	○	○	○	○	○
Schematic Design: Establishing Design Intent	○	○	○	○	○
Design Development	○	○	○	○	○
Construction Documents	○	○	○	○	○
Bidding and Negotiations:	○	○	○	○	○
Construction Administration	○	○	○	○	○
Maintenance	○	○	○	○	○
Post Occupancy Evaluation	○	○	○	○	○

Figure B.1 (cont.)

* 14. Do you think the augmented reality can work with any of the following stages of a landscape architecture project?

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Pre-design: Client Consultation	○	○	○	○	○
Design Charrette	○	○	○	○	○
Concept Design	○	○	○	○	○
Background Research, Inventory, and Analysis	○	○	○	○	○
Schematic Design: Establishing Design Intent	○	○	○	○	○
Design Development	○	○	○	○	○
Construction Documents	○	○	○	○	○
Bidding and Negotiations:	○	○	○	○	○
Construction Administration	○	○	○	○	○
Maintenance	○	○	○	○	○
Post Occupancy Evaluation	○	○	○	○	○

15. Are there any examples of projects your firm has worked on featured on your website, or elsewhere, that you might be willing to highlight? If so, please state the project and role of virtual/augmented reality below:

Figure B.1 (cont.)

Appendix C: Other Relative Data from the Survey

Firm's Service Category and acquaintance with mixed reality

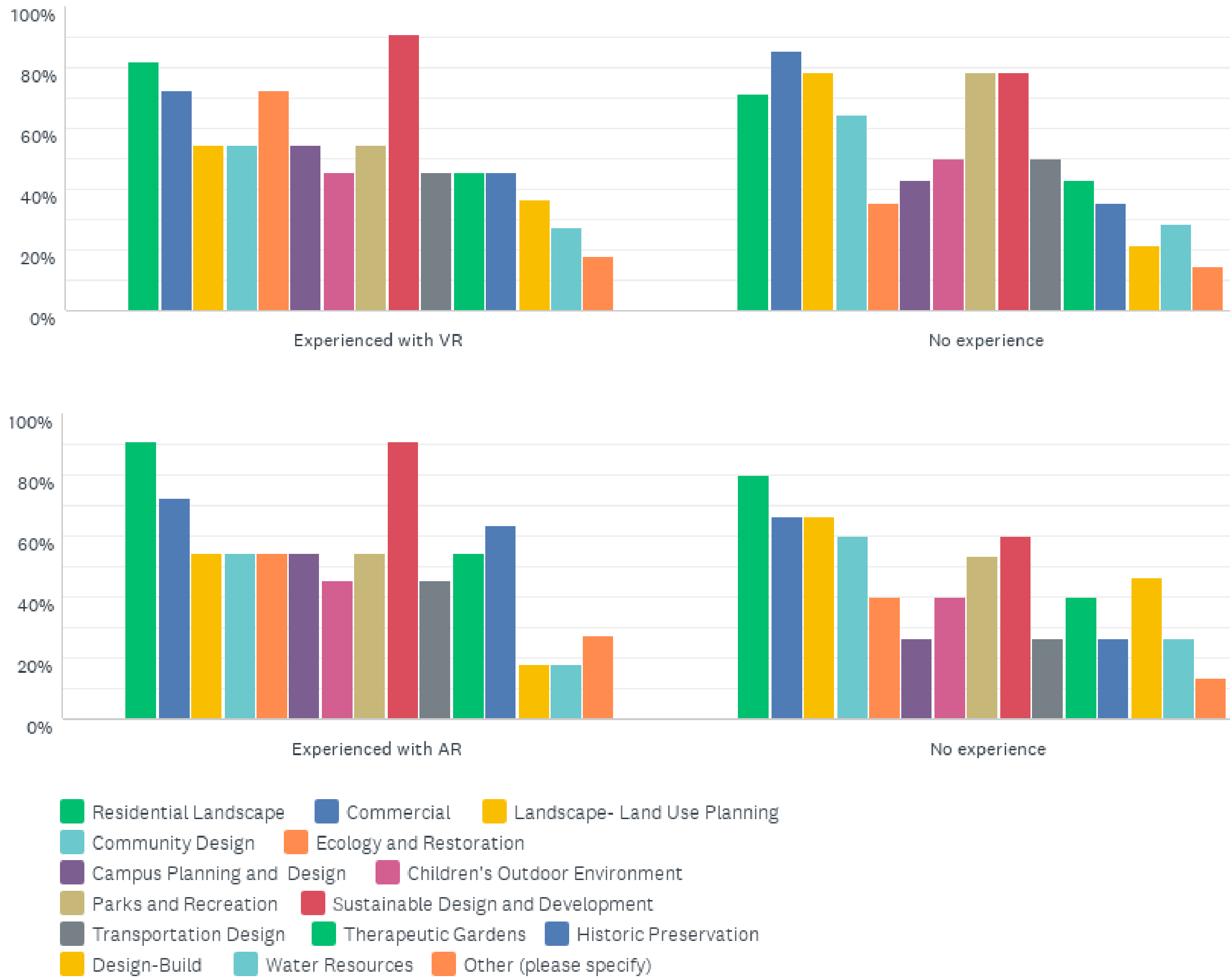
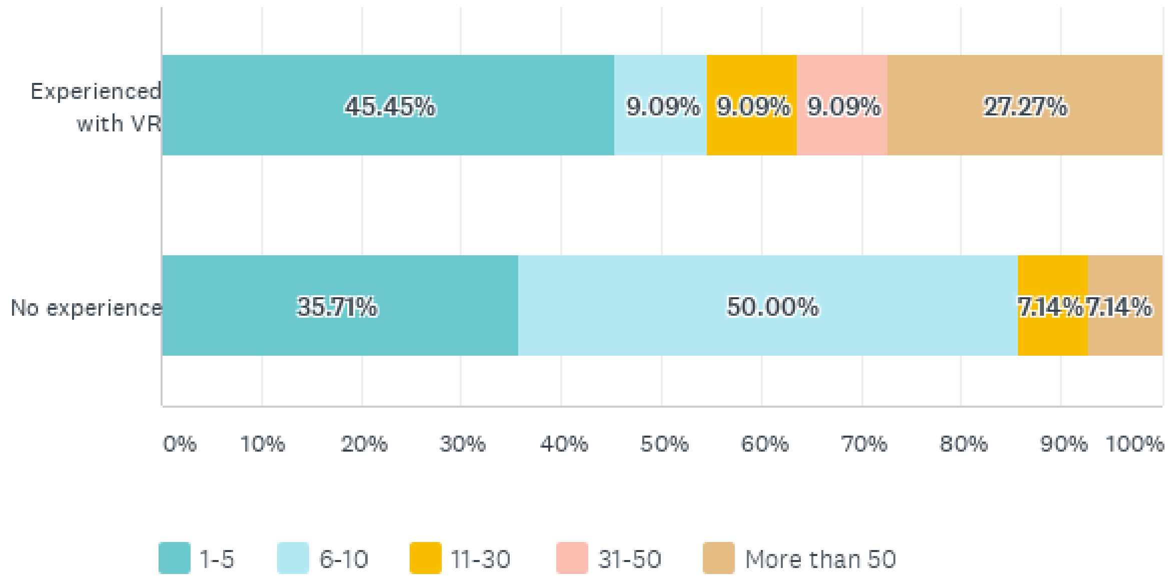


Figure C.1: The comparison of whether practitioners experienced MR relate to the project genre

