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# Virtual Reality and the Landscape Architecture Design Process

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# OVERVIEW

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# PREFACE

This thesis is a research-based investigation on the viability of using immersive VR technologies in landscape architecture, with a focus on the impact this technology has on the design process. It was submitted in partial fulfilment of the requirements for the degree of Master in Landscape Architecture at NMBU (the Norwegian University of Life Sciences) during the spring of 2018.

I chose the topic in part to ensure that this research will be useful throughout my career. Although the VR technology may evolve quickly, topics such as design processes, 3D modeling and visualization will remain important to landscape architecture.

My interest in VR does not stem from a general enthusiasm for advanced technology, but rather from the desire to understand how art, nature, and environments affect human psychology and is a continuation of my passion for drawing and painting.

I would like to thank my primary and secondary supervisors Deni Ruggeri and Ramzi Hassan (both Associate Professors in Institute for Landscape Architecture and Spatial Planning at NMBU) for valuable feedback and guidance throughout the development of this thesis.

I would also like to thank numerous colleagues at my current employer Norconsult AS, who have kindly suggested projects for use as a case study, been flexible with their time, given helpful feedback and participated in the survey. Special thanks to the project leader for the case study, Anne Irgens.

IrisVR has kindly provided me with a free student license to their Scope VR app, which was helpful throughout the project.

Finally, I would like to thank the developers of Lumion at Act-3D, and the moderators for the Lumion official forum. Nearly instant technical assistance, bug fixes and software improvements were very valuable numerous times.

# ABSTRACT

Popularity of Virtual Reality has increased dramatically since 2016. However, adoption rates within landscape architecture remains low.

The thesis explores use of VR technology during the design process of landscape architecture. Research questions investigates how VR differs from alternative forms of presentation, how this can affect design evaluation and collaboration, and whether practical obstacles limit usefulness. A case study puts the technology to the test, using an ongoing landscape design project. Interviews of 18 landscape architects are employed to evaluate the result from the case study.

The findings reveal that currently available VR technology has potential to improve the outcome of the design process and can be employed in a cost-effective manner. However, there are significant limitations and downsides that should be factored in. If employed under the wrong circumstances, VR technology may lead to a hampered design process and inefficient time expenditure. Some factors that should be considered before employing VR are:

- Project type, scale, complexity, purpose and design team.
- Individual designers’ processes, workflows and experience.
- Synergistic uses of 3D model throughout the project.

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# 1 INTRODUCTION

## Purpose and broad outline of thesis

The purpose of this thesis is to understand how *Virtual Reality* (VR) might affect the design process for landscape architecture.

The theoretical framing seeks to understand and predict how Virtual Reality has been known to alter the design process within landscape architecture, based on prior research. The case study puts these theories to the test, using an ongoing project, the redesign of the Botanical garden in Milde, Norway. Within this case, a survey of practicing landscape architects attempts to evaluate the potential impact of VR on their understanding of the design process. The thesis seeks to lay out generalizable conclusions, challenges and opportunities arising from the use of VR technology in landscape architecture practice.

## Constraints

Much of the prior research on VR has employed technology that is either prohibitively expensive to most practitioners of landscape architecture, or that has a high threshold for adoption. Recent technological developments have dramatically lowered the cost associated with certain VR-technologies. This thesis focuses on technology, equipment and software, which is already widespread or has a low threshold for adoption (*smartphone-based HMD VR sphere*).

## Target group

The primary target group for this thesis is landscape architecture professionals and students, or academics interested in practical applications of VR-technology.

The secondary target group is designers interested in VR technology more broadly.

# VR technology, terms and software

The VR technology explored in this thesis is *VR sphere,* a *stereoscopic* image file presented using a smartphone inserted into a VR headset. VR sphere is considered low-threshold as costly and highly specialized software/hardware are not required for use. VR spheres can potentially display very high visual fidelity and realism but are limited to a fixed vantage point. For a more extensive description of technical terms and software/apps employed, see appendix I.

## Glossary of technical terms

| | |
|---|---|
| **Virtual Reality (VR)** | Computer-generated simulation |
| **Immersive VR** | Immersive VR simulation, generally stereoscopic |
| **HMD VR** | Head-mounted display VR (also known as VR headset) |
| **Smartphone-based HMD VR** | VR simulation presented with a smartphone and headset |
| **VR sphere** | Panoramic/spherical stereoscopic rendering from fixed vantage point |
| **Navigable VR model** | VR model which is not pre-rendered, can be freely explored |
| **Stereoscopic vision** | Depth perception based on discrepancy between left and right eye |
| **CAD/3D modeling/BIM** | Common methods for generating digital drawings |
| **Photogrammetry** | Technique used to generate 3D model from photographs |
| **Equirectangular projection** | Map projection for projecting a sphere to a rectangular format |

## Software and apps used

| | |
|---|---|
| Trimble SketchUp | 3D modeling software |
| Act-3D Lumion | (VR) Rendering software |
| Adobe Photoshop CC | General-purpose digital imagery |
| Autodesk ReCap | Photogrammetry |
| Autodesk AutoCAD | Adjusting plans before importing to SketchUp |
| IrisVR Scope | VR presentation smartphone app |
| Oculus 360 Photos | VR presentation smartphone app |

# 2 RELEVANCE

## Potential to change design process

Landscape architecture can be defined as the shaping and design of outdoor spaces for achieving aesthetic, environmental and socio-behavioural outcomes (Stiles, 1994). A design process is usually employed to explore ideas and identify appropriate solutions. Alterations to the design process can lead to short-term or long-term changes in the practice of landscape architecture. An improved design process can potentially lead to better design outcomes, ultimately improving the physical environment. The design process might also become more efficient, saving time during the planning phase. A more effective design process can also reduce the risk of expensive modifications at a later phase, e.g. during construction.

## Timing

Primitive immersive VR technology is decades old and has benefited from gradual innovations and improvements over the years (Albracht, 2016). Even so, adoption rates among landscape architects have remained low. Although VR held great promise, factors such as high cost and insufficient practical application limited widespread implementation (Portman et al., 2015).

A burst of recent developments and products may have changed this situation. Facebook and HTC released specialized VR headsets around 2016, with some commercial success. This lead to increased awareness of VR technology, and the development of software which explores the possibilities of VR.

Perhaps even more interestingly, a number of inexpensive smartphone-based VR headsets were released around the same period. These gadgets gained popularity faster than the specialized devices (Sandler et al., 2016), with millions of units sold within a few months. The VR headsets take advantage of recent improvements to smartphone display resolution, resulting in visual performance often comparable to the specialized devices. This development contributed to the growth of VR-related smartphone apps.

In 2016, the rendering platform Lumion issued an update, which made the program capable of producing VR renderings for smartphone-based VR headsets. 2017 and 2018 have seen numerous other improvements to smartphones, headsets, rendering software such as Lumion and smartphone apps such as IrisVR Scope. This thesis argues that the cumulative effect of these technological developments and improvements has finally made VR technology inexpensive and practical enough for widespread use in design firms. However, there are not many signs that significant numbers of landscape architects are adopting VR technology as of 2018.

Although this technology is likely to continue improving, the recent advances have reached a threshold in quality and user-experience, which some authors suggest is unlikely to be dramatically changed in the near future (Arnowitz, 2017).

## Limited research on specific topic

There is a large and growing body of research around virtual reality and design. Common themes are perceptions of virtual environments, efficient modeling, visualization and community or client communication, educational use or technical aspects. Some research has also focused on VR during design stages, and some have suggested that this is where the potential for VR is highest (Solheim, 2011).

The majority of research on VR for designers is aimed at architects, engineers or large-scale urban planning, with relatively few studies focused on landscape architecture (Yan, 2014). This thesis will argue that practical uses of VR are very different for each design field, and that landscape architecture may be the design field where immersive HMD VR has the greatest potential to alter the design process, and perhaps more difficult technical challenges to overcome.

Much of the research on VR emphasizes potential benefits, rather than practical aspects of VR. There appears to be a significant gap between professional and academic use of VR technology (Portman et al., 2015), perhaps due to discrepancy between needs, such as time constraints in design firms. This thesis will focus on practical as well as theoretical aspects of VR and will compare costs to benefits.

## Cross-disciplinary insights

This thesis combines research on VR with insights from the fields of GIS and 3D modeling, geography, botany, design theory, architectural visualization and environmental psychology.

## Guide for early adopters

Although the focus of this thesis is to explore the potential of VR to alter the design process, the case study examines alternative strategies for creating VR simulations and address a number of technical issues. This will likely result in some lessons, which may be useful for others interesting in this technology. In order to remain relevant over time, these suggestions will deal with general recurring difficulties when generating realistic VR simulations for landscapes, rather than resolve highly specific issues related to current software platforms.

# 3 BACKGROUND AND LITERATURE REVIEW

## Historical development: from 2D to 3D landscape design

### Drawing and modeling: 2D to 3D and BIM

The most basic design tools available to landscape architecture professionals are hand drawn site plan, section and perspective drawing. Although these methods are still widely used, several more advanced complementary or competing approaches have been developed and adopted since the 1980's: CAD drawing, 3D models, BIM and digital rendering.

The first experiments with digital tools began in the 60's, initially with GIS and CAD programs (Mengots, 2016). These tools were very expensive, had limited flexibility, and were not user-friendly. Widespread adoption of digital tools began in the 80's with programs such as AutoCAD by Autodesk, which is still prevalent.

Popular 2D CAD software such as AutoCAD and MicroStation developed functions which allow objects to have a position along a vertical axis, giving some limited 3D capabilities. This can be used to give contour lines on a site plan elevation values and is sometimes referred to as 2.5D. 3D Mesh surfaces representing terrain can be generated from "2.5D" contour lines, and later developments has made more advanced 3D and BIM modeling tools available within traditional 2D CAD platforms such as AutoCAD.

With more powerful computer processing, digital 3D modeling software emerged for various uses. Several powerful platforms capable of 3D modeling were developed during the 90's, such as *SolidWorks*, *3ds Max*, *Maya, Blender* and *Rhinoceros*. However, 3D modeling software did not gain much popularity within landscape architecture until more user-friendly tools such as SketchUp were released in the 2000s.

Landscape architects have been relatively slow to adopt advanced digital tools compared with related fields. Steep learning curve and high costs for software license are reported as some of the contributing factors (Li et al., 2014; Yan, 2014). Furthermore, highly Euclidian geometry embodied in modern buildings is more easily represented accurately in 3D modeling software than the organic, often fractal-like shapes which more accurately describe elements of a landscape.

While 3D modeling tools may be powerful, creating a high level of detail and accuracy can be very time-consuming. Making minor adjustments which affect the entire model, e.g. by adjusting site topography, are sometimes more challenging than re-drawing large parts of the model. Early BIM tools were developed during the 80's and 90's to address these kinds of issues. BIM uses parametric modeling, each element having a limited number of parameters that can be altered. These elements represent real-world objects, e.g. walls. A single line representing an external brick wall will automatically contain all the layers typically used, each with appropriate and modifiable widths. Adjusting the roof elevation will automatically adjust the height of every wall by the same amount. If used correctly, BIM software facilitates quick and accurate modeling. Collaboration across different fields is improved, and design revisions easier to implement. BIM tools also lets designers automatically calculate statistics such as quantities of each material used. For these reasons, BIM software such as ArchiCAD and Revit are widely used within architecture and engineering. Unfortunately, BIM tools are often not well adapted for the demands of landscape architecture. This is partially due to the huge variation in project type, scope, size, and detail- software for modeling constructions, editing topography, laying out roads and paths, showing sub-surface layers or objects, placing vegetation. Given such complex layering of information, making ad-hoc adjustments can be difficult to do through one digital platform alone.

### Visualization and VR

Digital 2D and 3D/BIM modeling tools are generally used in design development, a phase that eventually leads go the production of construction drawings (Figure 1). While these platforms can generate useful drawings, they may not be appropriate to create accurate representations of what a design will look like. Numerous programs and software extensions have been developed for this purpose.

For a long time, the most common forms of landscape visualization were hand-made drawings, watercolor paintings and physical models. Drawing is still widely used, although physical models are likely not in regular use by most firms in Norway (Hansen, 2013). During the 80's and 90's, two new platforms began to change the ways design proposals could be visualized: digital 3D models and raster graphics editing software. Although digital 3D models seldom look realistic while under development, techniques such as ray tracing are used to render more life-like imagery. This process is referred to as 3D rendering and uses information such as light sources, textures and surface properties to calculate what a scene might look like if constructed in the physical world.

Rather than creating detailed digital 3D models for rendering, it is common for landscape architects to produce digital collages using raster graphics editing software such as Adobe Photoshop. Photoshop was released to Macintosh in 1988, and to Windows in 1994. Since then, it has become the clear leader within the industry. Users can place items such as trees, people, ground textures, and backdrop together into an abstract or realistic composition representing the design scheme. The items inserted are often cut out of their original context and can be placed into a new setting, e.g. over a site photograph. Painting tools using various brushes add detail, texture, shadows or other elements.

3D renderings are often combined with digital collage, to take advantage of the strength of each technique. Although a large numbers of visualization tools are available to landscape architects, this work is often done by specialists, or by dedicated rendering firms. This outsourcing can be partially explained by the limited adoption of 3D modeling software, along with increasing demands for realism, detail, and aesthetic qualities.

Digital 3D models often lend themselves well to Virtual Reality visualizations. Early experiments with VR used analogue technology, and the first digital VR models were simplistic representations (Mengots, 2016). However, the field has advanced quickly over the last few decades. Improvements to 3D modeling and rendering have led to advancement of VR representations. Despite this progress, the lack of practical and inexpensive devices capable of delivering VR experiences held back VR technology. This has arguably changed with the "2016 shift" discussed in chapter 2.

## VR today

Limited research has attempted to systematize and quantify the use of virtual reality today. It is clear that few landscape professionals have brought VR into their workflow, and landscape architecture appears to lag behind similar fields (Portman et al., 2015). Many factors likely contribute to this low adoption rate, which may overlap with the reasons explaining why landscape architects have been relatively slow to adopt 3D modeling and BIM. Furthermore, it may not be clear to most professionals what the benefits of VR might be. Some authors have suggested that VR will inevitably become an important tool to landscape architects in the future (Wang, 2016), while others have highlighted unresolved issues.

*"Many challenges for the use of VR for landscape architecture pointed out over a decade ago still remain: i.e., while VR tools for landscape planning are increasingly being adopted, there is a lack of research addressing what is to be gained by VR or the cautions necessary for its use"* (Portman et al., 2015, p.380)

As immersive VR presentation simulates the way we generally perceive the environment, VR presentations have the potential to be more representative and realistic than any other method of conveying design proposals. However, this potential is held back due to difficulty in creating accurate models of 3D landscapes. Producing realistic representations of vegetation has long been perceived as a major challenge for VR in landscape architecture (Favorskaya & Jain, 2017; Lange, 2002; Portman et al., 2015). Both technical difficulties in modeling fractal geometry and lack of botanical knowledge have been identified as contributing factors.

# HMD VR and the design process

## Site planning

Project development within planning fields such as landscape architecture typically go through cycles, which can be broken down to smaller parts. Various models have been proposed to convey this cycle (Lynch & Hack, 1984; Simonds & Starke, 2006). Steps included in these models are problem definition, research & site analysis, schematic/detailed design development and implementation/construction. The number of steps and level of detail varies between different models, and reality is often messier than the models suggest. Kevin lynch suggests a cycle of 8 stages. (Figure 1)

## Design Process

When designers work through the creative stages of project development cycles (such as schematic design), design processes are typically employed to explore and evaluate ideas efficiently. Design processes are more universal than project development cycle models and can be implemented across any type of design fields. Models have been proposed to describe common design processes. These models typically feature specific stages such as input, generation of ideas or mental synthesis, development and evaluation (Bayzidi et al., 2015; Purcell & Gero, 1998; van Dooren et al., 2014). The designer goes through several steps, some of which are iterated in order to explore and evaluate alternative solutions (Figure 2). In practice, most design processes are likely a combination of several models and vary widely between individuals and projects. Research suggests that proficient designers typically generate more ideas, iterate more frequently, and spend more time making decisions. (Williams et al., 2011). The various models proposed for describing common creative processes are outlined below.