Company size and the use of mixed reality



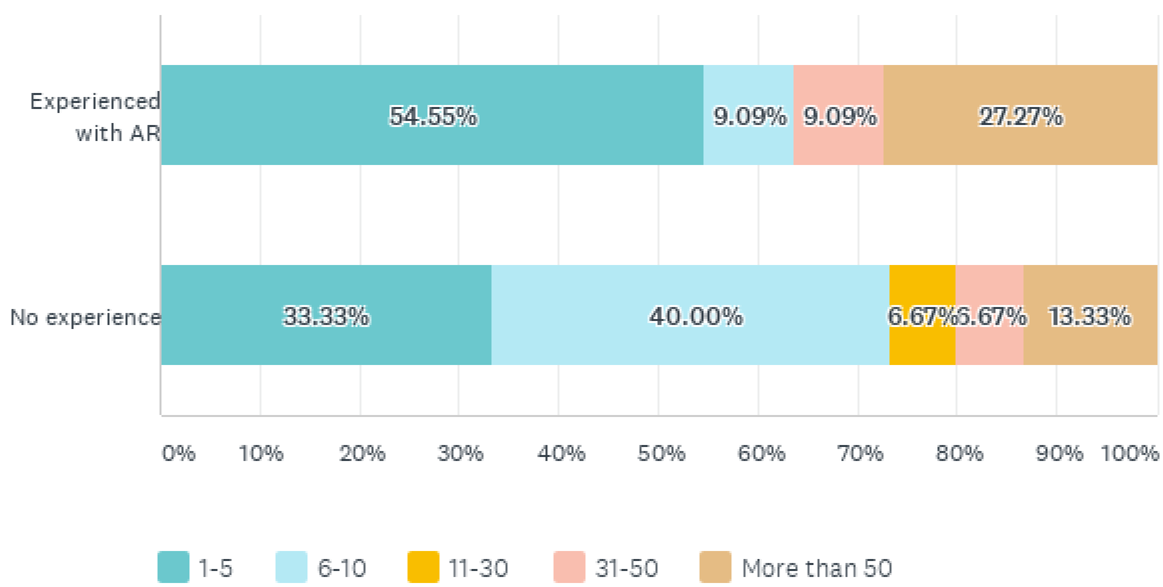
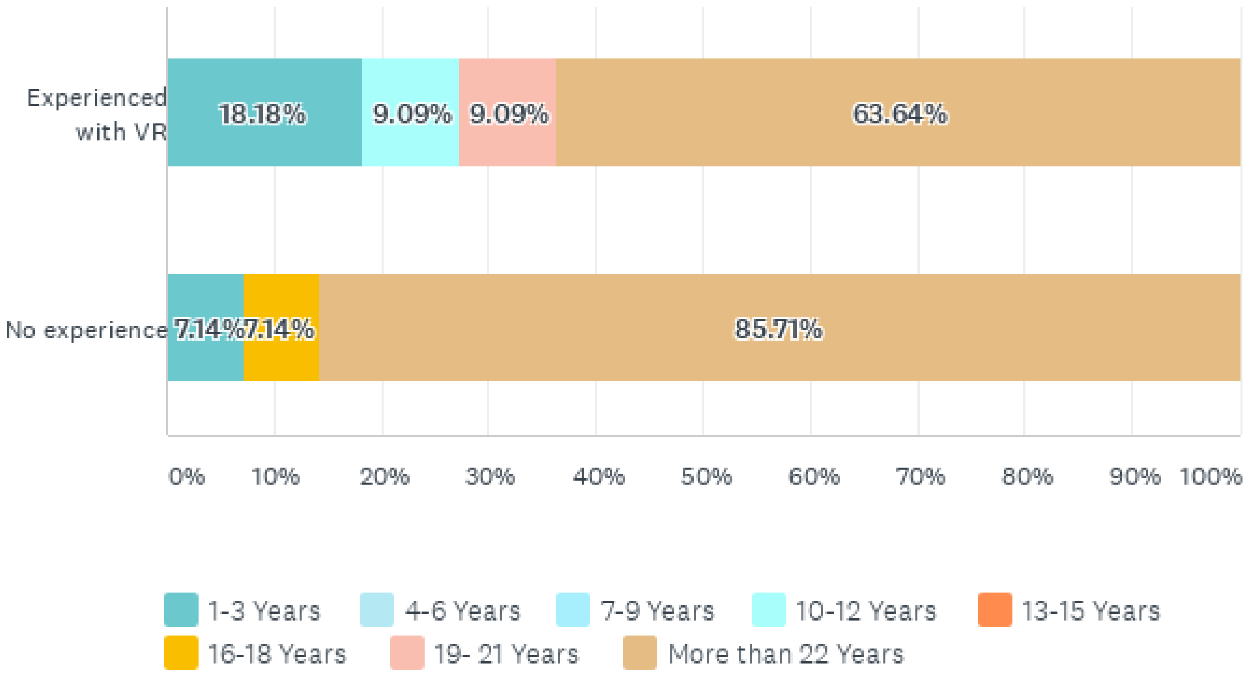


Figure C.2: Charts for showing how the company size relates to the experience of MR

Firm's Life-span and acquaintance with mixed reality



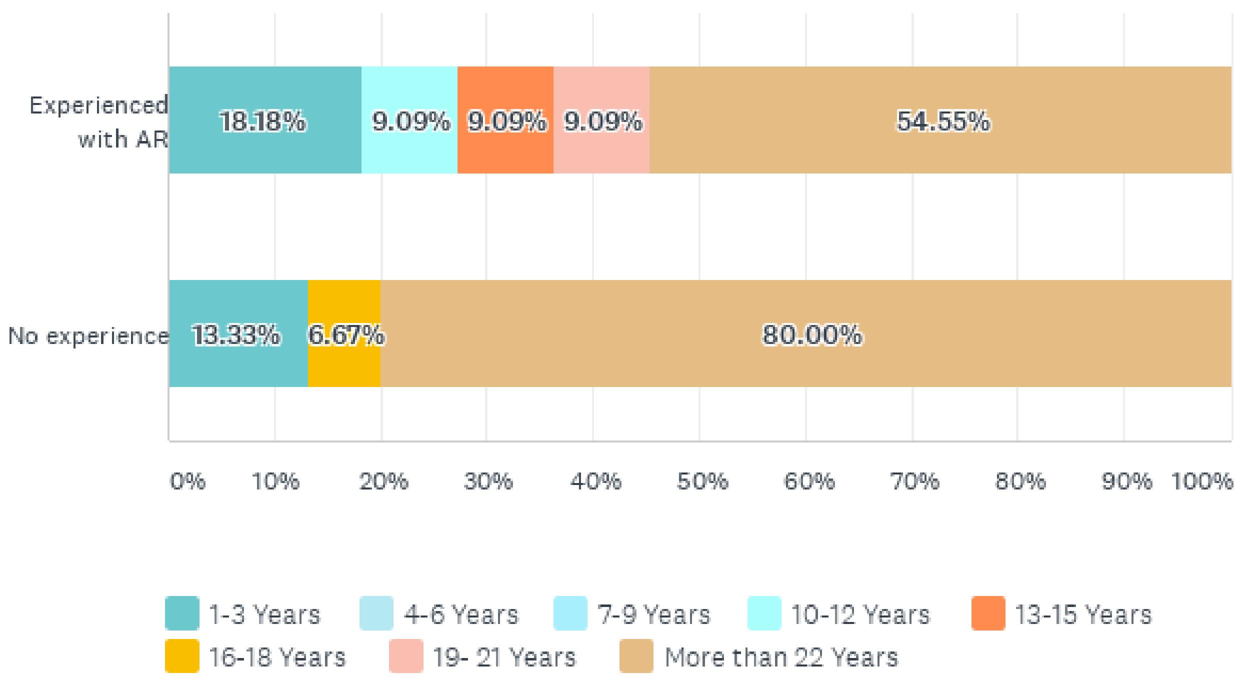


Figure C.3: Charts for showing how the company established years relates to the experience of MR

Comparison of the perspectives base on the experience with VR

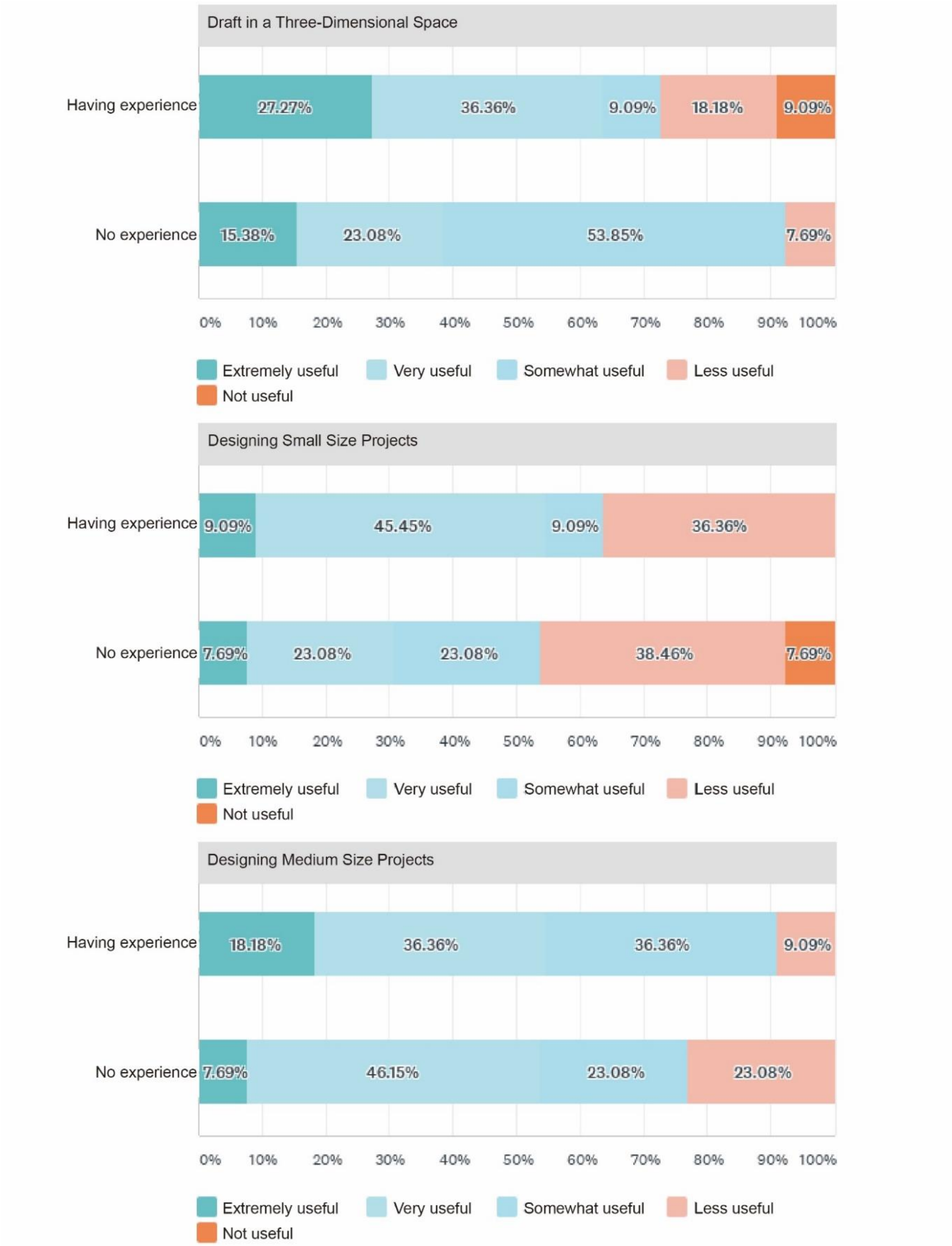


Figure C.4: The comparison of practitioners' perspective to VR base on the VR experience

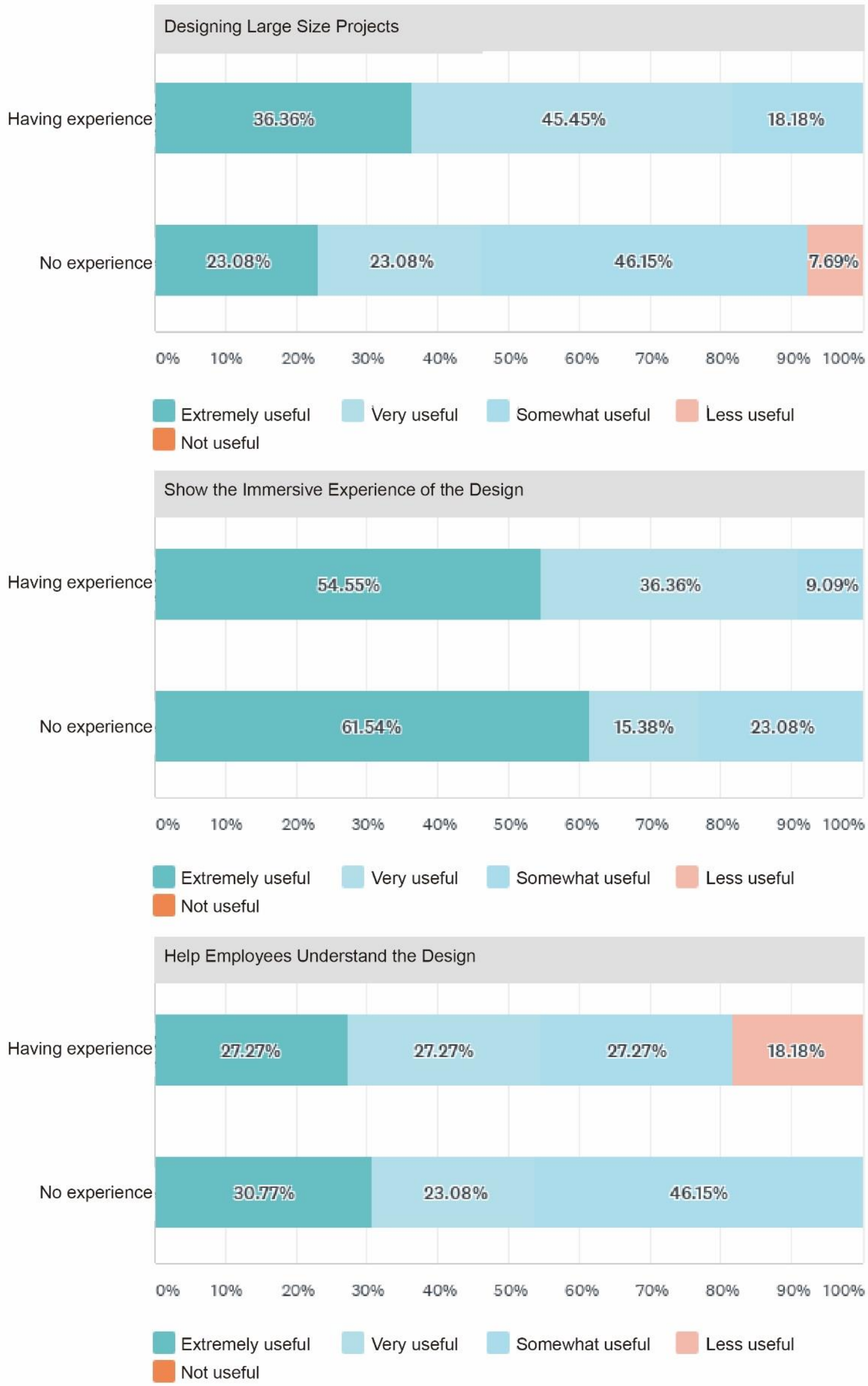


Figure C.4 (cont.)

Figure C.4 (cont.)

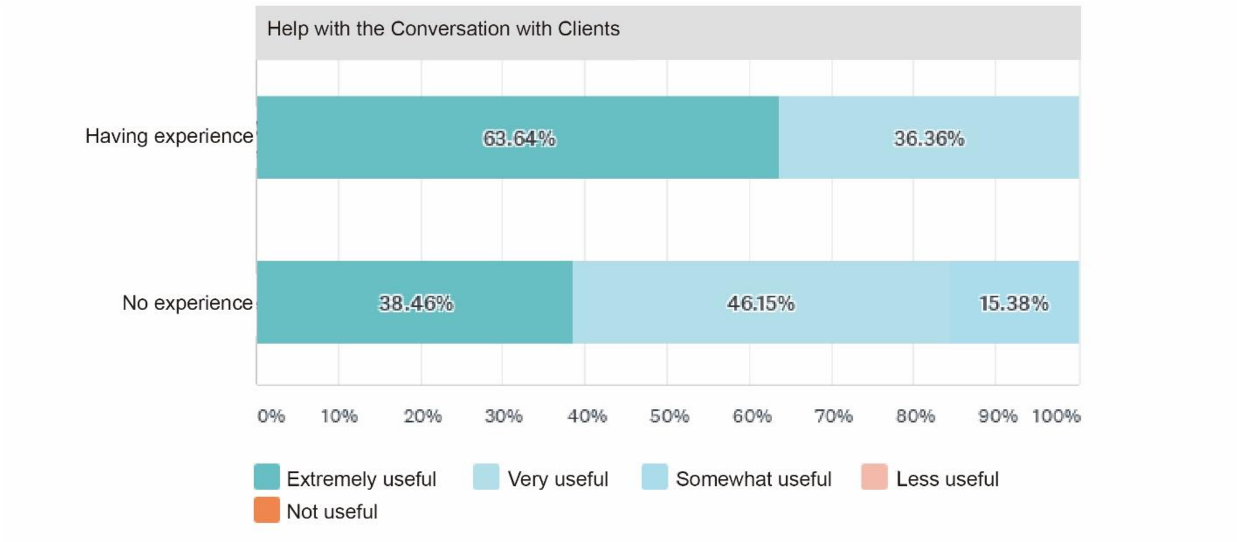


Figure C.4: (cont.)