- **"Black box"**
  This model refers to an unknown process, which might be very complex, or could be simple. However, the process leading to idea creation is not known, and not available for conscious introspection.
- **Linear**
  The linear model describes a simple, linear process where ideas are generated, then developed until the design

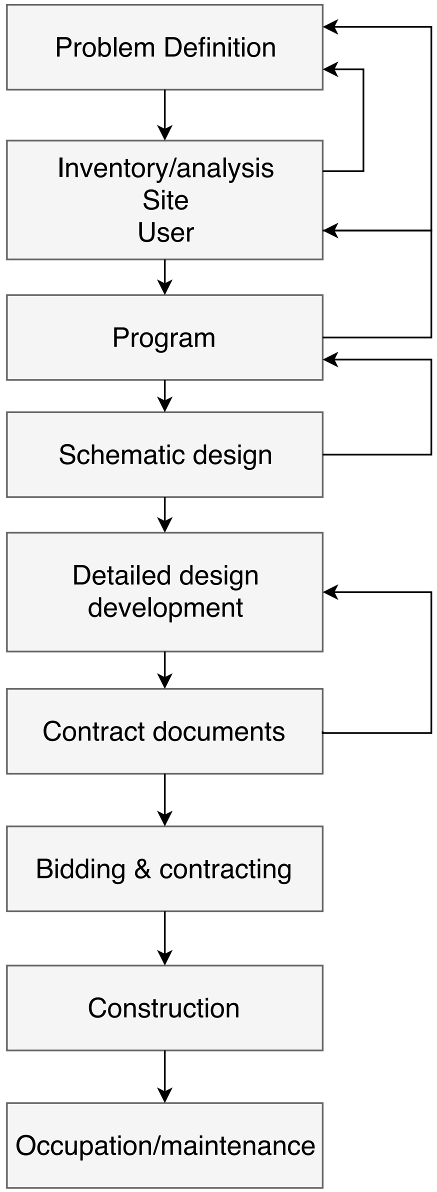


*Figure 1. Project development cycle. (Lynch & Hack, 1984)*

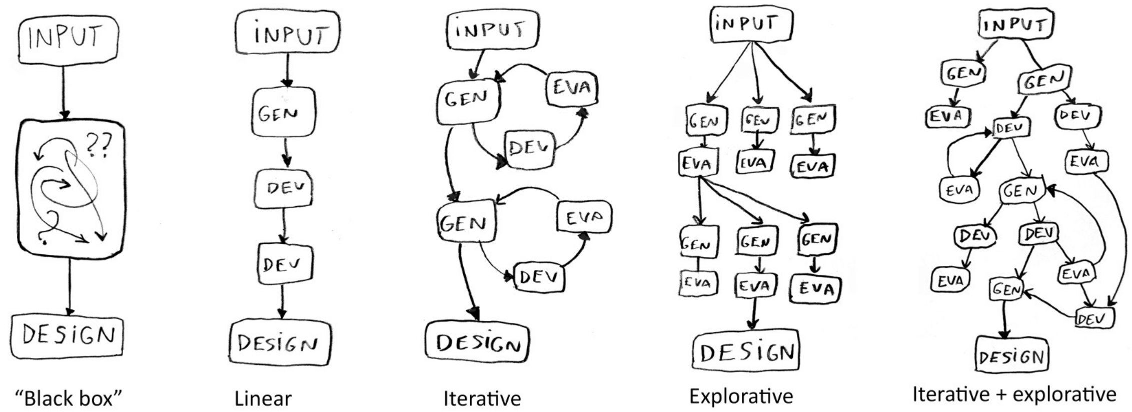


*Figure 2. Various models proposed for describing creative processes*

problem is solved. The designer does not focus much on exploration and evaluation of ideas. Design processes similar to this are likely more common among non-designers, or when time constraints are prioritized over creativity and design outcome.

- **Iterative**
  Ideas that are developed and evaluated in repeating cycles can be described as iterative. When compared to the linear design process, inappropriate ideas are more likely to be discarded, leading to improved design outcomes.
- **Explorative**
  This describes an evolutionary process where multiple ideas are generated, developed and evaluated in parallel. Some ideas are discarded, while others are kept, and used as a basis to create new developments.
- **Iterative + explorative**
  This mix of design processes describes a disordered, complex process where ideas are generated, developed and evaluated in parallel, and iterative cycles take place. This model is likely more familiar to many professional designers.

## Tools supporting the design process

Creativity within design fields is often described as the synthesis of formerly separate concepts or ideas (van Dooren et al., 2014). These ideas can be internal and originate from the designer’s memory, or be external, e.g. an inspiring project catalog. The designer then develops and evaluates the result of the synthesis.

Generation/synthesis of ideas typically takes place in the ‘visuospatial sketchpad’, which is part of the short-term working memory. This is commonly known as mental imagery or mental representation. Mental imagery is essential for designing, and is often used in conjunction with other design tools (Bilda & Gero, 2007). Input from long-term memory or external sources is manipulated or combined, generating solutions and alternatives. However, the short-term working memory is very limited, as most people have experienced when trying to memorize a phone number. Visuospatial working memory (VSWM) is easily overloaded, and memory decay is rapid. To continue synthesizing ideas and generating/developing alternatives, information has to be externalized. During initial phases of any design process, this is typically done with quick sketches. The sketches serve to offload VSWM and amplify the designer’s imagination during the design process (Tversky & Suwa, 2009). Experimental research suggests that sketches lead to better design outcome than mental imagery alone (Schütze et al., 2003).

Anecdotes suggest that Frank Lloyd Wright could design an entire building using mental imagery alone (Bilda & Gero, 2007). Construction drawings are only produced and the end of a mental design process. While most designers likely benefit greatly from externalizing, there is a significant individual difference in short-term working memory capacity. For this reason, some designers have greater need of externalization than others (Purcell & Gero, 1998)

Sketch models are also widely used by designers. While hand sketches are more immediate, sketch models can often convey spatial information more easily and accurately. (Tversky & Suwa, 2009)

As the design develops, sketches and sketch models become inadequate stores of information. Sketches are inaccurate, and their exclusive use limits the level of detail. At this stage, digital 2D or 3D CAD drawings are typically created. These also serve as input for mental synthesis using VSWM (visuospatial working memory) or can be printed out and sketched over. 2D CAD is generally more quickly altered, while 3D models can convey a lot more spatial information. Some research has explored the potential of these tools to improve the design process within architecture (Cote & Mohamed-Ahmed Ashraf, 2011).

Virtual reality simulations can be seen as a continuation of this progression. A VR model is even less immediate than CAD drawings, but once set up, can potentially convey a lot of information. This information is represented in a style more consistent with the experience of an end user, due to various factors such as field of view, depth perception, perspective etc.

As a result of this, a smaller portion of the limited visuospatial working memory is taken up trying to imagine how a scene will be experienced. A highly detailed and accurate VR-model taxes working memory less than a more abstract model, as less imagination is needed to envision the proposal. Consequently, more attention can be paid to mental synthesis. Additionally, more environmental factors can be taken into consideration – e.g. affective evaluations of space, lines of sights or vistas, perceived openness, legibility etc.

For the reasons described above, two important limitations of VR are important to emphasize. Firstly, any form of immersive VR model is likely time-consuming to set up. A good design process is characterized by a high number of ideas/numerous iterations, which quick sketches facilitate well (Tversky & Suwa, 2009). Any benefit from accurate representation and lower VSWM tax must be weighed against a potentially slower design process.

Secondly, any mental synthesis occurring while wearing headset needs to be externalized at some point (Cote & Mohamed-Ahmed Ashraf, 2011). Sketching on paper or CAD is obviously not practical unless the headset is removed.

## Collaboration

The above-mentioned description of the design process does not take into consideration that projects are often developed by a team. Even when a single designer controls development of a project, feedback from colleagues (and other parties) is commonly used to explore and evaluate alternatives.

In collaborative design processes, a common understanding of the proposal is crucial. Mental imagery cannot easily be communicated verbally, although sketches can help, at least in early design stages. Creating accurate 2D and 3D CAD drawings to communicate accurately becomes increasingly more important as the project develops. (Sopher et al., 2017)

When asking for feedback from a colleague unfamiliar with the project, a 2D CAD drawing may not be ideal to efficiently convey all the relevant information. A proper understanding of factors such as scale, topography, vegetation lines of sight etc. might be difficult to extract easily from a quick look at a plan drawing. In these cases, a 3D model presented on-screen can be more useful. However, a highly detailed VR model could be a very effective way to quickly share the designer's vision accurately, although it is more time-consuming to set up (Albracht, 2016).

A problem in communication arises when watching a scene using HMD VR. The person wearing the VR display has no obvious way to convey information with others, except through talking. Personal experience shows that users will intuitively point towards the object of discussion as they experience it through the HMD VR. Naturally, this does not help anyone not wearing HMD VR to understand what they are observing.

In some cases, simply passing around the VR display is adequate to communicate specific aspects. However, when discussing specific aspects in detail, it would be preferable for several people to experience the same scene together, without needing to use multiple HMD VR devices at the same time.

Specialized mobile VR-solutions such as Oculus Rift and HTC Vive are linked to a PC and monitor, which presents a flat mirror image of what they are experiencing through the display. This facilitates communication, as other individuals can see what they are experiencing.

Using mobile-based VR, mirroring is less practical. Screen-mirroring solutions do exist, but currently have a significant lag between mobile HMD and monitor mirror, making communication very slow. Dedicated hardware such as Google Chromecast has improved this but is an unattractive solution, as it makes the technology less flexible and instant in use.

## Effect of media on evaluation

Evaluation is a crucial step in the design process and should be based on precise and relevant information. An accurate 3D model can be an effective means to store and present the information. However, this model can be presented in various ways, such as 3D model shown on screen, quick renderings or virtual reality representation.

It is important to consider that the various presentation techniques available do not convey information identically, and the chosen method of representation could inadvertently affect evaluation of alternatives (Arnowitz, 2017; Castronovo et al., 2013). As an analogy, consider two forest scenes – a rich forest with lush undergrowth, compared with a more open, less visually complex forest. When experiencing the scene in person, the observer might find both scenes pleasant and beautiful. The observer then takes pictures of both scenes. When studying the photographs, the more open and visually simple forest remains attractive. However, the visually complex forest may appear less appealing – the image feels "flat" and illegible. Distant and close objects blend into one another. Stereoscopic vision made the scene legible in real life, but lacks on a photograph, resulting in a less appealing scene. (Figure 3)

This section will discuss how various technologies can affect perception and evaluation in unexpected ways or can be

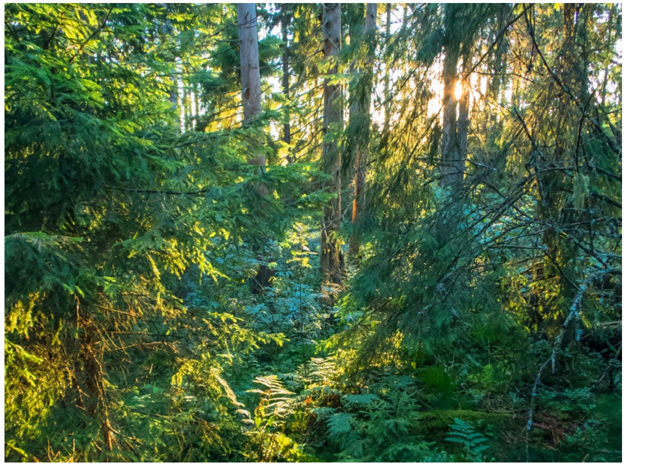

*Figure 3. Comparison of two forest areas in Ås near Oslo.*
*When visiting this forest, the upper scene felt more appealing than the lower scene. However, the strong visual impact of the upper scene has largely been lost in a photograph. Stereoscopic vision was important for making sense of the dense understory vegetation, and the scene is now rather flat and illegible. The lower scene relies less on stereoscopic vision for depth perception and has maintained its visual appeal.*

unintentionally misleading. We can divide design considerations into groups: factual information, affective response, or a combination of these.

- **Factual information** refers to specific, non-emotional factors such as direct line of sight to an exit sign, or whether buildings on a forested hilltop produce a silhouette effect against the sky. This form of information is likely less affected by viewing media, as long as the model used is accurate.
- **Affective response** refers to the emotional reaction to a scene (Ulrich, 1983), e.g. whether a space feels safe or unsafe, or if a retaining wall appears too visually dominating. Responses in this category are often highly individual, and likely more affected by viewing media, often in subconscious ways.
- **Combination**- Contemplation over the removal of trees to reveal a vista can be a combination of both – information about line of sight is factual but assessing the visual value of the vista vs the trees is an affective evaluation. 3D models presented in HMD VR can be highly accurate, and the increased immersion can be effective at producing an emotional response. For these reasons, this thesis hypothesizes that VR is particularly useful at evaluating factors, which combine factual information with affective response, when compared to alternative methods.

Important aspects which may affect the accuracy of information and affective response are **level of realism, visual perception, and aesthetic evaluation.**

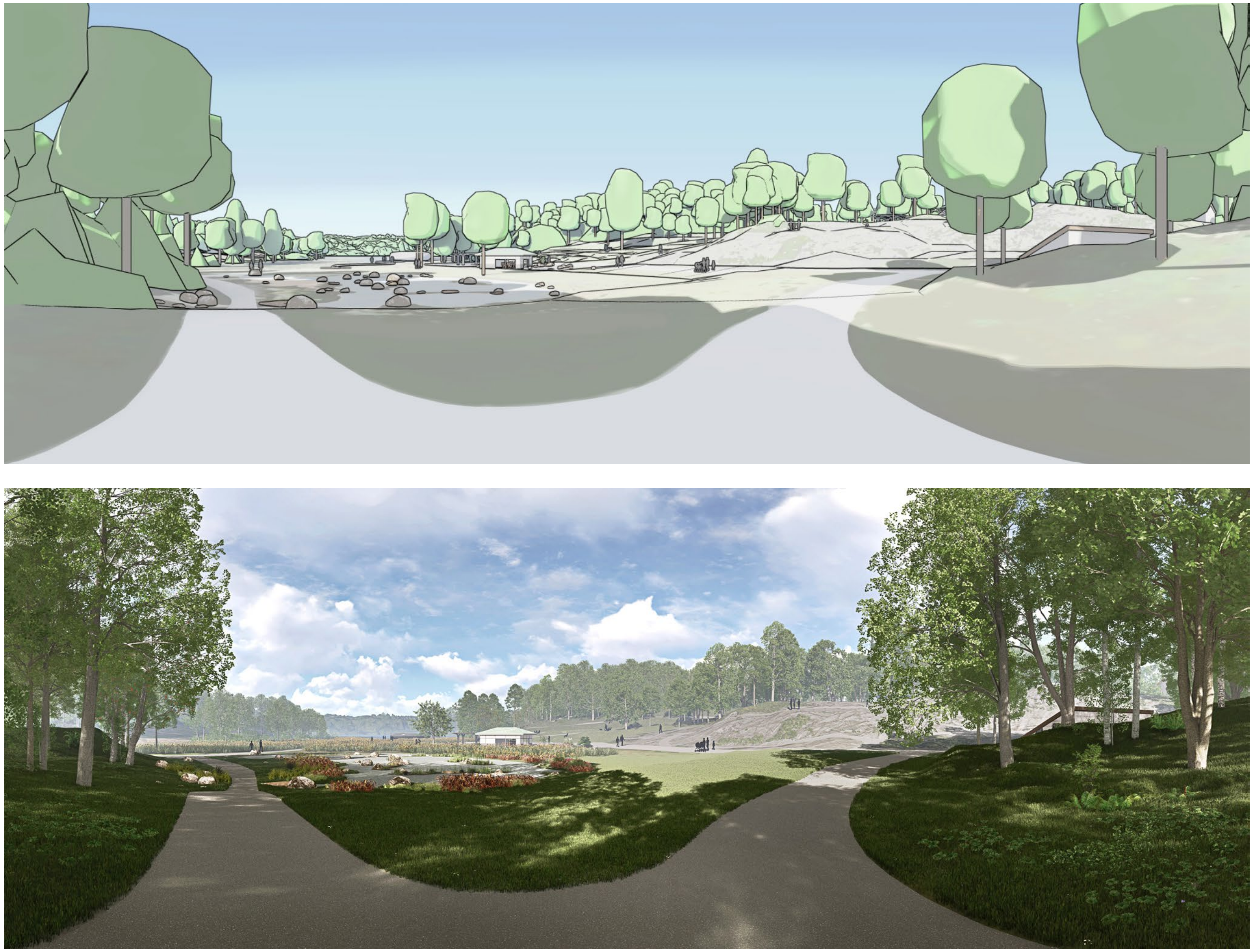

*Figure 4. The same scene presented with varying level of realism. (From the case study)*

## Level of realism

Realism in representation of virtual landscapes is achieved by a combination of high level of detail when modeling, adding accurate textures and surfaces properties, and using realistic "ephemeral conditions" such as atmospheric fog, light, and shadow. However, if these factors are inaccurately represented, the result might be misleading. Some research suggests that merely using immersive VR as representation method can increase the level of perceived realism (Dannevig & Thorvaldsen, 2007).

Experimental research suggests that more realistic and detailed virtual environments lead to more accurate perceptions of the simulated space (Loyola, 2017). However, realistic simulations are generally more time-consuming to produce than simpler ones. In certain situations, realism might not be necessary or even desirable. (Figure 4)

2D renderings and VR spheres generally have a higher potential for visual realism than 3D models presented on screen, or navigable VR models. High level of detail (e.g. individual leaves on trees or grass) can dramatically reduce performance of a navigable 3D model, rendering it unworkable or uncomfortable to navigate. This is aggravated by realistic surface properties such as reflections, high quality textures and *normal maps* (additional texture which simulates height information) as well as ephemeral conditions such as realistic light, shadow and fog.

Computer performance is usually not an issue in small spaces (e.g. a building interior scene) but can quickly become serious issues in visually complex outdoor scenes.

## Visual perception

**Depth perception** is the ability to experience the world in three dimensions, and judge distances between objects. Several techniques are used to achieve depth perception. The most relevant depth cues for this purpose are objects of familiar size, *aerial perspective*, *textures gradients*, *parallax,* and *stereopsis*.

Placing humans, cars and other objects of familiar size, as well as textures on surfaces are simple ways to improve depth perception and are not affected by means of representation.

Aerial perspective (Figure 5) is generally available to 2D and VR sphere renderings, but not usually when watching a 3D model on screen.

Conversely, parallax is only available to 3D models (and navigable VR models with high framerate). Parallax refers to the effect where nearby objects appear to move faster than distant object when is the spectator is in motion. Rotating a 3D model can achieve this effect.

Due to short distance between each eye, stereopsis has limited range. This range is further limited in VR due to comparatively low resolution. For nearby objects, stereopsis can be highly effective to achieve depth perception. For distant scenes, however, aerial perspective and relative size of objects are more important depth cues.

**Field of View**

As any photographer has experienced, the field of view used to capture a scene affects its visual impact. Wide-angle lenses tend to exaggerate the size of spaces and diminishes the size of distant objects, while telephoto lenses have the opposite effect.

Similarly, 3D renderings created with wide-angle perspective result in very different outcome than 3D renderings with narrow, telephoto-like field of few. A major advantage of HMD VR over 3D models or renderings displayed on a computer screen is that the field of view presented will be similar to that experienced in reality.