Comparison of the perspectives base on the experience with AR

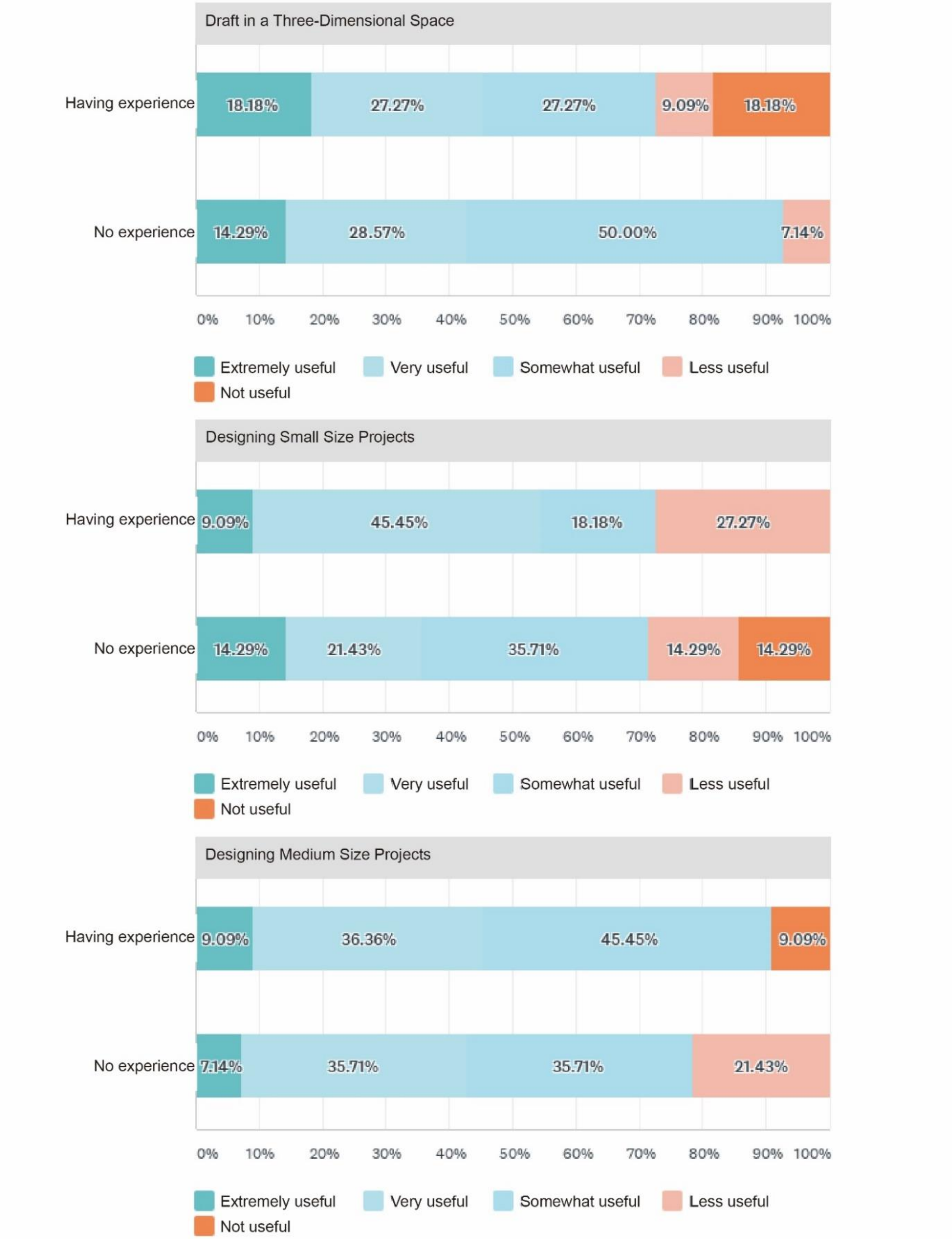


Figure C.5: The comparison of practitioners' perspective to AR base on the AR experience

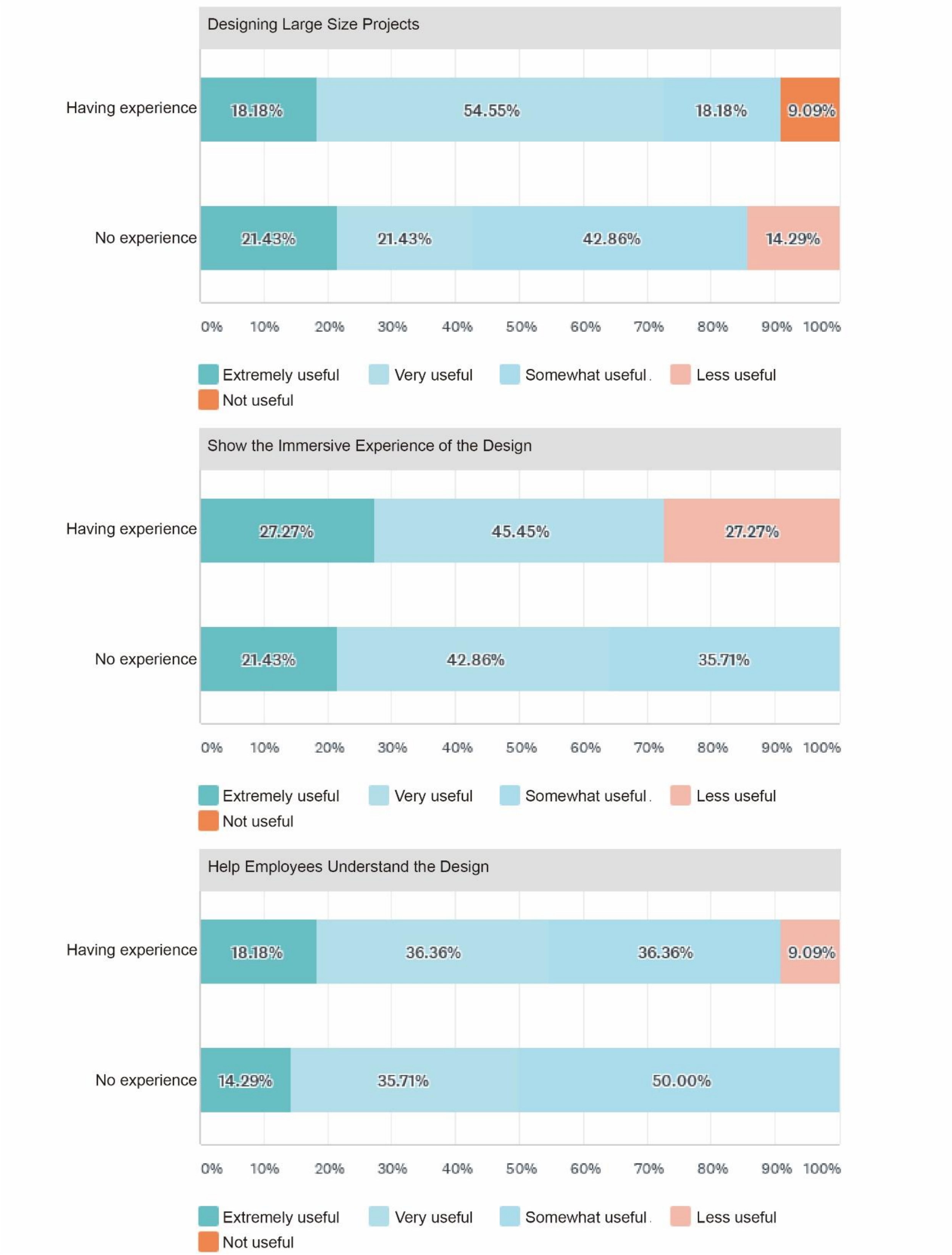
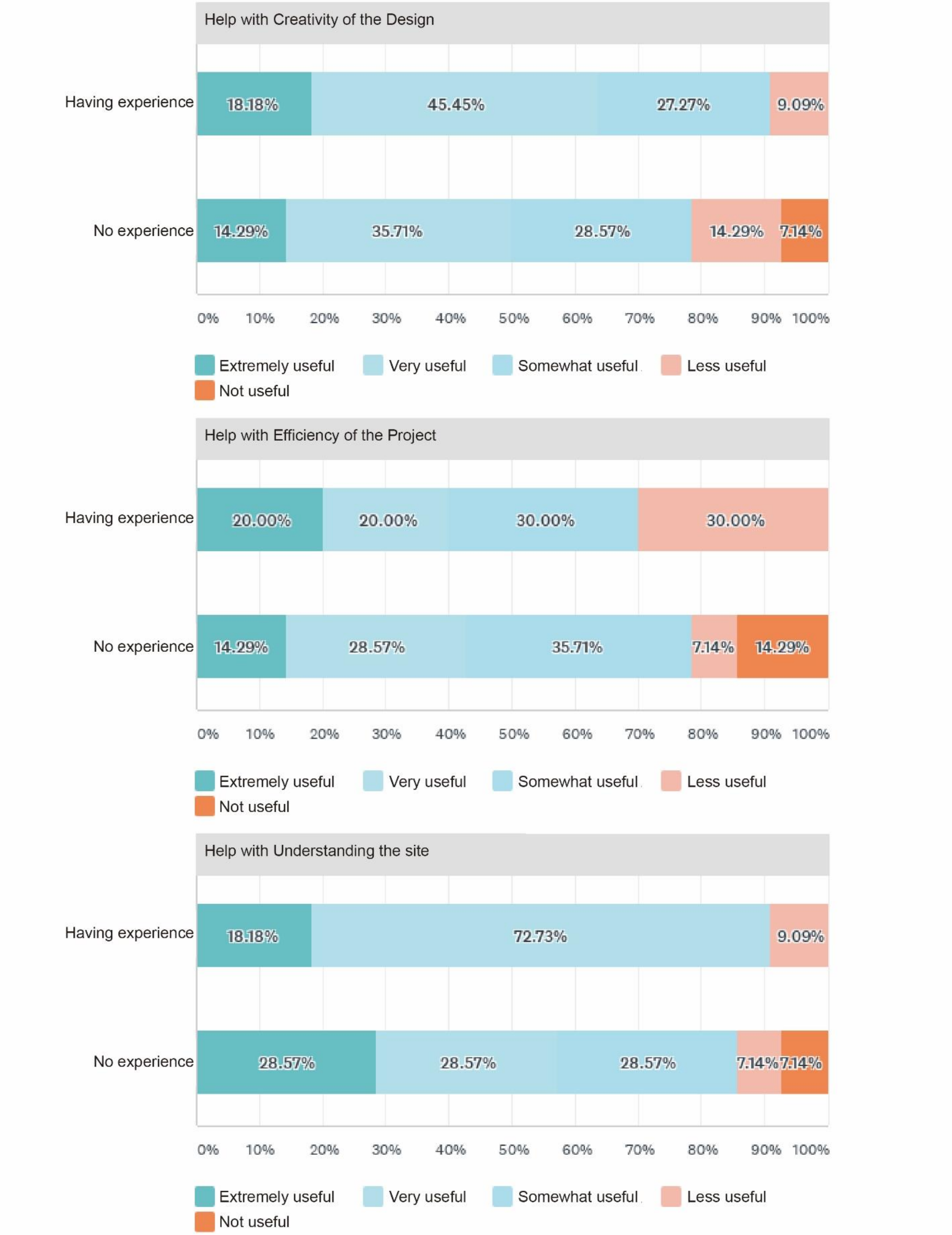


Figure C.5: (cont.)



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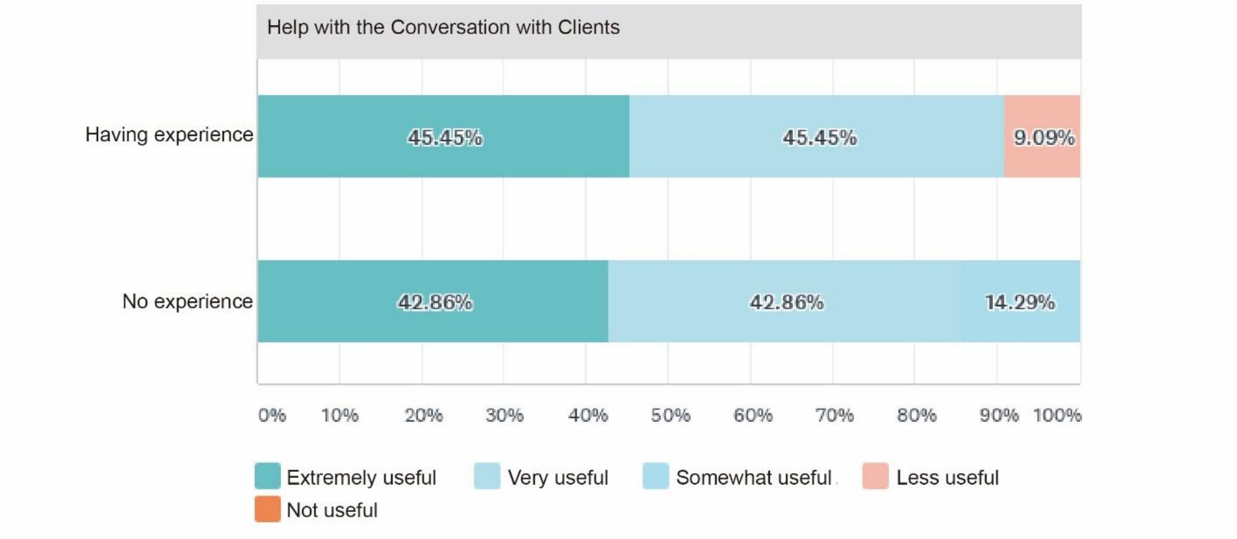


Figure C.5: The comparison of practitioners' perspective to AR base on the AR experience

Comparison of the practitioners' points if view base on the experience with VR

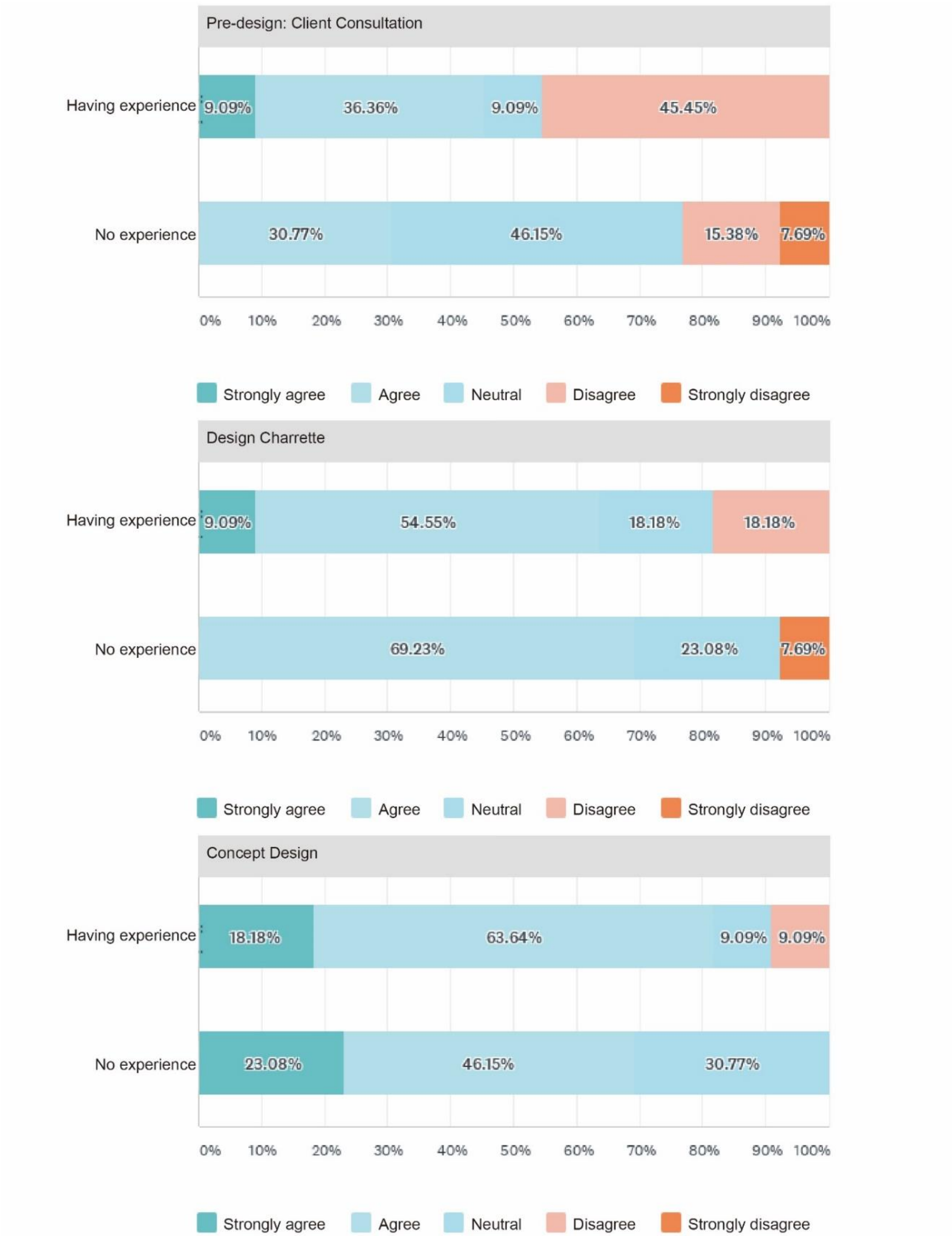


Figure C.6: The comparison of practitioners' perspective to utilize VR in each stage of the universal workflow