Although VR spheres share the disadvantage of a fixed view-point with 2D renderings, VR sphere techs have the advantage of being able to turn one's head – not only revealing more information, but also making it easier to imagine what the same scene might look like from a nearby, visible vantage point.

*Figure 5. Aerial perspective – distant areas display lower contrast and cooler colors. (From the case study)*

## Aesthetic evaluation

Visual preference is often perceived as entirely individual and unpredictable (Pinker, 2002). However, the fields of philosophy, art theory and modern science have often made claims to the contrary. Several modern theories concerning visual preference are presented below, with a summary of how they can be affected by the means of presentation.

**Realism and familiarity vs novelty**

A robust finding from empirical aesthetics is that visual representation is generally preferred if it is realistic, rather than abstract (Cupchik & Gebotys, 1988). Furthermore, research suggests that people tend to prefer familiar environments over novel ones (Tuan, 1990). Contradicting this are studies suggesting that unique and visually striking scenes are often preferred (Bell, 1999). It is often suggested that a balance must be struck between familiarity and novelty. Predicting how this could affect alternative presentation of simulated environments is problematic. A more abstract representation may be more appealing for appearing novel, or could conversely feel unappealing due to being too unfamiliar, or for presenting a lower level of realism. To further complicate things, some authors have suggested that high but imperfect levels of realism are experienced as eerie and uncomfortable. This effect is commonly referred to as "uncanny valley", and some research have suggested that it could affect VR simulations of architecture designs (Kuliga et al., 2015).

**Habitat selection/biophilia**

Researchers have hypothesized that aesthetic judgment of environments has evolved as a guide for selecting habitats appropriate for human activity and settlement. Humans tend to prefer natural environments over built environments, and natural scenes can have restorative effect on human health and attention. (Hartig & Evans, 1993; Kaplan & Kaplan, 1989; Ulrich, 1983). This is particularly true for lush landscapes containing vegetation and bodies of water. A related idea is the biophilia hypothesis (Wilson, 1984). This theory suggests that humans have an innate presence for "life-like processes" and "living systems".

Recent experimental research has examined whether computer-generated environments presented through virtual reality have a restorative effect similar to the effect observed in real landscapes (Vallo, 2017). The body of research within habitat selection and biophilia could have implication for the representation of virtual environments: affective response may be disturbed by unrealistic representation of elements such as vegetation and water. It is unclear precisely how visual preference for these is affected by the level of detail and realism.

**Exploration**

Psychologists have theorized that scenic beauty evolved partially as an incentive for early hominids to explore their environment (Kaplan, 1987). According to this hypothesis, visual preference is increased when the cost of exploration is low, and the reward appears high. In practice, this could refer to a scene where some foreground elements, e.g. topography and vegetation obstructs a more open scene. However, there is a visual connection to the open area, e.g. an path through the forest (Figure 6). Visual appeal incentives the explorer to take a few steps along the path to examine the new area. This effect is well-known within traditional painting and photography, and is widely used within traditional and modern landscape design. Crucially, the effect is not present when the open vista is readily available, or excessively obscured. This phenomenon has been dubbed *mystery* within the environmental psychology literature and has been found to be a consistent predictor of beauty in experimental research (Kaplan et al., 1989)

In order to produce this effect, visual clarity and some degree of realism might be necessary. Vegetation should be realistic enough to obstruct or reveal information in a representative

*Figure 6. Mystery: Promise of more information nearby. Foreground is darker than background, and a more open scene is partially revealed. (From the case study)*

manner. Different tree species do not provide the same level of obstruction: mature pine, elm, aspen and birch trees tend to have tall, light crowns with limited impediments to lines of sight while hazel, juniper and yew are typically very dense at eye level. Treating all vegetation as the same could inadvertently affect mystery.

Furthermore, the sense of mystery is often achieved through disparity of brightness and darkness in different areas – the open landscape at the end of the path is often brighter than the foreground. This effect is typically not shown while editing a 3D model but can be achieved with 2D or VR renderings, which causes light and shadow to be depicted realistically.

**Coherence and legibility**

Several approaches have converged on the idea that coherent, legible landscapes are more aesthetically appealing or pleasant. For example, Kaplan et al (1989) suggest that coherence and legibility are important features of landscape preference.

An important aspect of legibility is depth perception, which facilitates organization of information in space. While all presentations of virtual environments can support some form of depth perception, direct stereopsis achieved through HMD VR is very effective, and has been linked to higher preference. (Higuera-Trujillo et al., 2017)

Level of detail and realism will significantly affect coherence and legibility. Details which are repeated or subservient to a larger whole might increase legibility, while large number of different items (e.g. signs, lamp posts and storm drains) that stand out visually typically reduce coherence and legibility. For this reason, simpler representations which omit such details might appear more appealing than the real landscape would. This affects every aspect of the model, including terrain, built elements and vegetation.

**Organized complexity**

Although legibility and coherence alone would suggest that simpler scenes might lead to preference, it has been consistently observed people prefer moderately complex scenes over simpler ones (Van der Jagt et al., 2014). In 1928, George D. Birkhoff hypothesized that aesthetic pleasure is achieved through the act of perceiving and understanding a complex scene (Rigau et al., 2007). This can be expressed as *beauty = order X complexity*, until the level of complexity is too high for effective mental organization.

An extreme example of high order coupled with high complexity is a fractal pattern (Mandelbrot, 1983). Fractal geometry refers to shapes which repeat themselves over several levels of magnification and are often observed in nature. Computers can generate perfect fractals, while natural fractals typically display statistical rather than perfect self-similarity. Vegetation typically display strong fractal properties (Figure 7). Highly fractal geometry is also found in traditional architecture (Salingaros & Mehaffy, 2006), and is very evident in structures such as gothic cathedrals.

Researchers have hypothesized that people tend to prefer fractal geometry over similar geometry without fractal properties (Hagerhall et al., 2008; Taylor et al., 2005). Although fractal patterns are often found in natural landscapes, painters have often exaggerated these, consciously or not. This may have led to increased aesthetic appeal.

Level of realism and detail in simulated landscapes is inherently linked to fractal geometry. Highly detailed trees or rock textures will typically more reveal fractal properties than simpler, more abstract simulations. Computer-generated plants are often created using simple algorithms, and for this reason, may display more fractals properties than real plants often do.

The level of visual order and complexity in landscape architecture project will likely have significant impact on visual assessment. If a virtual reality simulation is utilized to predict the overall visual appeal of a design scheme, it should ideally aim for a representative level of order and complexity.

*Figure 7. Scenes from the Arboretum near Milde Botanical Garden. Vegetation displays high levels of organized complexity and fractal properties*

**Nausea**

Users often report some discomfort or nausea during or after experiencing HMD VR. This is often explained by a disparity between sense of sight and sense of balance. Imperfect head tracking, as well as slight latency between head motion and display, are likely the main culprits. It seems probable that discomfort will affect affective response of a simulated environment. This issue seems to affect navigable models more than VR spheres, especially when high complexity of the model affects frame rate of head-mounted display.

## Cost vs benefits

Although there are clear benefits to working in digital 3D, there are also significant costs (Mengots, 2016). Creating 3D models is time-consuming, in an industry where time is a limited resource. Creating a detailed and accurate model for realistic VR is more time-consuming than a rough sketch or Photoshop collage. The cost of creating a 3D model, especially when adding a high level of detail could be offset if the model has multiple applications.

A realistic model with high level of detail capable of VR is also suitable for generating architectural visualizations or animations, which clients often require. 3D models, renderings, animations or VR representations can potentially be used to communicate with the client, or for receiving feedback from end users (Li et al., 2014).

When created early in the process, a 3D model of a landscape and its surroundings may inform site analysis even before the design phase is initiated. This model should be used in conjunction with the more traditional inventory collected via photographs. Ultimately, designers can compensate for time expenditure on a 3D model later in the process, e.g. via more informed decisions and fewer errors during construction (Solheim, 2011).

Clients frequently require sun/shadows analyses that are difficult to achieve through hand drawings or 2D CAD. An accurate 3D model can be the basis for such analyses. The same 3D model can also generate the foundation for sections and other drawings, or to calculate material quantities (e.g. surface areas and volumes).

The time spent creating a 3D model will vary greatly between individuals, project, and workflow. An effective designer with high proficiency in using 3D modeling software and an effective workflow can create and update a model many times faster than a novice.

It should be noted that creating accurate, detailed and realistic 3D models is not always significantly more time-consuming than abstract models. Placing out realistic trees might not be slower than placing simplified trees, and programs such as Lumion allow realistic effects to be stored as presets for future projects. 3D grass can be generated automatically on appropriate areas, and foreground plant elements such as plants and rocks can be quickly scattered randomly around an area using pre-selected parameters. However, a highly detailed 3D models tend to make the software work slower, which can significantly hamper the workflow – especially on less powerful computers, or when working with poorly optimized meshes and textures.

### Comparison of tools for evaluation and collaboration

VR sphere technology used in this thesis is one of several alternative methods for evaluating and communicating design proposals. Table 1 compares some common methods, highlighting advantages, disadvantages and challenges with each.

| Method/technology | Advantages | Disadvantages | Challenges |
|---|---|---|---|
| **Mental imagery** | - Very fast | - Limited detail, accuracy and realism<br>- Cannot be shared | - Individual variation in STWM/capacity |
| **Sketch drawing** | - Quick | - Low detail, accuracy and realism | - Late stages or complex projects |
| **2D CAD** | - Accuracy/detail (in plan)<br>- Quick to draw and adjust | - Limited 3D information content | - Unintuitive for spatial considerations and for predicting affective response |
| **Sketch model**<br>(Physical model) | - Facilitates group discussions | - Limited realism<br>- Slow, especially with high LOD<br>- Inflexible in use | - Late stages or complex projects |
| **2D render from 3D model** | - High resolution<br>- High potential realism<br>- Sending/shared easy<br>- Can be sketched over | - Restricted field of view<br>- Visual field does not match real life<br>- Judging size/distances difficult<br>- Not stereoscopic | - Effort required to generate sense of depth<br>- Good composition/field of view important for visual impact |
| **3D model on screen**<br>(e.g. SketchUp model) | - Parallax adds depth<br>- Can move around freely<br>- Can be edited quickly | - Visual field does not match real life<br>- Resolution limited<br>- Not stereoscopic<br>- Limited realism | - Slow if scene is complex/detailed, must be somewhat optimized<br>- Sending/sharing requires compatible software |
| **Navigable VR**<br>3D model is experienced in VR, and can be navigated "live" (not pre-rendered) | - Field of view matches real life, head tracking<br>- Parallax may add depth<br>- Can move around freely | - Limited resolution<br>- Limited realism<br>- Sending/sharing model less practical<br>- Limited ability to share observation<br>- Lower immediacy when making alterations<br>- presenting multiple design options less practical | - Slow if scene is complex/detailed, must be highly optimized<br>- May cause nausea |
| **VR sphere (used in case study)**<br>3D model is pre-rendered to stereoscopic image file and presented in VR. Can be considered "Low-threshold" VR tech. | - Field of view matches real life, head tracking<br>- High potential realism<br>- Sending/sharing in browser easy | - Limited resolution<br>- Limited ability to share observation<br>- Lowest immediacy, design alterations require re-rendering | - Realistic 3D model more time-consuming to generate<br>- Model must be optimized for efficient workflow<br>- Sending/sharing VR experience requires headset<br>- May cause nausea |

*Table 1. Comparison of methods for evaluating and communicating design descisions*

Related to realism/representation
Related to ease of collaboration
Related to immediacy/ability to make alterations during the design process)

# 4 RESEARCH QUESTION

## Main research question

### What is the potential of VR to improve the design process within landscape architecture?

Landscape architects typically employ creative design processes to explore and evaluate ideas during the design stages of the planning cycle. Exploration, critical evaluation and exchange of ideas are important parts of this method.

Several tools can facilitate exploration, communication and evaluation of ideas, each with different strengths and weaknesses (Table 1). How does VR compare to traditional tools in practice? These are some important aspects of the design process which VR can potentially change:

- High levels of exploration/richness
- The number of factors that can be taken into account
- the quality/accuracy of site information
- Overall time expenditure/efficiency

Answers to the main research question is affected by many different factors, which are reflected in the sub-questions.

## Sub-questions

### Can VR assist in evaluating a design proposal?

Experimentations with VR during the preparatory phase, discussions with colleagues and literature review has led to writing up a list of recurring issues, which VR might be useful to evaluate. These are:

**Evaluating whether spaces are legible and well-defined**
VR might help designers evaluate whether an area is well-defined, orderly and legible. Stereopsis and the ability to look around might be useful for this.

**Evaluating the effect of design decisions on site topography**
Topography can be difficult to assess from a 2D plan. Hills can turn out surprisingly steep or retaining walls can be very dominating. Stereopsis and eye-level perspective might be of benefit.

**Evaluating the visual effect of constructions**
Stairs, ramps, fences, buildings and other constructions can have unexpected visual effects, e.g. add too much visual clutter or feel overshadowing and towering. Realistic representation might help to evaluate these.

**Evaluating the choice of vegetation**
Botanical knowledge and design with vegetation are often seen as the main factors separating landscape architecture from related fields. Vegetation is often the most conspicuous component of a site. However, plants are notoriously difficult to plan in detail, as factors such as ecological needs, morphological development and future level of care are often unpredictable. For this reason, accuracy may be inherently limited when simulating plants, except perhaps when existing vegetation is concerned.

**Evaluating the effect of design decisions on lines of sight within site**
The most obvious use for VR is to examine how lines of sights are affected by design decisions. Topography, vegetation and constructed elements can obstruct or reveal objects in a way difficult to predict.

**Evaluating the effect of design decisions on external vistas/ borrowed views**
"Borrowed views" is a term from Japanese garden design and refers to external vistas "borrowed" as a design element in a landscape. External vistas relate to the previous point. However, these may be more difficult to take into account when using methods such as a physical site model, over digital 3D model which can more easily be extended into distant surrounding areas.

**Evaluating the visual effect of focal points**
Various garden traditions such as Japanese gardens and English landscape gardens use visual focal points as important design elements to create stability and guide navigation. These are typically objects such as buildings, pavilions, unusual vegetation or other features. Using too few or too many focal points are common design mistakes. VR might be a powerful technique to simulate the effect of focal points and might be of aid in the process of creating a pleasant composition.

**Evaluating the effect of sunlight and shadows**
3D models are commonly used to create "formal" sun study, which reveal how light and shadow are distributed across the site over specific points in time. VR can take this a step further and provide a first-person view of the effect of light and shadow.

**Evaluating whether spaces feel appealing and safe or not**
Many factors such as openness, brightness, familiarity and materials contribute to the sense of safety in an area. VR can potentially simulate the effect of each of these and suggest how safe or appealing a site will feel.

**Evaluating how users will experience navigation on site**
Visibility of elements such as paths, entrances, exits and signs help to ensure that users will be able to navigate on site. VR can represent these accurately. However, VR spheres do not support direct navigation and may be of limited utility.

**Uncover unexpected issues before construction**
Issues that arise during or after construction are often not predicted by the designer but become clear when visiting the construction/finished site. Creating VR spheres in important areas to check that everything looks as anticipated could be useful to avoid unexpected situations.

## Can VR facilitate collaboration during the design process?

The design development within landscape architecture usually involves collaboration. This requires an information exchange between individuals, leading to a shared understanding of the design proposal.

This exchange can take place within design teams, between team members and other designers (e.g. for input or feedback) or between designers and other parties, such as consultants (e.g. engineers).

Most methods used for design development are also used to communicate the design proposal between designers – sketches, 2D CAD drawings, 3D models etc.

Virtual reality simulations used for evaluation of design decisions can also be used to communicate design proposals between individuals. How do differences between VR and other presentation methods affect collaboration?

## Do certain design processes, methods, design fields and project types benefit more from the introduction of VR?

Different designers use a wide range of work methods for carrying out similar tasks. Some prefer working in 2D CAD, others in digital 3D model or BIM and some prefer traditional methods such as drawing and sketch model. Factors which contribute to these preferences will presumably affect VR tools. Are these preferences predictable? Under what circumstances is VR likely to be preferred?

## How does VR differ from alternative methods of representations?

Method of presentation is likely to affect understanding and evaluation of a project. Some examples given in the previous chapter include level of detail and realism, depth perception, field of view and VR-induced nausea.

It may be impossible to take all of these dynamics into account at all times. However, it may be useful to understand factors, which may (consciously or subconsciously) influence project understanding and affective response.

## How can VR be part of an effective workflow?

Virtual reality is unlikely to be useful for practicing landscape architects if it does not become part of an effective workflow. Can detailed and accurate 3D models useful for VR be created efficiently, and become a part of a larger workflow? Are there currently some highly time-consuming, unavoidable steps?

## When is a high level of detail and realism more desirable?

Virtual reality simulations are uniquely close to the way we perceive our environment, because of head tracking, stereoscopic vision and realistic field of view. Does this realism in presentation synergize well with realistic representation, or could virtual reality models be more useful to the design process if kept more abstract?

## Is currently available “low-threshold” VR-technology useful?

If virtual reality is deemed useful, is this true of the currently available technology? Should practicing landscape architects wait for some technological breakthroughs or improvements to usability?

## Are benefits of using VR likely to outweigh the costs?

Prior research on VR has often focused on the opportunities of VR technology, and paid less attention to significant costs incurred, such as additional time expenditure. Will potential benefits of employing VR be worth this cost? Can complementary uses of the 3D model offset the cost?

## Why is VR not widely adopted within landscape architecture?

If virtual reality technology is deemed useful and can be cost-efficient, how can low adoption rates within landscape architecture be explained?