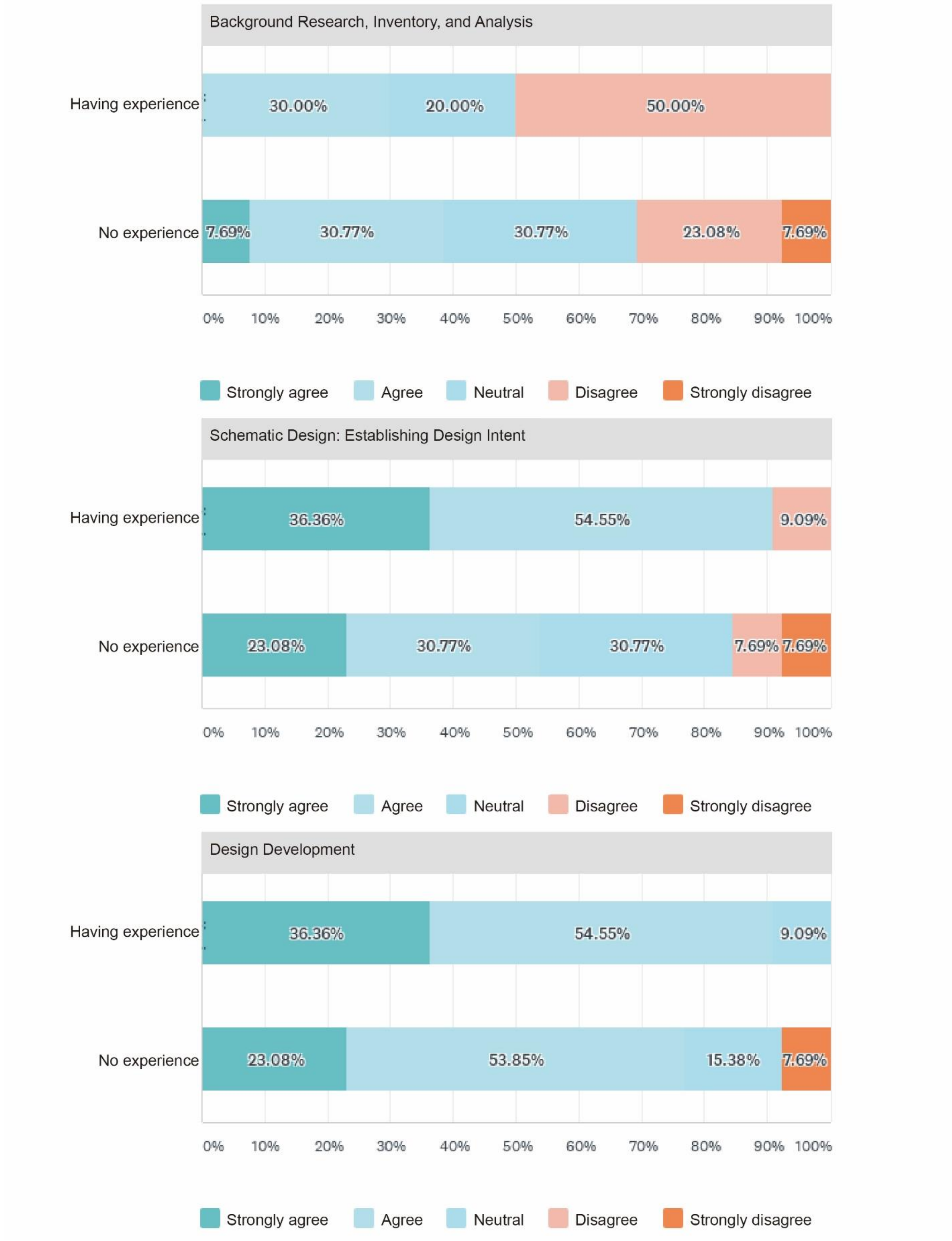
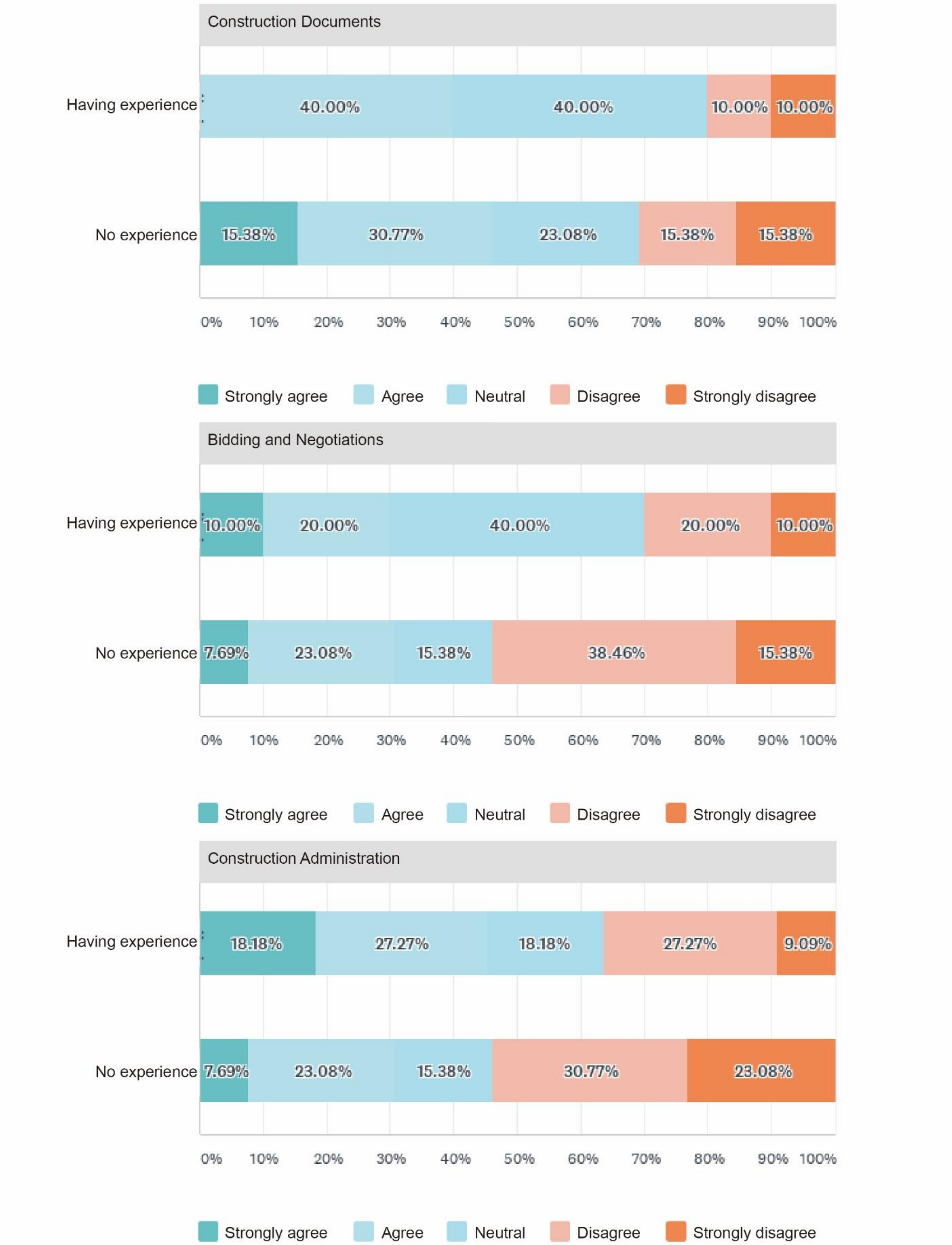


Figure C.6: (cont.)