# 5 METHODOLOGY

## Case study

In order to assess the potential usefulness of VR during the landscape architecture design process, a case study was selected. This project is called *Adiabata* and involves the redesign of a botanical garden south of Bergen. Adiabata is a real, ongoing, large-scale landscape architecture project where affective/aesthetic aspects are central. (Figure 11)

During design development, specific issues and decisions which could be resolved using VR were identified by the design team. Appropriate vantage points for addressing these issues were chosen. A digital 3D model of the entire site and context was created, and VR spheres rendered from these vantage points. These VR spheres were presented to the project designers and used to generate feedback to advance the project. Feedback was also given on the 3D model and vantage points.

Based on this feedback, a new batch of VR spheres was created, often with altered vantage points, materials, light conditions etc. These updated spheres were then presented to the designers again.

After a few batches of VR spheres have been produced, the case study was deemed completed, and discussions with the project leader attempted to reach some conclusions about how the use of VR impacted the project.

A few particularly useful or representative VR spheres were then selected. These were presented to the survey group, to demonstrate the capability of VR as a design evaluation and collaboration tool.

## Survey purpose

The use of HMD VR during the case study gave designers the opportunity to explore the usefulness and cost-effectiveness of HMD VR in solving design-related problems. However, this group was too small to be representative of all landscape architects. For this reason, a larger group of professional landscape architects were interviewed while experiencing VR simulations created for the case study.

Although the sample group in the survey is relatively small for research purposes (18 participants), it is significantly larger and more representative than the design team.

The main purpose of the survey was to shed light on the thesis research questions, using the case study as a demonstration of VR capabilities and limitations.

The full survey is included in appendix II.

## Survey completion

A pilot study was first conducted with 6 landscape architecture students.

An E-mail was then sent out to landscape architects in the largest Norconsult offices of Southern Norway. This email explained the thesis topic in broad outlines and asked for participants to volunteer. Additional emails to smaller offices were sent out as needed, until at least 14 landscape professionals have agreed to participate. 2 volunteers were unable to participate due to time constraints, but 6 additional participants signed up. A total of 18 landscape architects participated, from the three largest Norconsult landscape/planning offices in Southern Norway: Sandvika, Bergen and Hamar.

Norconsult is among Scandinavia’s largest cross-disciplinary engineering, architecture and design firms. It was chosen for convenience in terms of access to information and potential participants. It should be noted that there are some statistical differences between small and large architecture firms, which may affect responses to the survey. For example, larger firms such as Norconsult are more likely to use advanced 3D visualization tools than smaller offices (Hassan et al., 2014).

Prior to the interviews/experiments, participants were invited to express themselves freely and be critical of VR. The VR demonstrations and interviews lasted approximately 35 minutes per participant. Participants were interviewed one at the time in a small meeting room with a Samsung Gear VR headset, plans and photographs used to describe the project, and a laptop for recording the responses. Sound recording was employed (if consented to by participants) to capture particularly interesting and relevant quotes accurately.

The results were documented and analyzed using Microsoft Excel. When chunks of texts occur, grouping according to themes/codes was used to analyze and make sense of the responses. The interviews were conducted in Norwegian. Questions and answers have been translated into English.

# Guide for formulating survey questions

## 1. Questions related to design process and work method

The background literature suggests that experienced designers are more likely to use complex, explorative design processes. Furthermore, introducing virtual reality into the design process is more likely to be of benefit if designers make frequent use of exploration and evaluation.
- What type of design processes do the surveyed designers report using? How does this compare with the literature?
Prior research indicates that landscape architects are less likely to use advanced digital tools.
- Do the surveyed designers make use of 3D modeling presentation tools?
- Will the history of slow tech adoption rates likely affect adoption rates of VR within landscape architecture?
- Are particularly tech-savvy designers more likely to find presented VR tools useful?

## 2. Questions related to experience with, and perceptions about VR.

Prior research indicates that few landscape architects are likely to have used VR in their work.
- Is this true of the surveyed sample?
- Can low adoption rates be explained by widely held presumptions about VR?

## 3. How useful is VR for resolving specific design-issues?

Background literature reveals that specific, practical uses for VR within landscape architecture have not been clearly defined. A list of common and recurring issues was presented in chapter 4 (page 18) and is explored in the case study.
- Can each of these issues be clarified/resolved more easily by using HMD VR, or are traditional methods preferable?
- Are these issues relevant to design outcomes?

## 4. Questions related to abstract vs realistic representation

Discussions surrounding preferred level of abstraction vs realism still needs to be answered (Portman et al., 2015). Three levels of detail are presented to the participants.
- Which of these are deemed most useful for conveying relevant information during early/late design stages, and why?

## 5. General questions concerning VR usefulness

Research on VR and other forms of visualization has often emphasized that digital representations can be as misleading as they are informative.
- Are the presented VR spheres deemed representative of the site and proposed scheme?
If VR is widely believed to lack practical utility, exposure of VR (as used in the case study) could lead to improved evaluation.
- Did the demonstration of VR change evaluation of VR tech usefulness?
- How useful is this technology to quickly share ideas with colleagues, e.g. for feedback?
Some VR technologies allow multiple users to share the same field of view. This is not currently possible with VR spheres, which could lead to difficulties with collaboration.
- Is communication experienced as problematic, slow or inaccurate while wearing the VR headset?

## 6. Questions related to cost/benefit

Prior research on VR has often focused on the opportunities of VR technology but often paid less attention to significant costs incurred.
- Is use of HMD VR likely to lead to a better design outcome, all things considered?
- Creating large-scale, detailed 3D models and VR spheres is time-consuming. Are the benefits of VR for similar projects likely worth the cost in time?
- Is overall time expenditure in projects similar to the case study likely to increase or decrease if VR tech is introduced?
- What barriers might keep survey participants from employing VR technology?

# 6 CASE STUDY: ADIABATA

## Preparatory work

During the fall semester of 2017, I experimented with various VR technologies in several professional and academic projects. The purpose of this investigation was to foresee and solve potential issues, explore potential uses for VR, create libraries of materials and presets, choose the appropriate HMD VR technology, and pick the ideal case project for this thesis. The result of the preparatory work was:

- Choosing VR sphere with Gear VR and Google Cardboard over alternative technologies.
- Selecting redesign of Milde Botanical Garden as case study.
- A list of specific issues which may be resolved or clarified using VR.
- A large library of textures and *normal maps* used to create realistic landscapes, as well as rendering presets for Lumion. This saved large amounts of time for the case study, as well as future projects.
- Uncovering effective workflows, especially integration of AutoCAD, SketchUp, Lumion and Photoshop.
- Creating a library with detailed tree 3D models using SketchUp. Although Lumion has an impressive library of vegetation models, these do not cover most species commonly used in Norway, are not flexible in use, display limited level of realism and size range, and are generally not botanically accurate. When experimenting with VR during preparatory work, tree models felt like the main issue holding back the level of realism. As discussed earlier, producing and presenting realistic vegetation has long been perceived as a major challenge for VR in landscape architecture (Favorskaya & Jain, 2017; Lange, 2002; Portman et al., 2015). For these reasons, I spent 4 months studying and modeling 16 common species trees native to Norway, with about 5-10 age/shape variation of each species. The final batch of 80 models was completed in January 2018 and was used to populate the case study site model with trees. To ensure that every part of this thesis remains replicable, these tree models are released free of charge under Creative Commons License (models can be obtained by contacting the author).


*Figure 8. Comparison of trees from the Lumion library with the newly created trees.*
*Trees that stand close together (aspen, birch and elm) grow apart from each other in search of light, and their branches do not overlap. This is more realistic than standard 3D tree models, which typically show radial symmetry from above, and unrealistically dense foliage occurs where several trees overlap. Subtle details of this kind may have a significant impact on perceived realism, consciously or not.*

# Overview of case study project

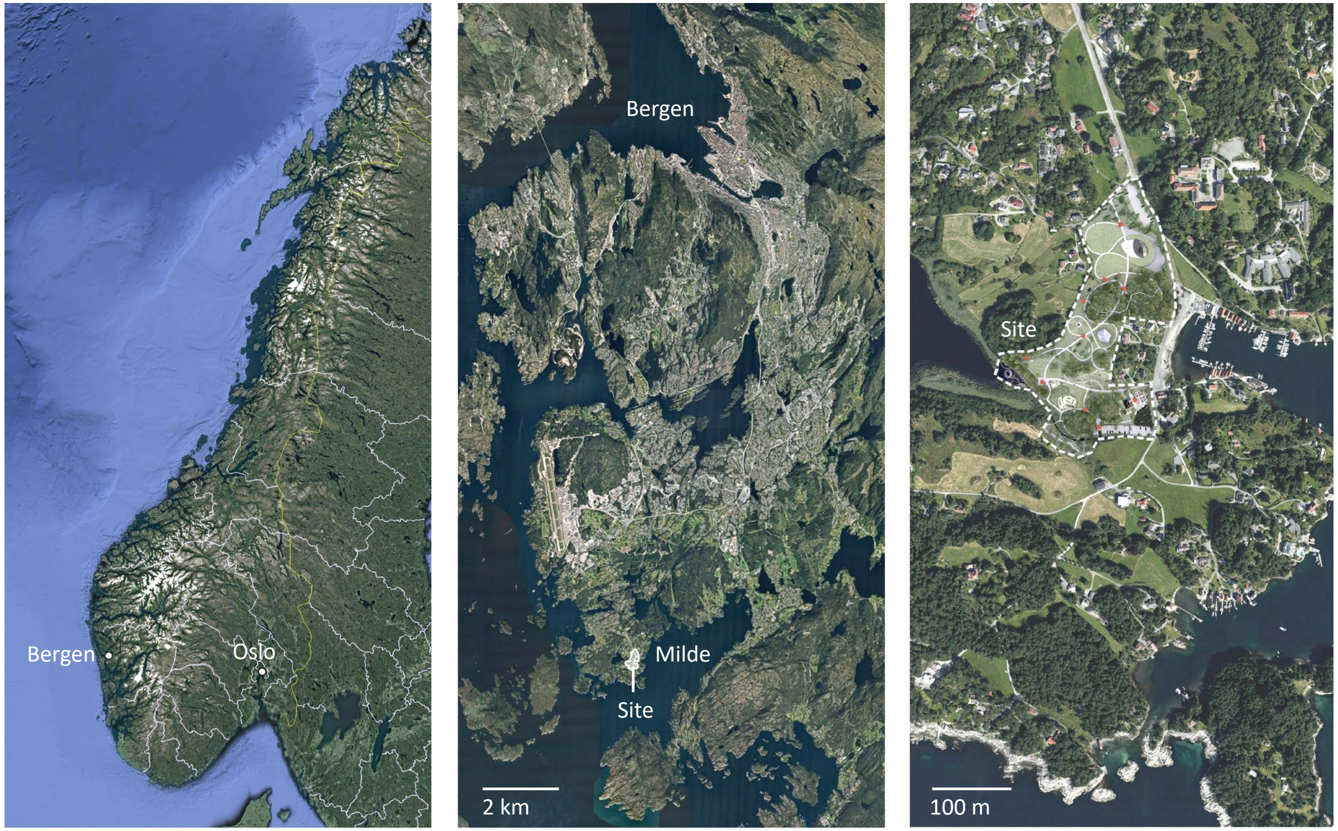


*Figure 9. Site location. Downloaded from Google Earth Pro. ©2018 Google, ©2018 CNES / Airbus, ©2018 Digitalblobe.*

The subject of the case study is a botanical garden in Milde, Hordaland which belongs to the University Museum of Bergen. The park-like garden was opened in 1996 and has been expanded and modified several times (Figure 10). In 2016, the University Museum decided to further expand and modernize the garden. Norconsult's Bergen office was selected to redesign parts of the garden. The author was part of the design team over a period of 4 months between 2016 and 2017.

In the new proposal (Figure 11), the design team expand the northern part of the park, and rework paths to unify the garden. A wheelchair-accessible main path connects the southern and northern entrances, while a longer, winding path meanders across the entire site, intersecting the main path at regular intervals. The Japanese garden and an alpine garden, currently the most visited attractions, would remain unaltered and were not included in the scope of work.

The client's program included two new buildings, a research/learning center and a greenhouse for botanical exhibition. Additionally, an old farm with a baroque garden will be moved to the site and restored. The university mathematical institute helped design a modern labyrinth next to the baroque garden. The designers also decided to integrate an unused forest patch into the botanical garden, with an elevated path navigating through the tree crowns (Figure 24). The team elected to name the new garden "Adiabata", which refers to the process where mountain ranges elevate moist air, leading to rainfall. This concept was chosen because of the local geography and climate- the site is probably the wettest botanical garden in Europe, and ecologists refer to forests in this region as temperate rainforest.

Design phase varies throughout the site. The site of the farmhouse and baroque gardens are currently undergoing construction. The areas around the southern parking is undergoing detailed design development, while central and northern parts are only in the schematic design stage.

I chose this project for the case study for several reasons. Firstly, it is a project where typical *landscape architecture* considerations are central, such as vegetation, spatial arrangement, lines of sight and focal points. It is a site of relatively high visual complexity with large numbers of factors to consider. The visual/emotional impact is at least as important as more practical aspects, such as accessibility. In other words, it is the sort of projects, which might gain the most from the introduction of Virtual Reality. Finally, the project leader wanted to explore the use of VR for making design decisions, and needed a 3D model of the site.

**Research design process**

Using a real project instead of a theoretical case study ensured that the issues explored were realistic, practical and relevant for practicing landscape architects.

I performed my thesis work from Ås close to NMBU, whereas the design team worked from Bergen. Although I visited Bergen a few times, most of the collaboration was conducted over Skype meetings, phone calls, and email.

The thesis case study work began with the identification of issues which VR could help resolve or clarify. The list presented in chapter 4 (page 18) was helpful in this step. It led to the selection of specific viewpoints across the site, which would be most appropriate to shed light on these issues (Figure 12).

The next step was the creation of a 3D model of the site with the new design, as well as the surrounding areas. After completing the first version of this model, I generated VR spheres from the chosen vantage points. I then sent these VR spheres to the design team in Bergen, who used them to evaluate design decisions, reflect over design options and look for unexpected issues. Based on their feedback I altered, added and removed viewpoints for VR spheres several times as issues were uncovered or resolved.


*Figure 10. Original situation. Downloaded from Google Earth pro. ©2018 Google, ©2018 Bergen Kommune*

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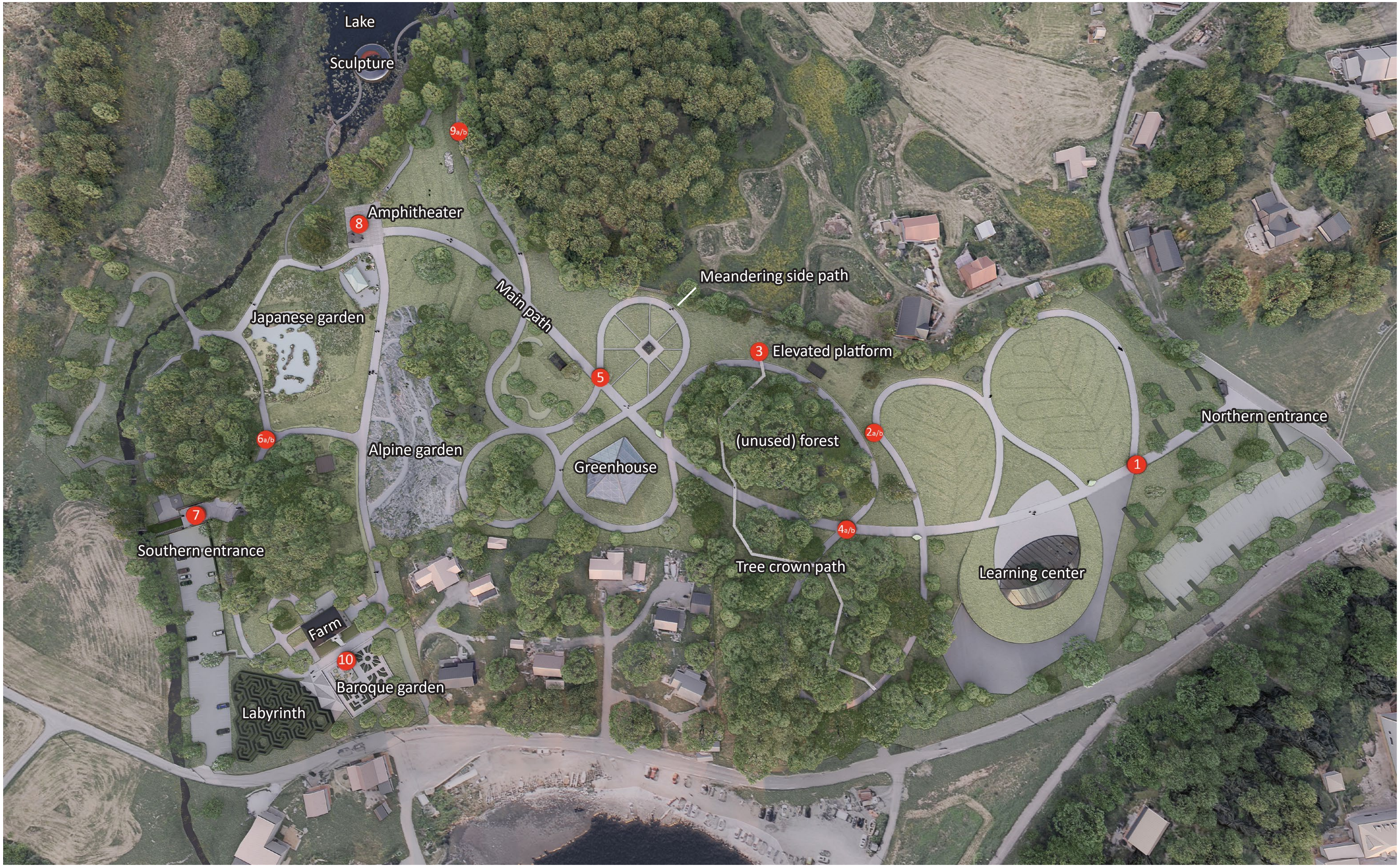


*Figure 11. Current design proposal, as of early 2018. Red dot marks VR sphere vantage points. (Aerial view of 3D model)*

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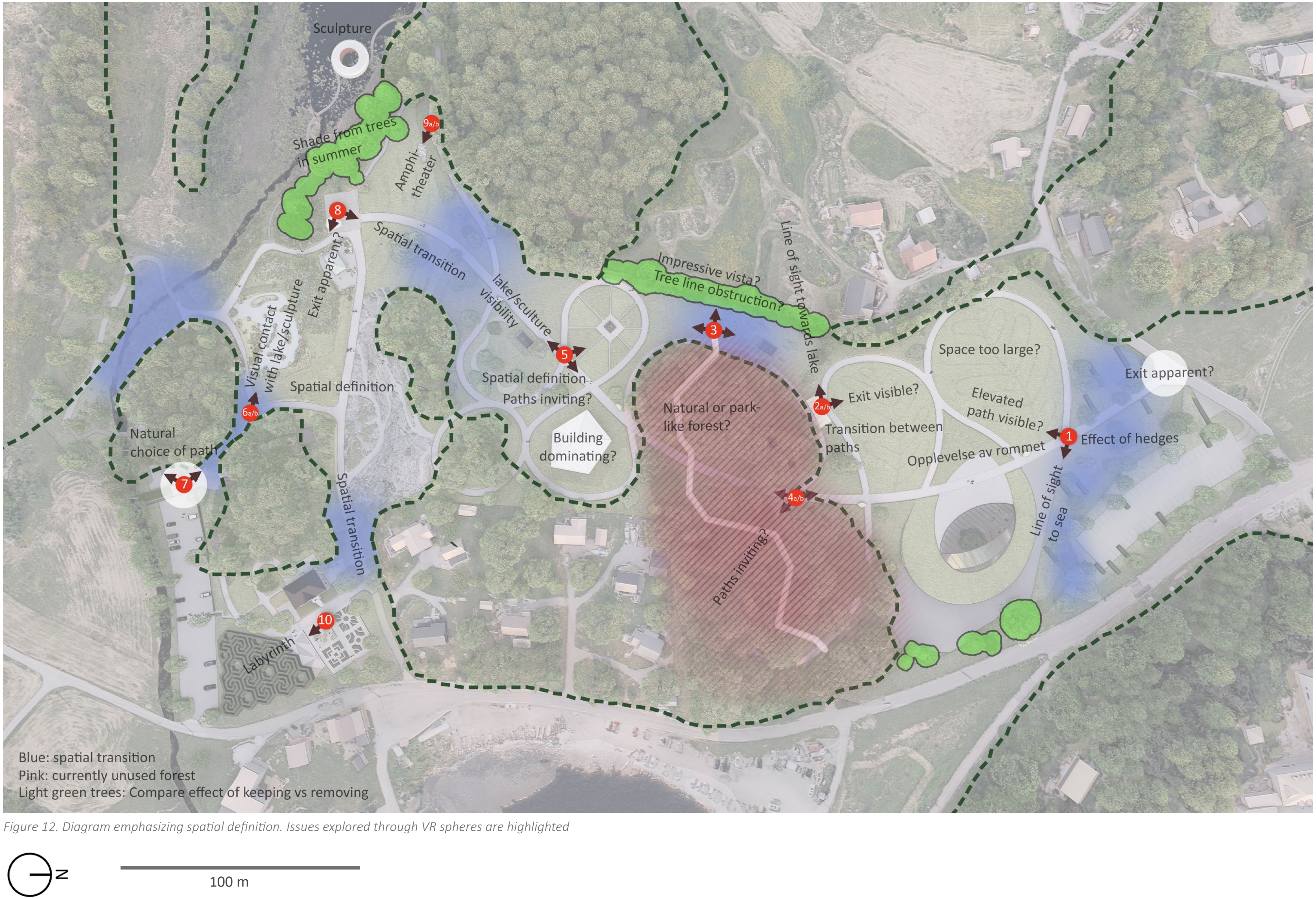



*Figure 12. Diagram emphasizing spatial definition. Issues explored through VR spheres are highlighted*

# Modeling

This section provides a brief overview of the component parts of the 3D model created for the case study. For a discussion concerning technical aspects of creating realistic 3D models efficiently, see the technical discussion on page 80.

Distant areas with low mesh resolution
Generated using DTM GIS data from hoydedata.no

Nearby areas with intermediate mesh resolution
Generated using DTM GIS data from hoydedata.no

Vegetation with intermediate mesh resolution
Generated using DOM laser data from Geodata/hoydedata.no

Site context with high mesh resolution
Generated using SOSI data from Kartverket

Site with high mesh resolution
Generated using SOSI data from Kartverket and AutoCAD plans

*Figure 13. Source materials for the site model*

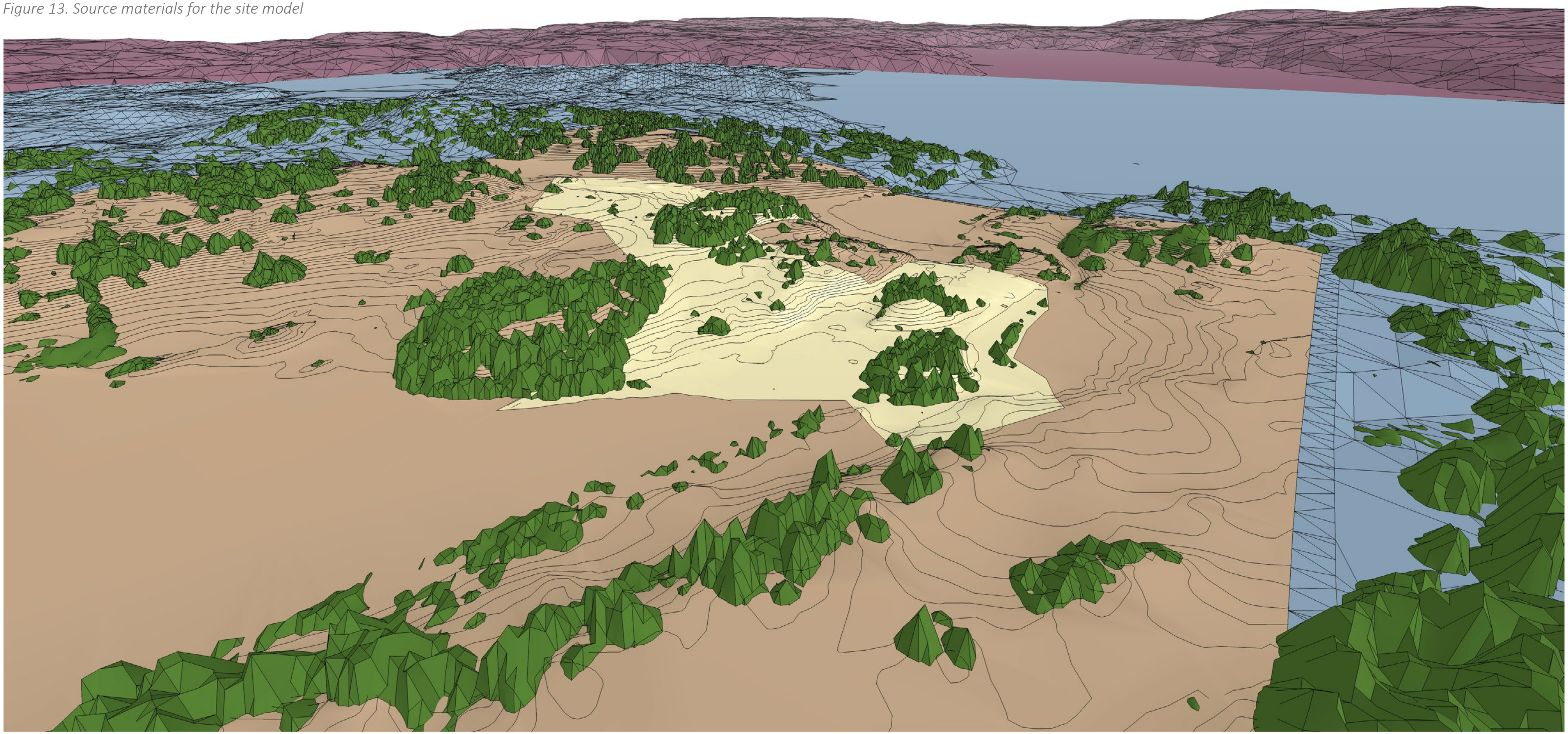


*Figure 14. Site plans and aerial photography were projected over surfaces using SketchUp. Plugins were used to generate nearby houses efficiently from SOSI GIS data.*

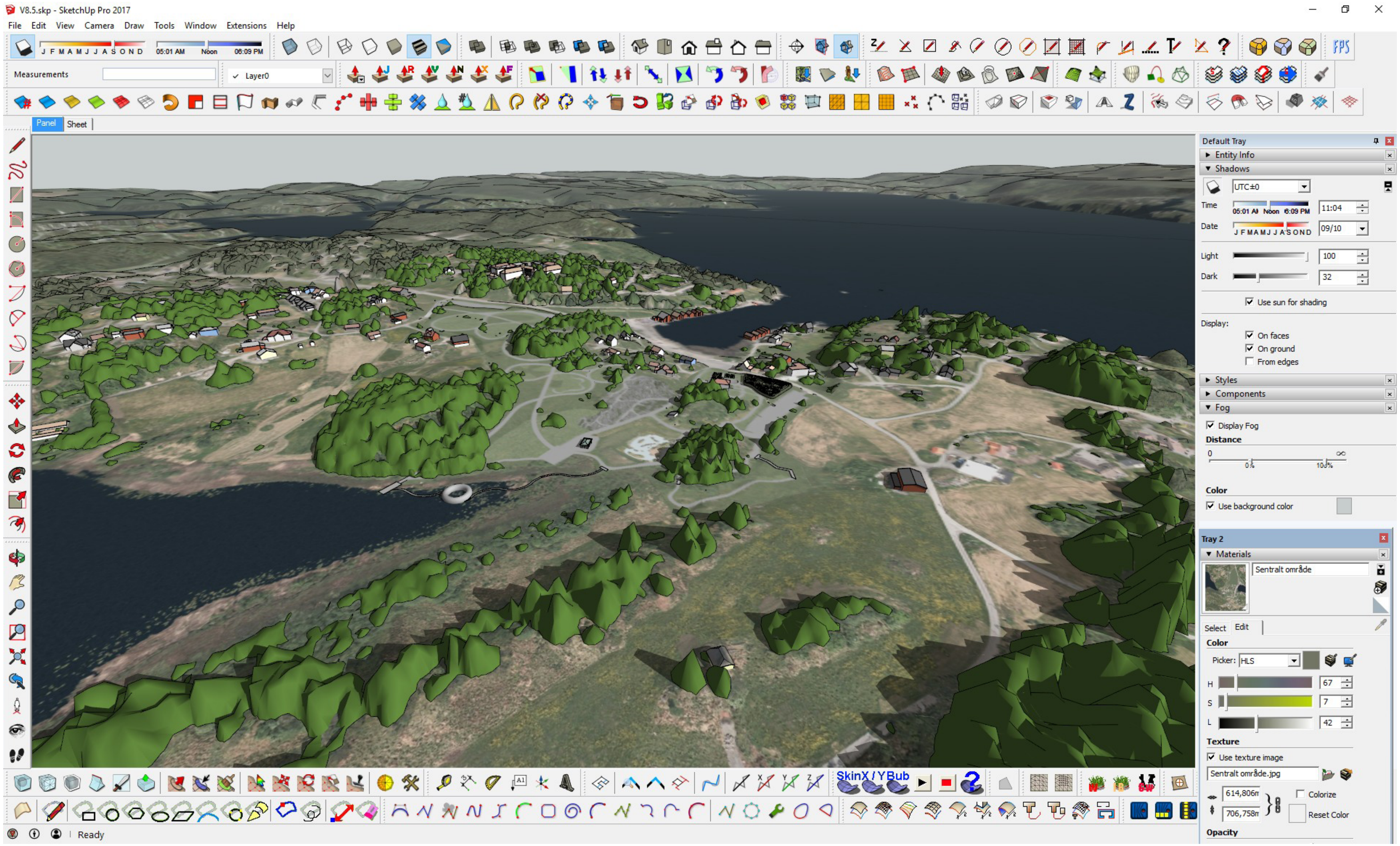


*Figure 15. Aerial perspective rendered in Lumion. Vegetation close to the botanical garden site was replaced with detailed models.*

*Figure 16. Model rendered from ground level (early version). 3D people were inserted to provide a more accurate sense of scale. We later decided to replace detailed 3D people with black silhouettes, as realistic people drew too much attention away from the landscape.*

# VR spheres

This section discusses the final versions of the main VR spheres created for the case study, and list some of the issues addressed by each sphere. VR spheres are numbered in the order in which they were created, which corresponds to the number shown on the site plans (Figure 11). The VR spheres are stored as 'equirectangular' projection JPGs, with the left eye view stacked above the right eye view (Figure 17). Only the top view of each sphere is presented in this section.

To assist designers in predicting possible sun and shade conditions, all VR spheres were initially created with sun conditions reflecting 12 PM during autumnal equinox, September 22. This was altered on some VR spheres to examine expected light/shade conditions during specific time periods.

As VR spheres are backlit when presented in VR, dark areas appear significantly brighter than when the file is printed on paper. For this reason, VR spheres presented below were adjusted in Adobe Photoshop (using batch actions) to automatically brighten dark areas.

It should be noted that the top and bottom regions of these images appear significantly enlarged when viewed on a flat surface, compared with the central region. This is caused by the equirectangular projections of spheres. As the top and bottom-most areas are relatively uninteresting and highly enlarged, these have been cropped away for presentation on paper.

Keymaps have been added to each VR sphere. Arrows over these maps point towards the issue highlighted in the figures.

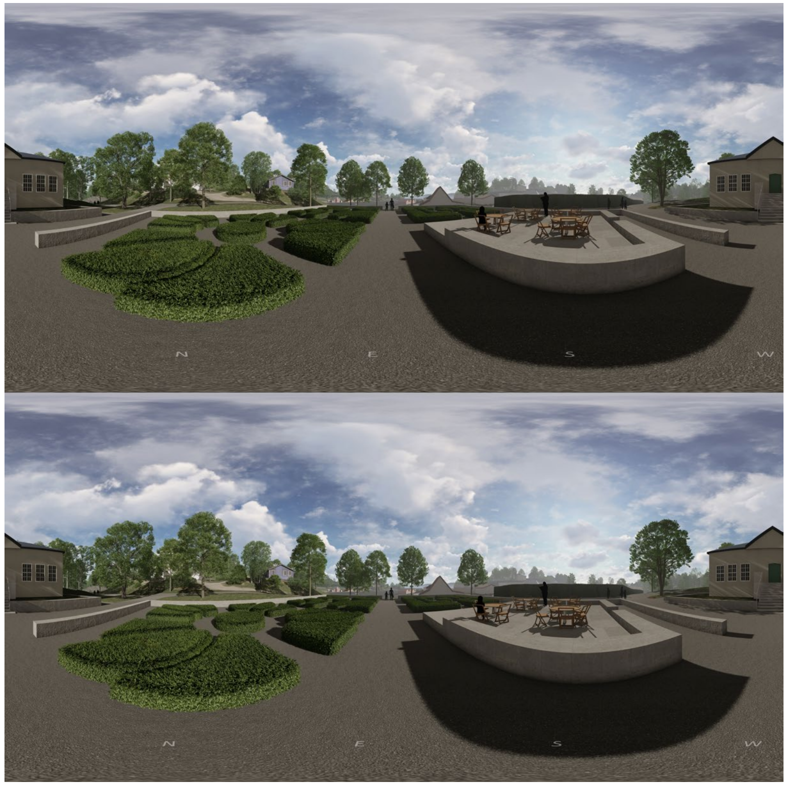


*Figure 17. Stereoscopic VR Sphere 10 shown without editing/cropping. Areas near the horizon line appear small and distant when presented on a flat surface, similar to how areas near the equator appear relatively small on a Mercator map projection. Notice 4 cardinal direction markers on the ground.*

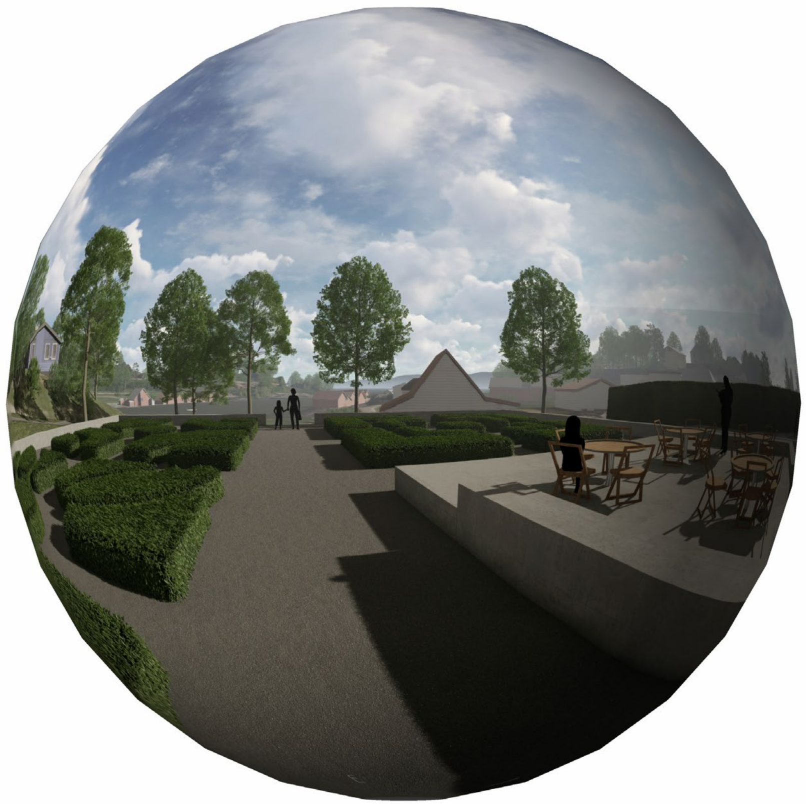


*Figure 18. VR sphere 10 projected on to a sphere – notice how central regions near the horizon line appear significantly enlarged compared with the flat projection. This gives a more accurate view of how the VR spheres are experienced using HMD VR.*