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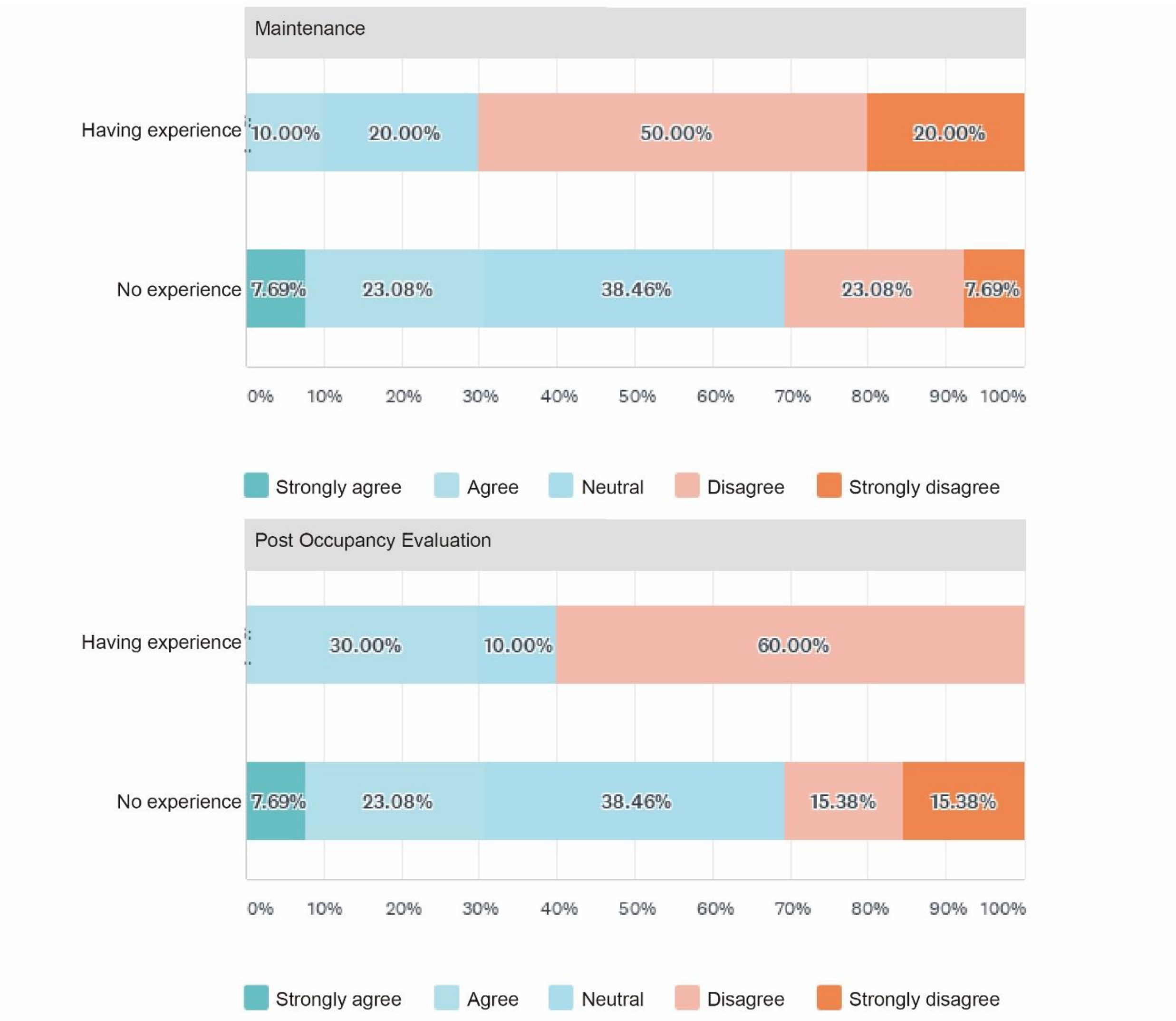

Figure C.6: The comparison of practitioners' perspective to utilize VR in each stage of the universal workflow

Comparison of the practitioners' points if view base on the experience with AR

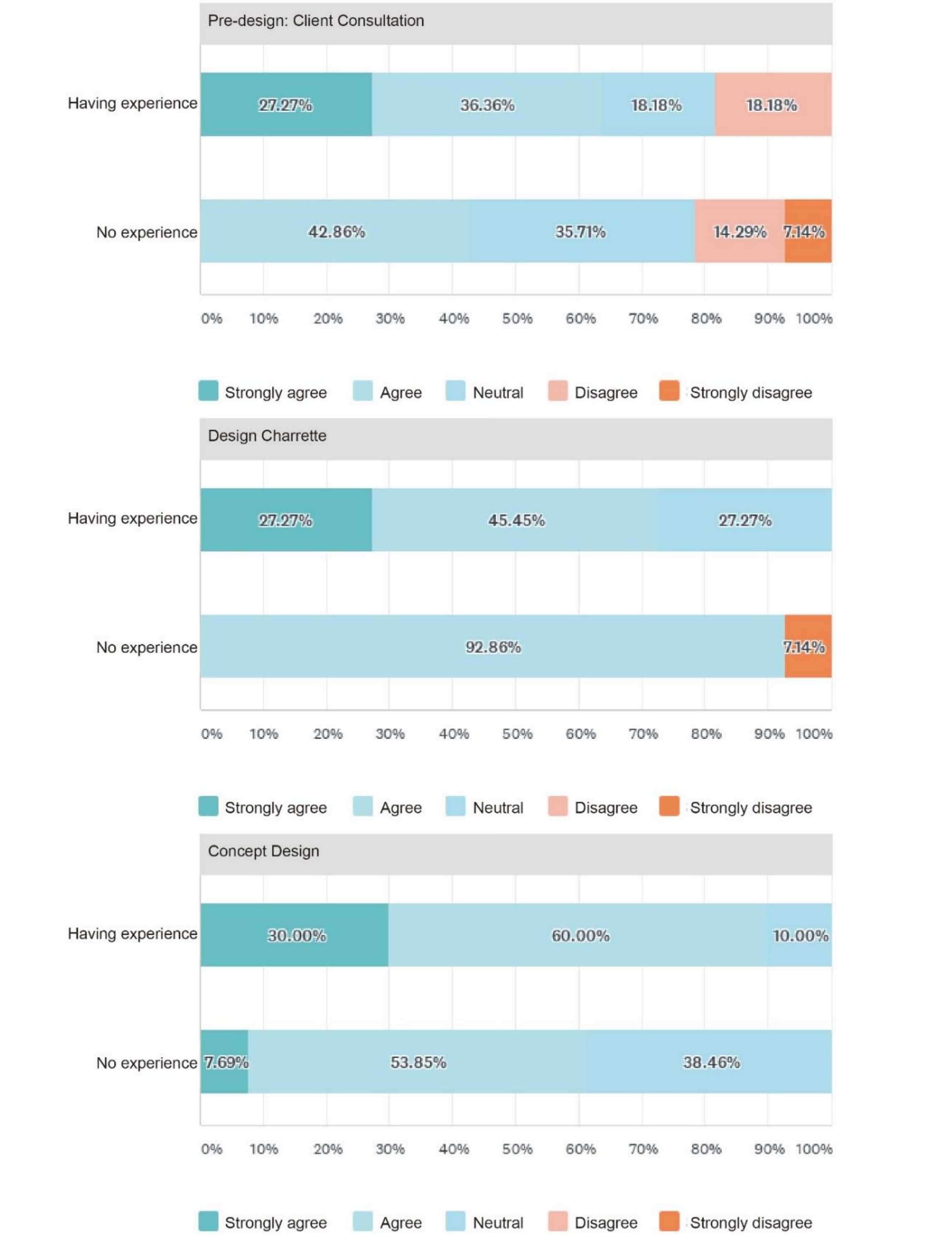

Figure C.7: The comparison of practitioners' perspective to utilize AR in each stage of the universal workflow