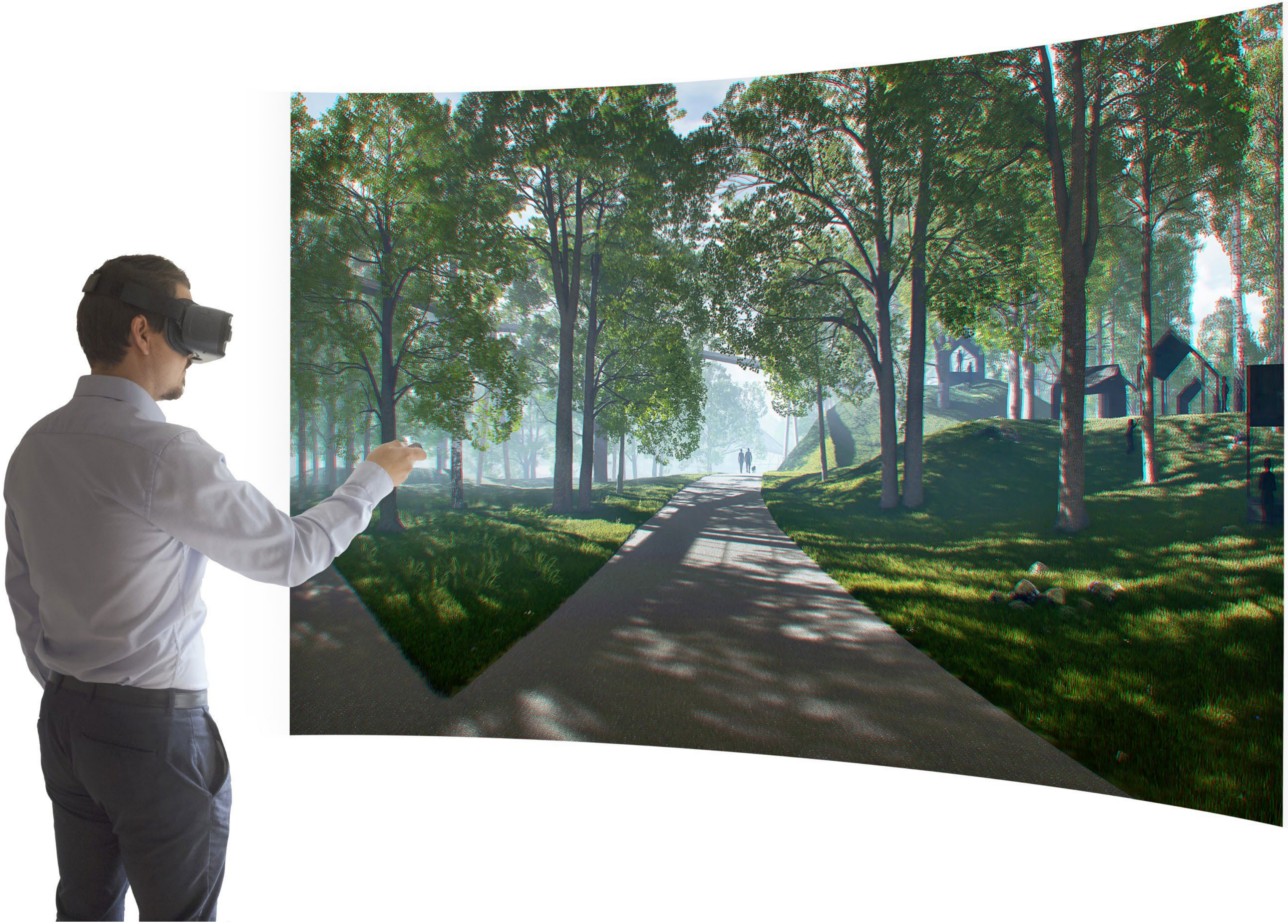


*Figure 19. Collage illustrating how VR spheres are experienced*

## 1. Northern entrance

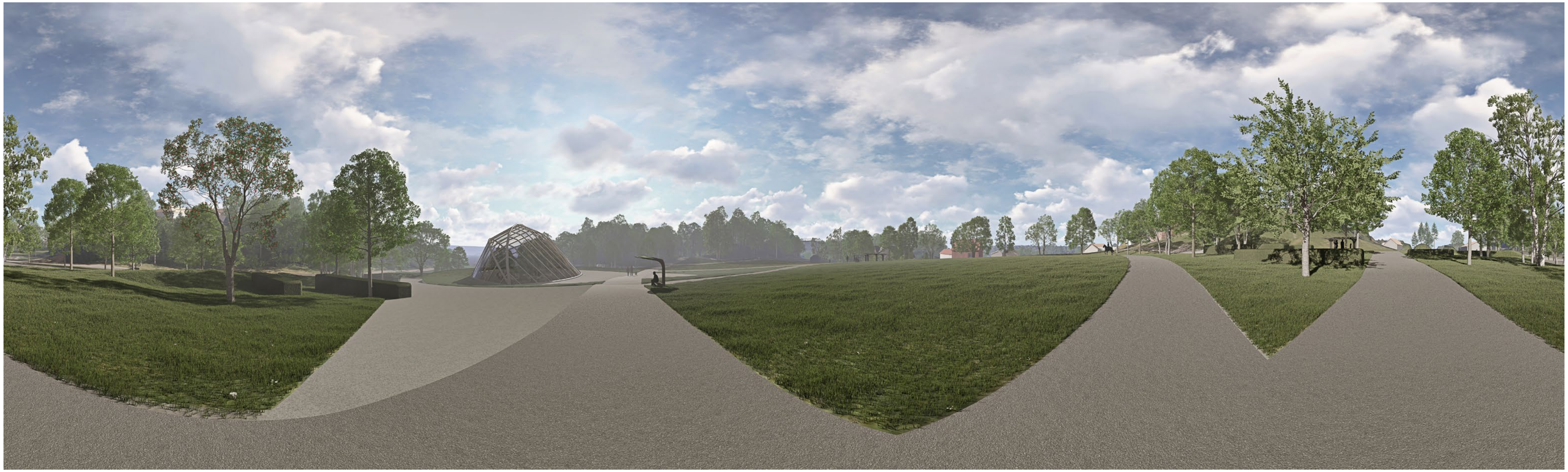


*Figure 20. VR sphere 1*

This VR sphere presents the first path division after entering from the northern gate. Some issues addressed are:

- Is the main path more, or less appealing than the sidepaths?
- is the northern exit of the park apparent if signposts are not present?
- Do trees planned behind the research building obstruct the view to the harbor and sea?
- Is the central space too large for a clear spatial definition?

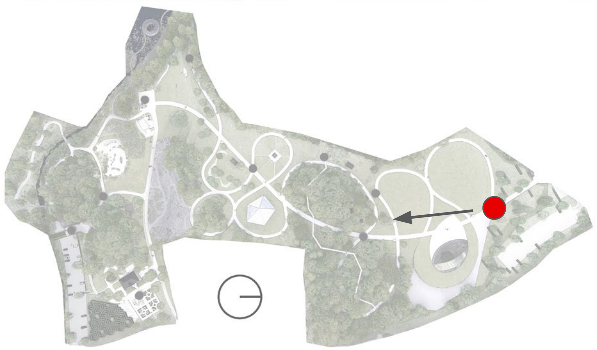


*Figure 21. Closer view of two important spatial transition areas*

## 2a/2b. Meeting point of northern side paths

*Figure 22. VR sphere 2a*

This viewpoint shows an unresolved area where two looping paths nearly encounter each other, but not do overlap.

- How can the two paths remain separate, yet allow users to move between them without weakening the grass?
- What is the effect of removing existing trees, which obstructs the view towards the nearby agricultural landscapes?
- Is the northern exit apparent as one arrives from the southern area?

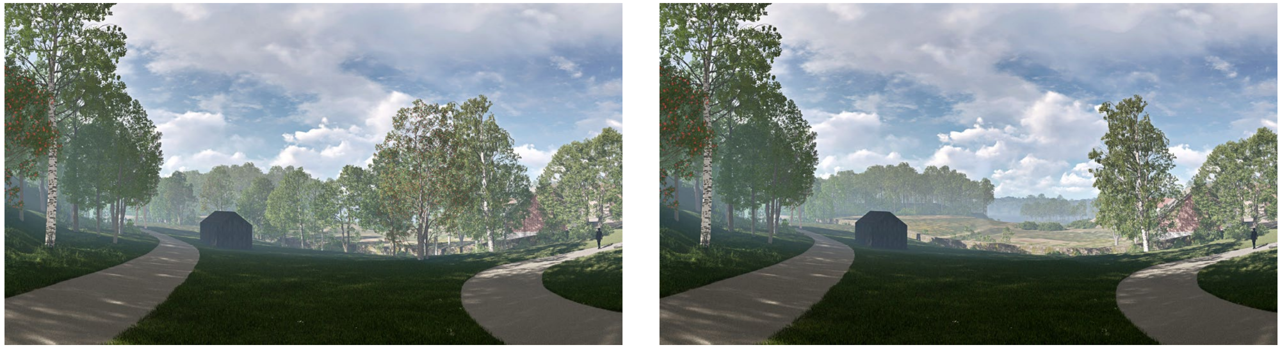
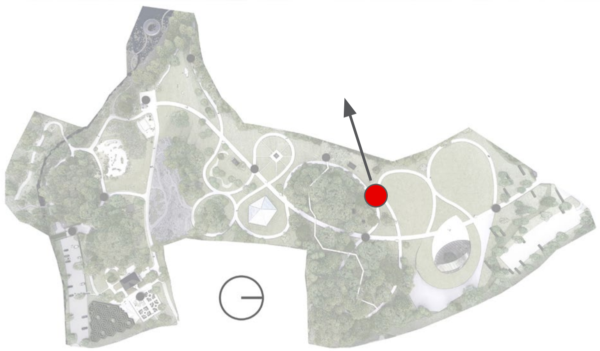


*Figure 23. Closer view towards the agricultural landscape, before/after removing the trees currently growing along a dry-stone fence.*



3. The elevated tree crown path

*Figure 24. VR sphere 3*

This VR sphere takes viewers up to a proposed platform at the end of the tree crown path.

- Can one get a good overview of both the southern and northern half of the garden simultaneously from this spot?
- Is the vista within and outside the botanical garden impressive enough to warrant a viewing platform?
- Do trees along the stone fence to the west obstruct the vista?

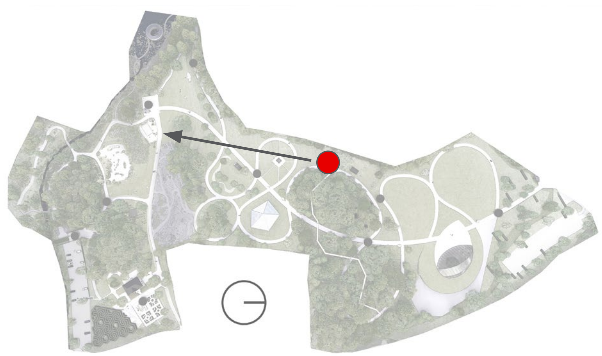


*Figure 25. Removing a proposed tree would reveal the Japanese Garden pavilion.*

## 4a/4b. The rainforest

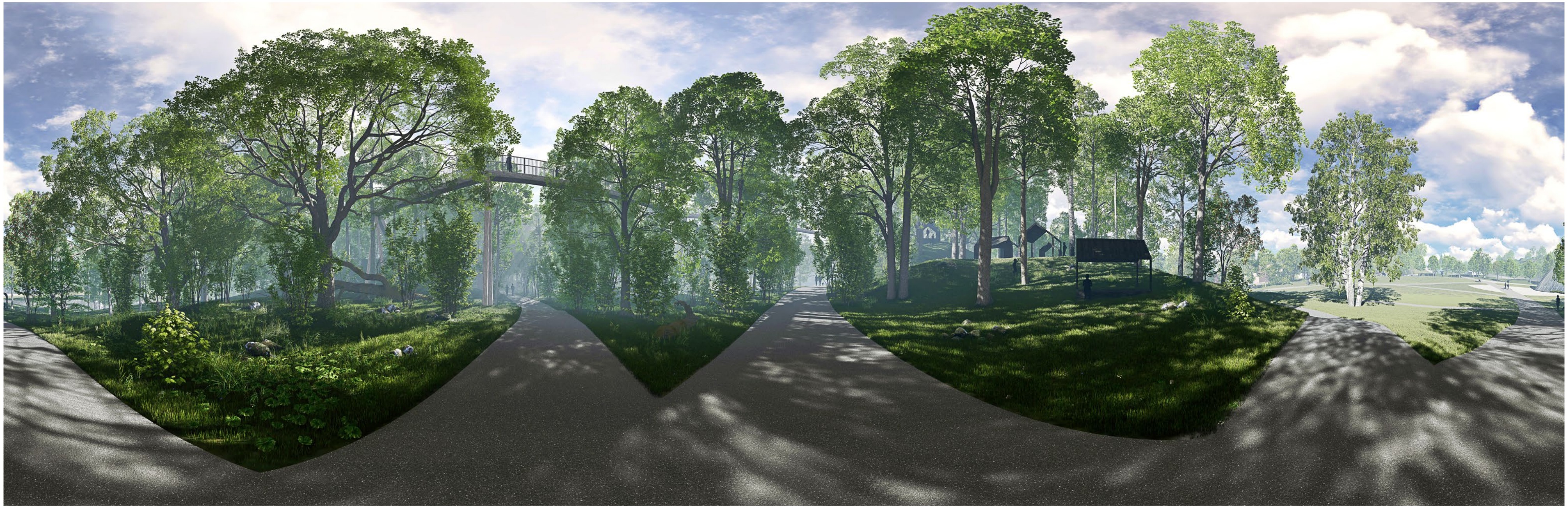


Figure 27. VR sphere 4a

"Rainforest" and "children's forest" area, with the elevated path.

- Should the dense understory be kept, or partially/entirely removed to create a managed and park-like forest?
- Does the "children's forest" play area feel safe and appealing?
- Is the northern exit apparent as one emerges from the southern part through the main path?

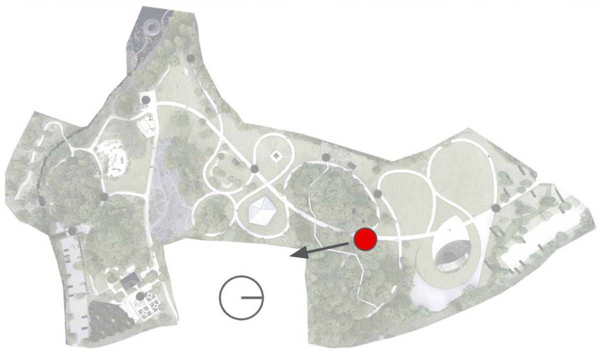


Figure 26. Comparison of dense and open alternatives.

## 5. Central region observed from main path.

*Figure 28. VR sphere 5*

- Is the transition between this space and the amphitheater space near the lake well defined, or too diffuse?
- Is the transition to the alpine garden clear and inviting?
- Does this area feel well defined and legible, or is it too busy? Should trees be planted in a less random pattern?
- Does the current design of the greenhouse appear too large and dominating for the site?

*Figure 29. View towards southeast and the alpine garden.*

## 6a/6b. Park observed from southern entrance

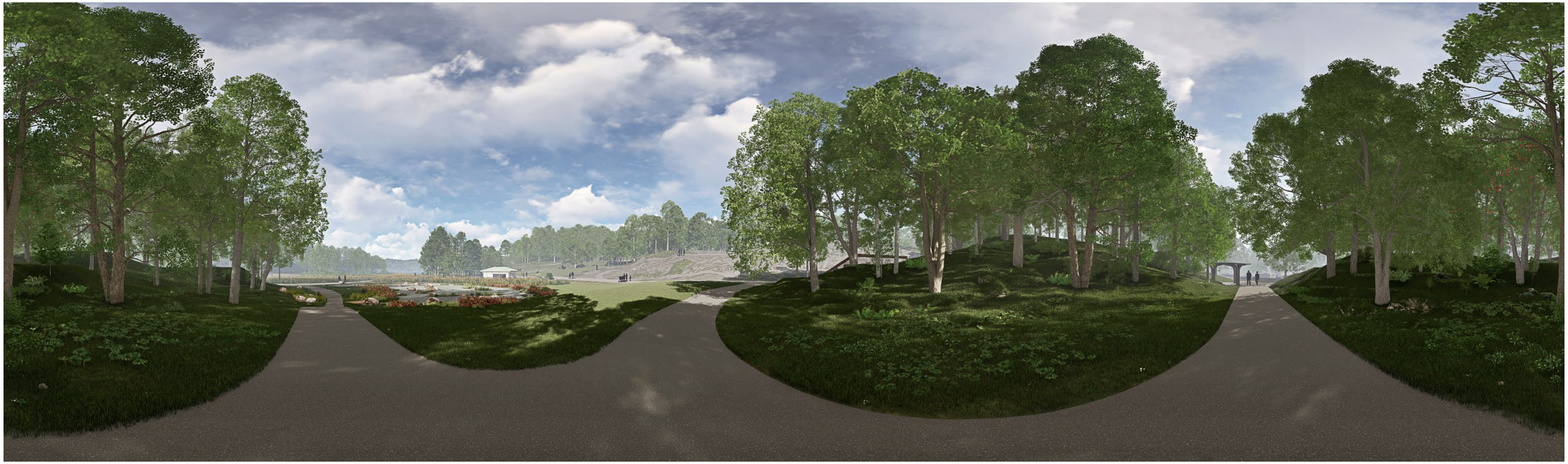


*Figure 29. VR sphere 6a*

- Is the lake and sculpture visible, or obstructed by topography/ vegetation as one enters park from the southern entrance?
- Do the pavilions, structures, Japanese garden and metal sculpture compete too much for attention?
- Is the southern exit area apparent?
- Are focal points clearly visible, or do they blend in with the background?

*Figure 30. The lake is barely visible in the background. The sculpture is obstructed by trees but could be made visible by removing some planned and existing (currently small) trees.*

## 7. Southern gate area.

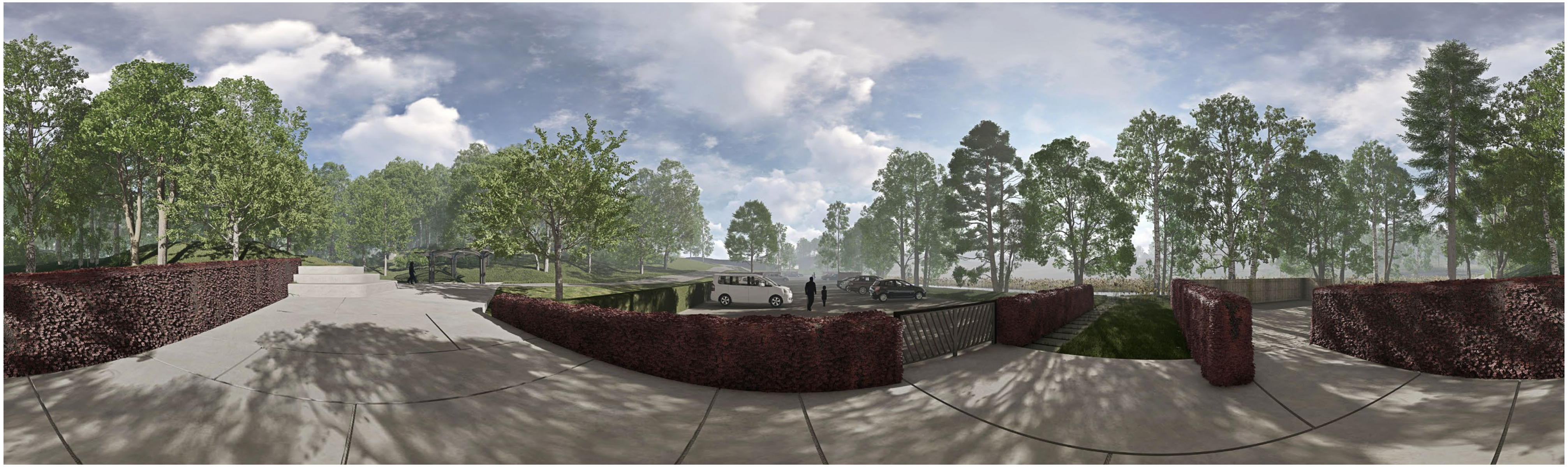


*Figure 31. VR sphere 7*

Although the southern entrance is retained, this area is largely re-designed. The intention of the hedges, amphitheater steps, and pavilion is partially to draw people towards the north-western part, rather than the original path heading southwest into the unaltered part of the botanical garden.

- Is the new path towards the northwest inviting, or does the original path remain more attractive?
- Do the old and new materials work well together?

*Figure 32. New path into the site. Do the steps feel relaxed and inviting, or create a visual barrier?*

## 8. Amphitheater scene area

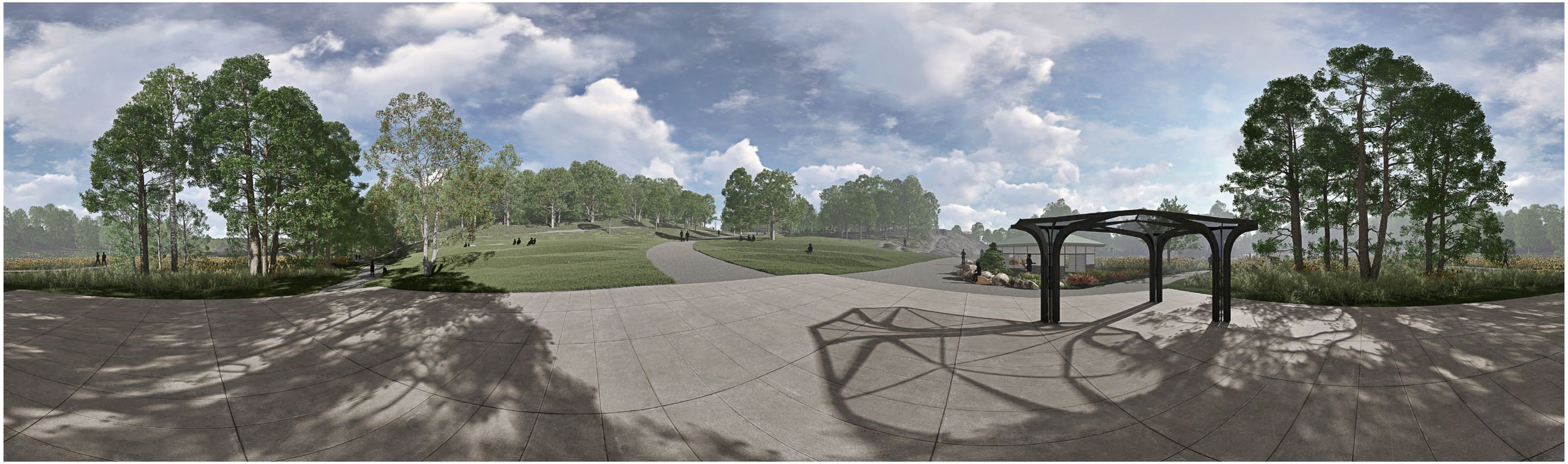


*Figure 33. VR sphere 8*

- How does the pavilion structure work visually? Are chosen materials appropriate for the site?
- What is the effect of the amphitheater created on the grass-covered hill? Should there be fewer and larger steps or higher number of smaller steps?
- Is this area clearly defined and legible, or too chaotic?
- Is the transition to the central part visually clear and inviting?

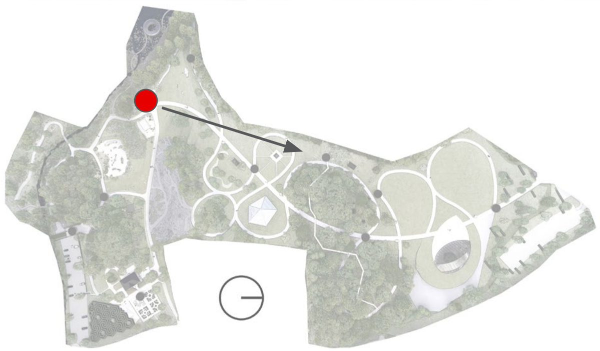


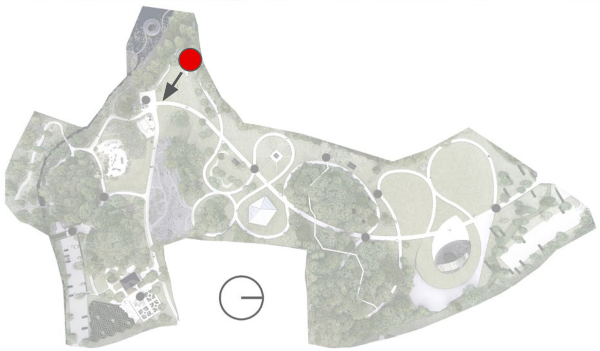
*Figure 34. The transition between the southern and northern areas. The sky is brought down to the horizon by moving some planned trees. Tree crown path becomes visible. (Comparison of earlier and later VR spheres)*

## 9a. The path to the lake

*Figure 35. VR sphere 9a*

- Do trees close off the connection to the lake and shade too much, or are they needed for a clear spatial definition?
- What is the visual effect of amphitheater steps and scene from above?
- Is lake path on each side of the metal sculpture visible as one approaches?

*Figure 36. Effect of shadows at 7 PM in late August, with and without alder trees along the lakeshore*



## 10. Baroque garden and labyrinth

*Figure 37. VR sphere 10*

- Does everything look as expected?
- What is the visual effect of the *parterre* and labyrinth?
- Is line of sight towards harbor and sea maintained?

*Figure 38. Entrances to labyrinth appear barely visible as the yew hedge is backlit at 12PM.*

## Discussions with project leader

I sat down with the project leader to discuss what impact the use of HMD VR had on the project. This discussion is summarized here:

- VR was particularly useful to understand the effect of built elements such as buildings and pavilions on the site. Their size, shape, placement in the landscape, materials etc. is difficult to predict, and surprises were uncovered.
- Although the purpose of the VR spheres was for internal use at the office, the VR spheres were shared with the clients from the botanical garden/University of Bergen during meetings. This reportedly had an obvious and constructive impact on group discussions. Participants loosened up, imagination was given a freer range, and partakers became more positive in general. It should be noted that participants on the client side were professionals within fields such as botany, communication, and planning, and could be considered part of the design team.
- From the perspective of the project leader, the most valuable use of HMD VR is collaboration (across professional backgrounds and interests), spurring debate and achieving a shared vision.
- Overall, the use of VR was clearly beneficial to the project, and worth the additional time expenditure.

## Time expenditure

Approximately 300 hours of work were allocated to landscape architecture for the schematic design phase of the project, with a total of about 1000 hours for landscape architecture across all phases (funds for other purposes than designing, e.g. traveling are subtracted from this sum).

It took 78 hours to create the 3D model, and to update it based on feedback from the team. When subtracting time spent exploring alternative methods of modeling and making amendments to the model based on feedback, about 45 hours were realistically spent creating the initial 3D model. This includes the various steps in SketchUp, Lumion, and Photoshop.

Approximately 6 hours were expended on top of this preparing, generating and sharing the VR spheres. This does not include time spent on overnight rendering (high quality and resolution VR spheres take longer to generate but can be queued and rendered overnight).

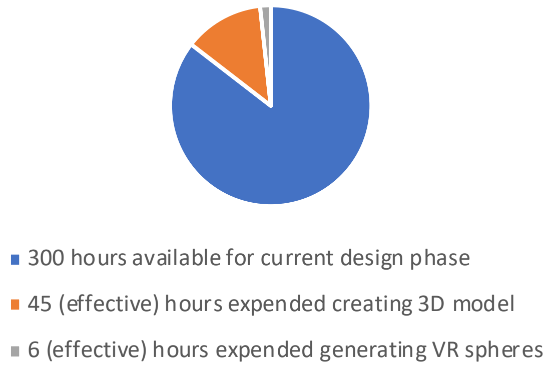



*Figure 39. Time expenditure on 3D model and VR sphere*

## VR spheres selected for the survey

While conducting pilot interviews with landscape architecture students, it became clear that presenting all 10 VR sphere viewpoints would be highly time-consuming and not practical. For this reason, 4 viewpoints were selected (presented on page 53), which shows at least one examples of each specific design-related question discussed in chapter 4 (page 18). These are the VR spheres 3, 4, 8 and 10. In addition, sphere 4 was presented in 3 different levels of detail/realism (Figure 68 on page 57).

# Presented material

To help participants understand the site and assess the realism of the VR spheres, five photographs from relevant areas were presented during the VR demonstration (presented below).

3 plan views were presented to the participants when explaining the project: Current situation, new plan with VR spheres positions and simplified plan highlighting relevant issues.

*Figure 40. Japanese garden pavilion*

*Figure 41. Location for amphitheater steps*

*Figure 42. Forest interior with large oak trees (unused forest)*

*Figure 43. Dense undergrowth. (unused forest)*

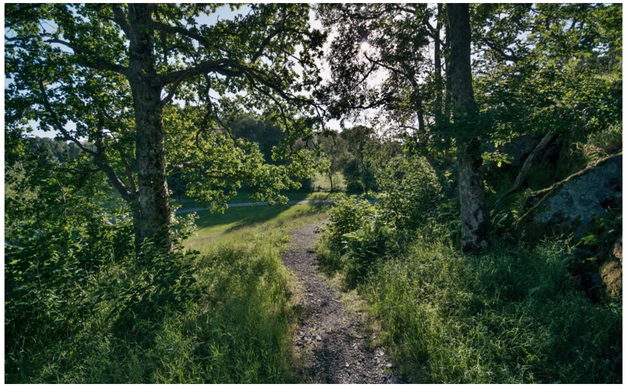


*Figure 44. Site for elevated tree crown path (ground level)*

*Figure 45. Current situation. ©2018 Google, ©2018 Bergen Kommune*

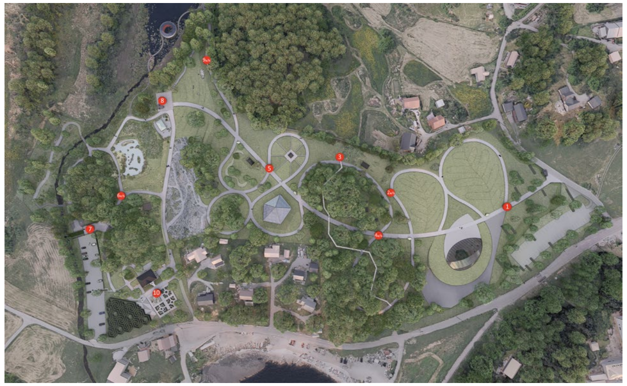


*Figure 46. New plan*

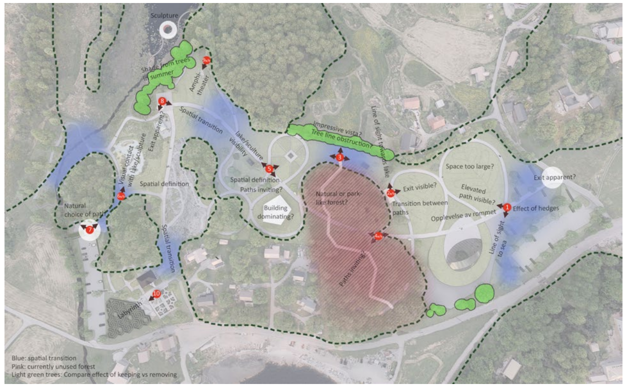


*Figure 47. New plan with relevant issues emphasized*

# 7 RESULTS

Participation rate: 18/24.

Questions will be presented in the same order as they were asked but will be discussed thematically in the next chapter. Results are presented using various types of diagrams to emphasize relevant aspects such as the ratio between answers and distribution of scores. Interesting and representative comments are added after to each question. All direct quotes are paraphrased.


*Figure 48. Distribution of years of design experience (years since graduation) among the survey respondents. (n=18 respondents)*

## Question 1

Which of these, if any, best describes your own design process? (Alternatives are briefly described verbally and presented visually)

**Alternatives**:
A. "Black box"
B. Linear
C. Iterative
D. Explorative
E. Iterative x explorative

Participants were generally quickly able to identify with one or more alternative. Only one participant described their design process as occasionally being linear (B). Several partakers described using different design processes on different projects, depending on the complexity of the task.

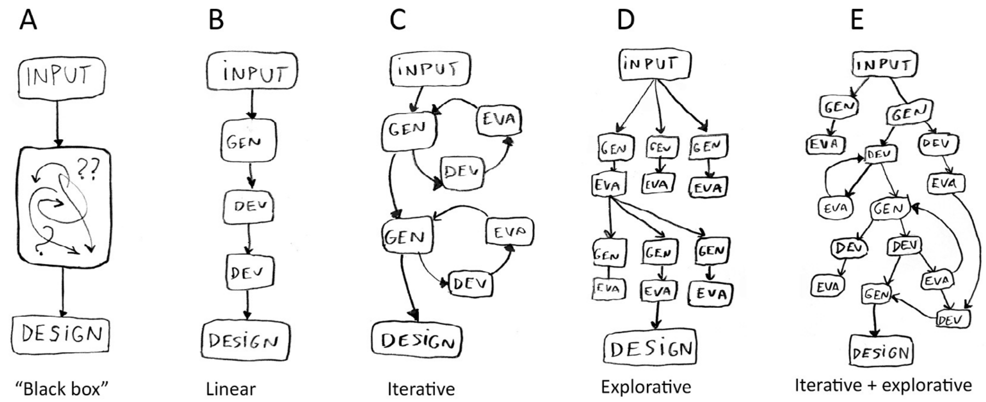



*Figure 49. Suggested design processes*

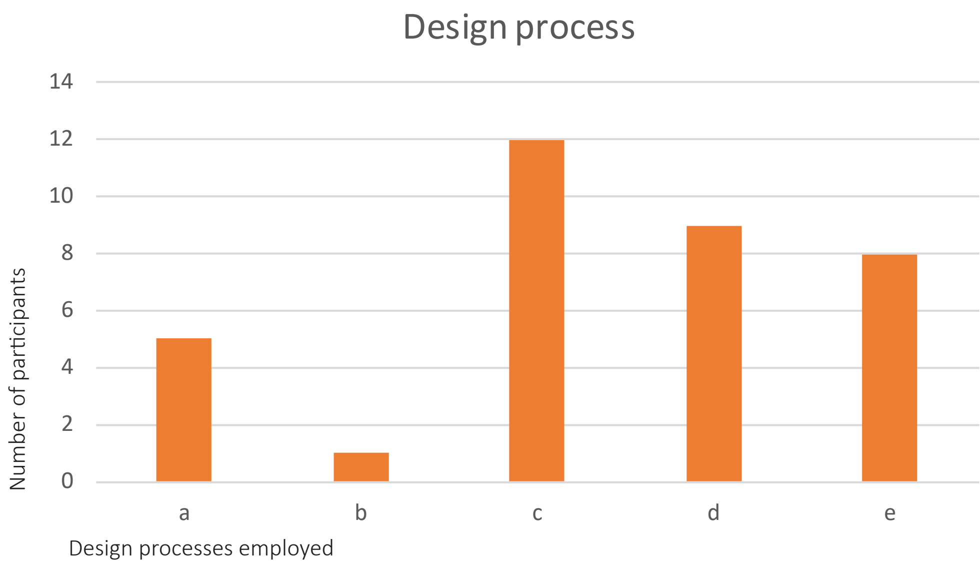



*Figure 50. Design processes employed by participants. (n=18 respondents)*

## Question 2

Which work methods do you use daily?