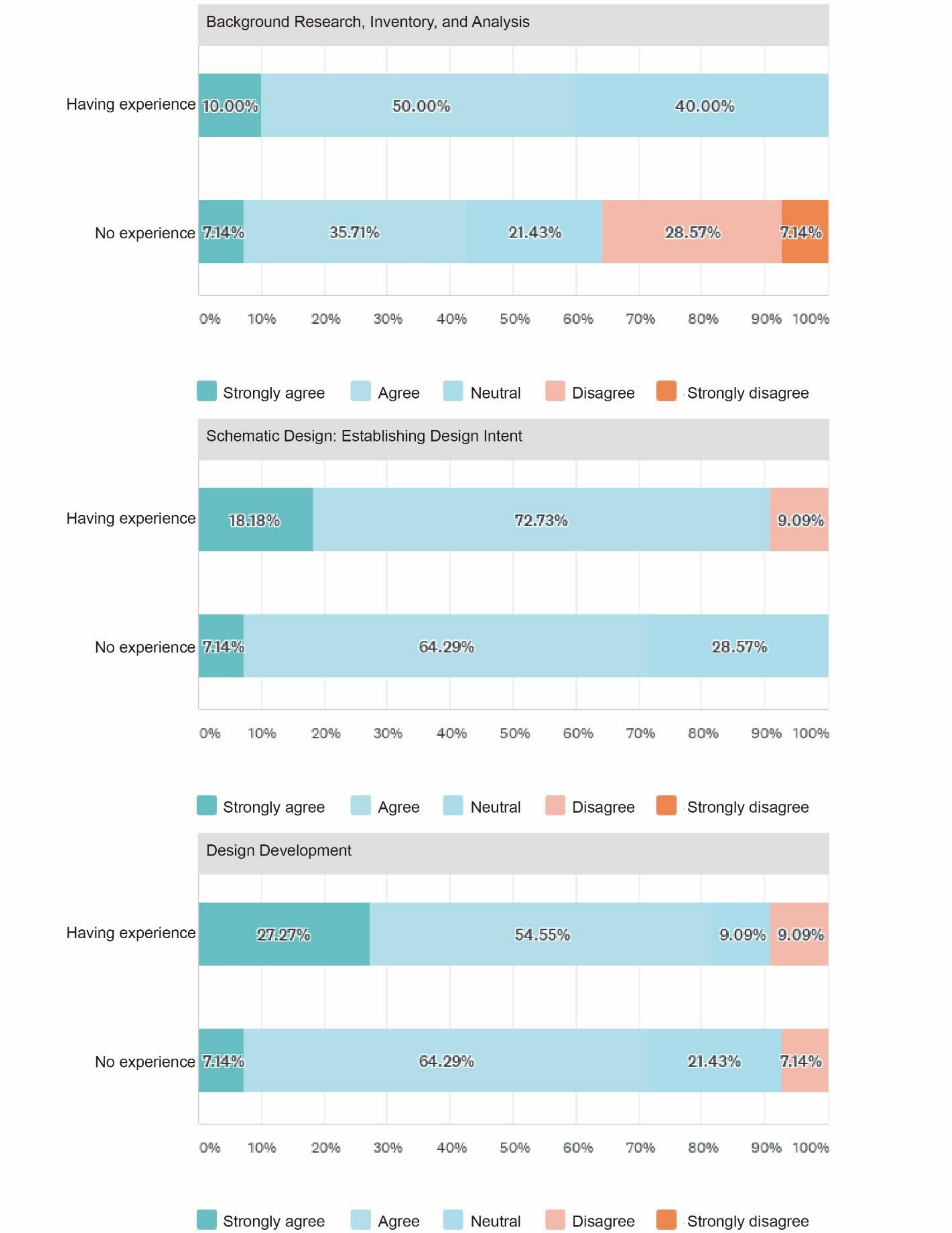

Figure C.7: (cont.)

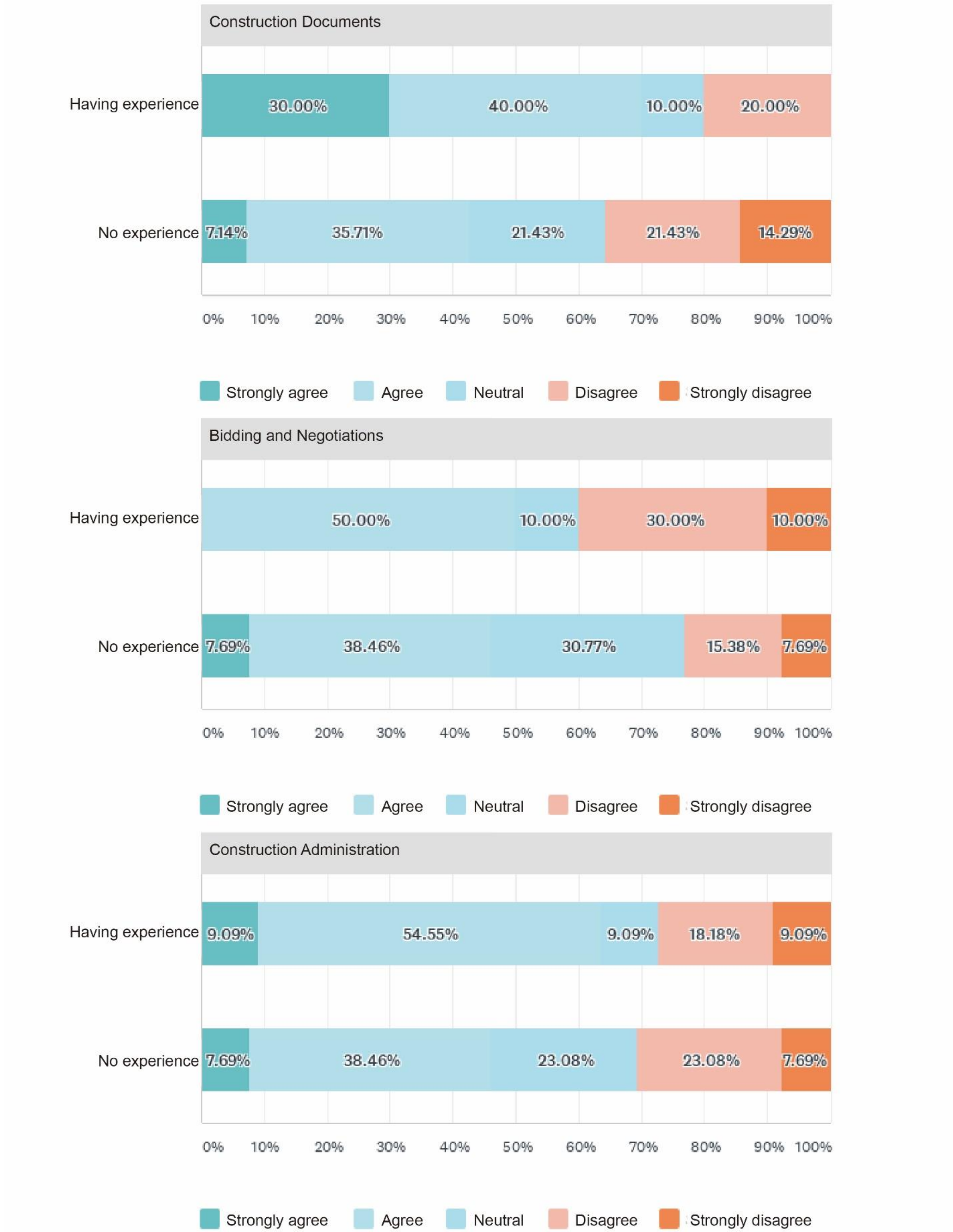

Figure C.7: (cont.)

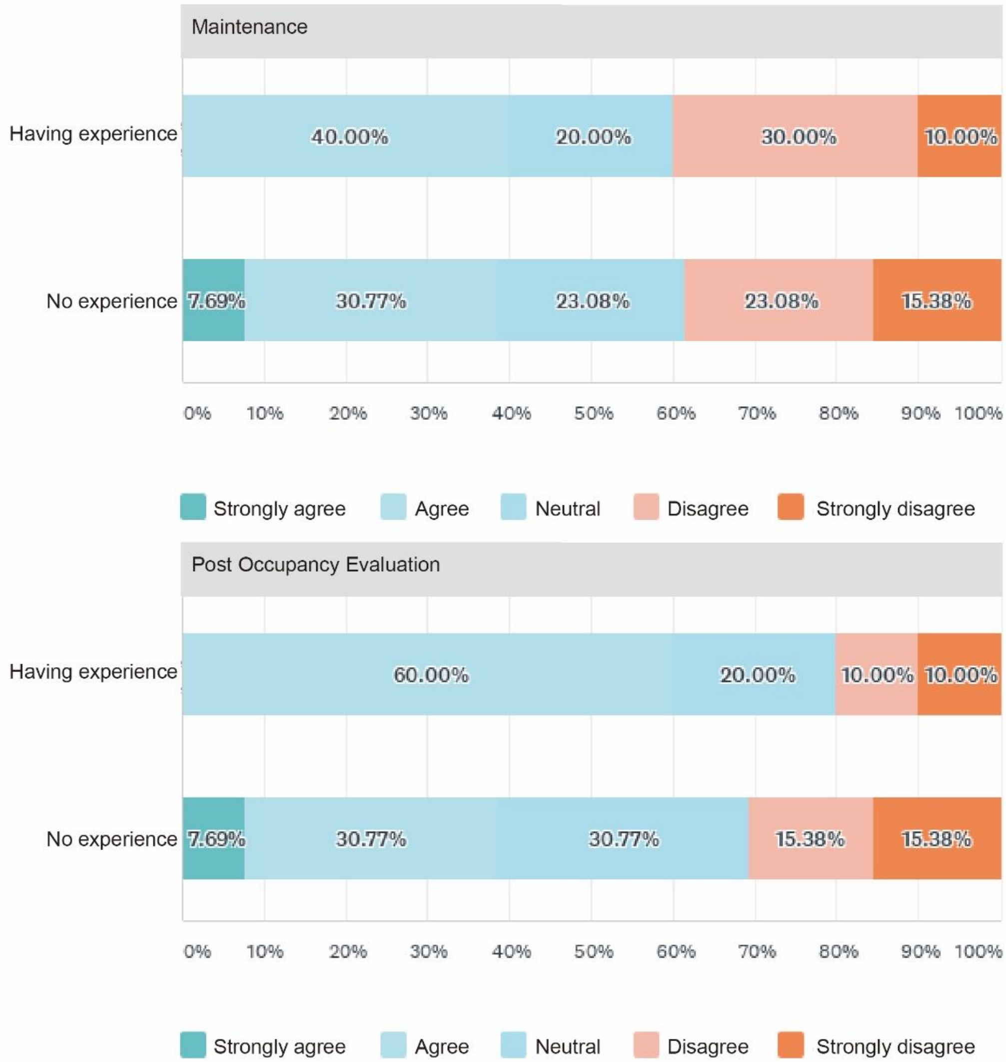

Figure C.7: (cont.)