## Question 3

Which work methods do you use occasionally?

**Alternatives**:
A. Hand Drawing
B. Physical model
C. 2D CAD
D. Digital 3D

None of the participants stated that they use physical models daily or occasionally, although some added that they used physical models very rarely. 16 of the 18 participants use 2D CAD daily, while half of partakers use digital 3D models daily.

> *"I miss using physical models, as we did when studying. You get a feeling of what you are doing. We could potentially work with physical models, but it is highly time-consuming. The clients do not want to pay for physical models".*

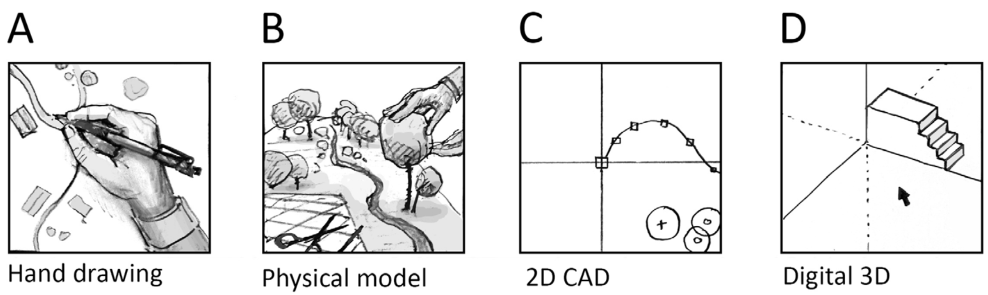



*Figure 51. Suggested common work methods*

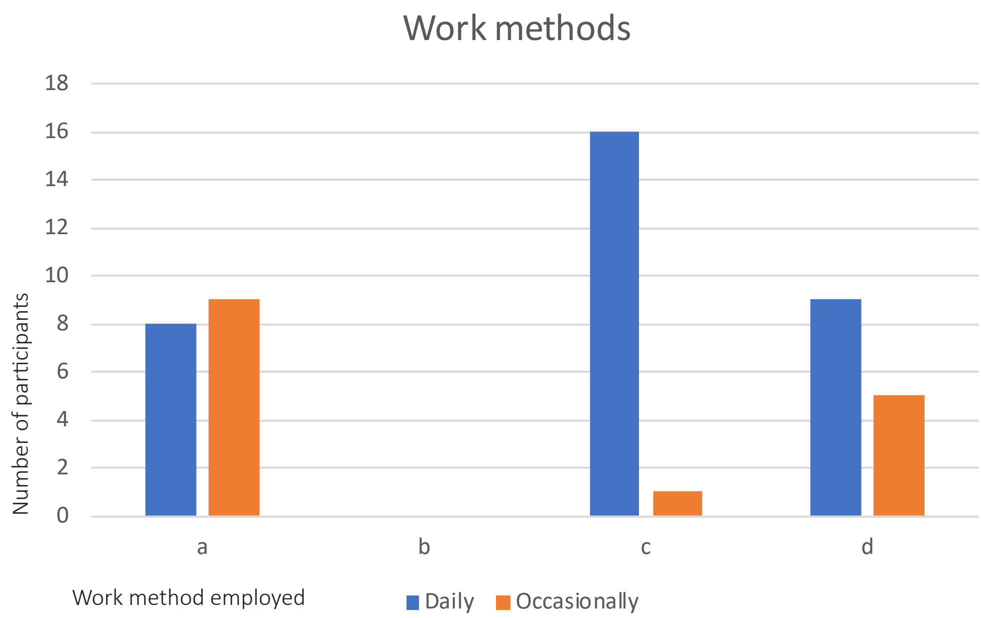



*Figure 52. Work methods employed by participants. (n=18 respondents)*

## Question 4

Which of these techniques do you commonly use to evaluate designs/ideas?

A. Mental imagery
B. Sketch drawing
C. (Physical) Sketch model
D. 2D CAD
E. Digital 3D model
F. 3D rendering
(Or other)

All 18 participants reportedly use mental imagery to evaluate design ideas. In addition, sketch drawings, 2D CAD and digital 3D models are used by more than half of participants.

> *"Once you have enough experience working with plans, you can easily imagine things in 3D"*

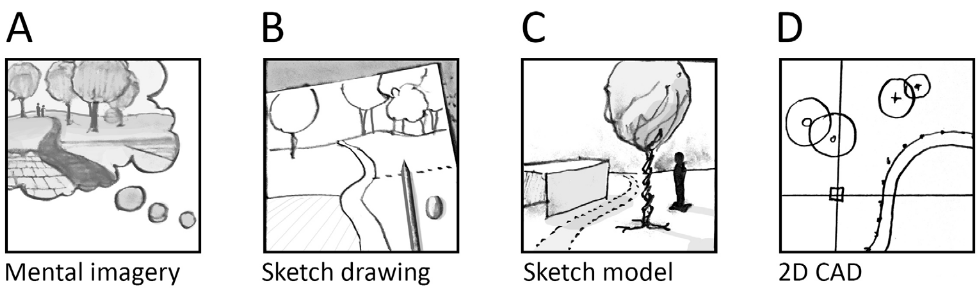



*Figure 53. Suggested common evaluation methods*

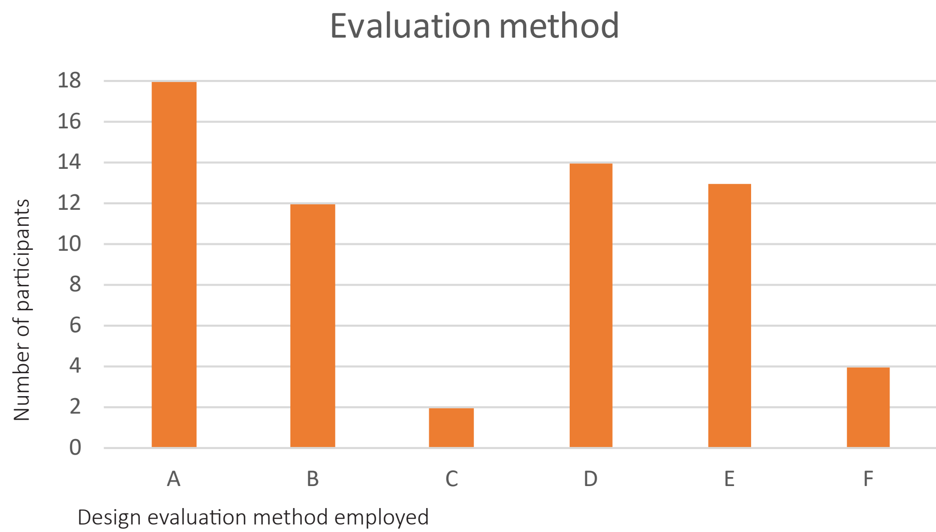



*Figure 54. Methods for evaluating design ideas employed by participants. (n=18 respondents)*

## Question 5

Are you familiar with the concept of Virtual reality?


*Figure 55. Familiarity with the concept of VR*

## Question 6

Have you gone through a virtual reality experience before?

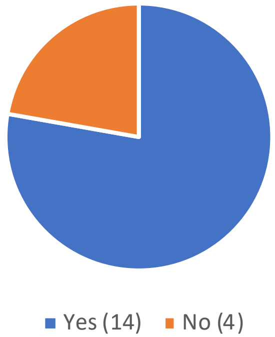



*Figure 56. Personal experience with VR*

## Question 7

Have you used VR tools in your design work before?

Although 14 of 18 participants had experienced VR, only one has used it for professional work.

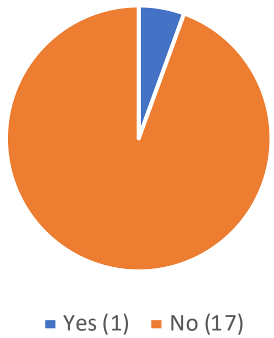



*Figure 57. Professional use of VR*

### Question 8

How useful do you expect VR to be in your design process?

**Alternatives:**
1-10 scale, don't know

1 = not useful at all
10 = enormously useful

Scores and comments reveal varying levels of expectations for VR, from low expectations to very high.

The average score was 7.5.

*"I am skeptical. We are trained to use and communicate using simpler methods. The technology can become a hindrance."*

*"It depends on how much experience one has. Someone new to the field will benefit a lot more. Fresh designers can have difficulties visualizing projects mentally. As you get more experience, you get better at visualizing."*

*"VR could be used similarly to Google Street View in the early stages, to gather information."*

*"I believe it may become a necessary tool."*

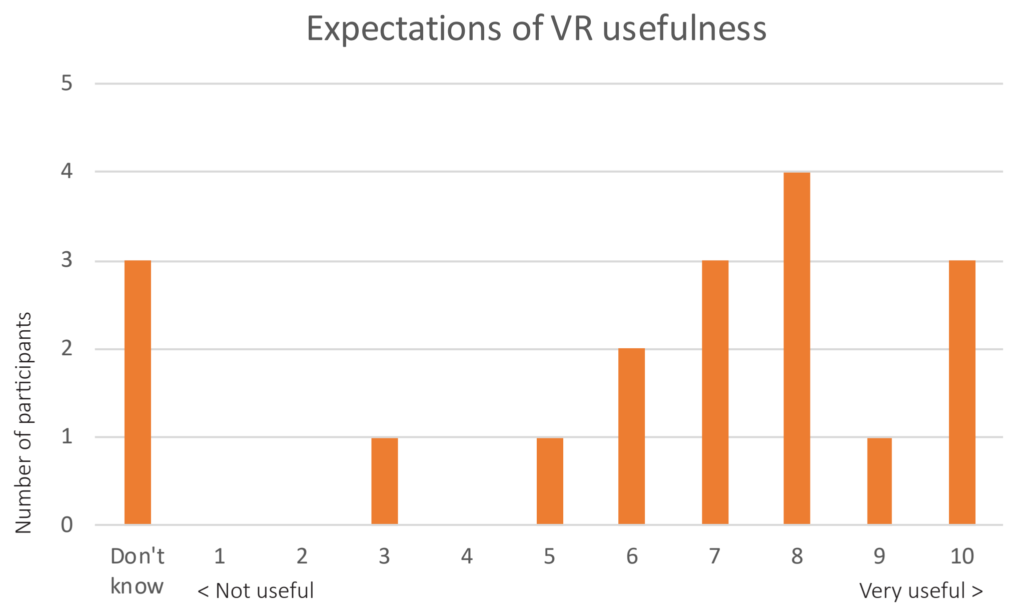



*Figure 58. Expectations that VR can be useful during design process, before demonstration (n=18 respondents)*

## Question 9

Why do you imagine VR is not more widely used within landscape architecture?

Participants gave a range of possible reasons explaining why VR is not more widely used. These were categorized and counted.

VR technology is very recent:
6 mentions

Landscape architects are slow to adopt new technology:
5 mentions

Not proven useful for landscape architecture:
4 mentions

Knowledge about VR is lacking:
4 mentions

Prohibitively time-consuming to learn:
4 mentions

Prohibitively time-consuming to use:
3 mentions

High initial threshold/expensive technology:
1 mention

*"VR is a relatively recent technology. I am sure it will be much more widely used in the future. Also, perhaps VR is not well adapted to landscape architecture work methods"*

*"I have not seen any good examples of practical applications (...) It is fun, but what do you gain form it?"*

*"I think it is because landscape architects lag behind when it comes to use of 3D tools. Most professionals studied 10-15 years ago, drew by hand, then worked to get into 2D CAD. It is already difficult getting over to 3D. VR is even more advanced."*

*"Landscape architects already have a lot to master. It is a broad field. We can't master everything."*

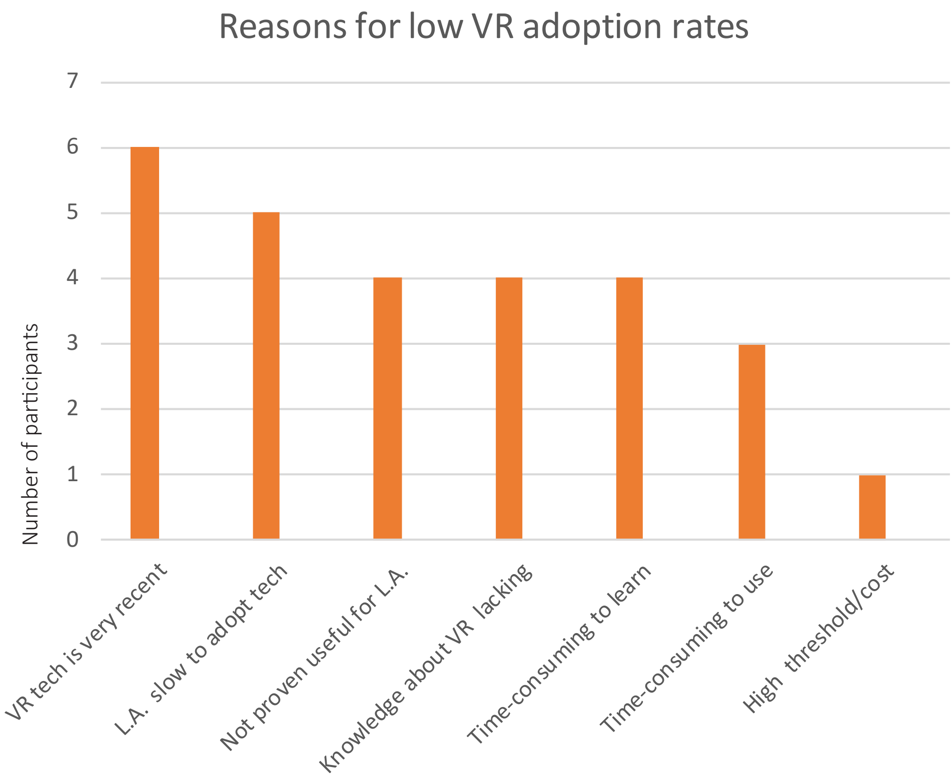



*Figure 59. Explanations as to why VR is not more widely used within Landscape architecture (n=18 respondents)*

### Question 10

How familiar are you with the botanical garden at Milde?

### Question 11

How familiar are you with the ongoing botanical garden redesign project?

**Alternatives:**
1-10 scale

1 = not familiar at all
10 = very familiar

Most participants had heard about the project through a presentation at a gathering in Sandvika.

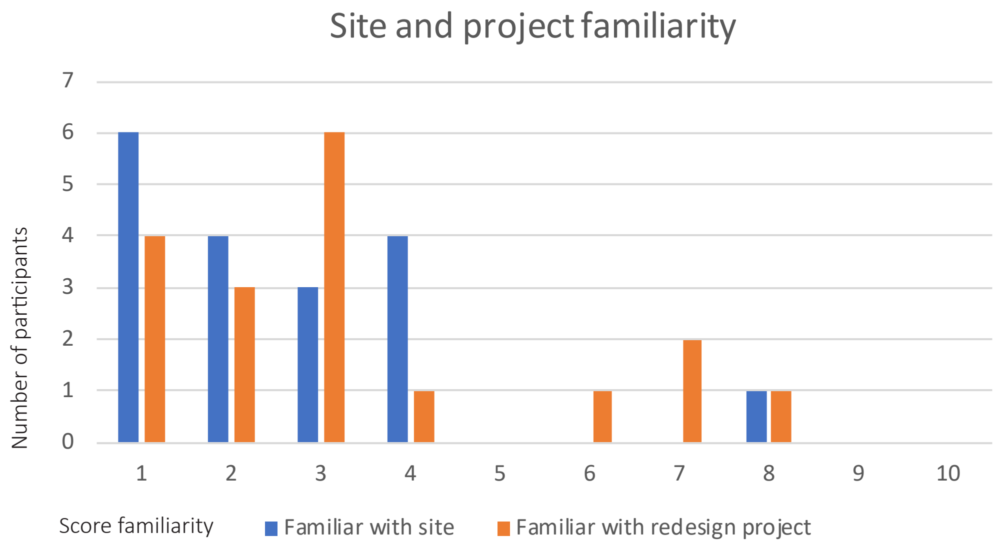



*Figure 60. Participant familiarity with the project and site prior to survey (n=18 respondents)*

## Question 12-22

VR spheres 3, 4, 8 and 10 were presented to demonstrate how VR had been used to examine the issues listed below. A relevant VR sphere accompanies each question.

If added to your current workflow, would this tech likely improve your ability to:

12. Evaluate whether spaces are legible and well-defined

13. Evaluate the effect of design decisions on site topography

14. Evaluate the visual effect of built elements (Materials, shape, placement etc.)

15. Evaluate the effect of design decisions on lines of sight within site

16. Evaluate the visual effect of focal points

17. Evaluate the effect of sunlight and shadows

18. Evaluate whether spaces feel appealing and safe or not

19. Evaluate your choice of vegetation

20. Evaluate how users will experience navigation on site

21. Discover unexpected issues before construction

22. Evaluate the effect of design decisions on external vistas/ borrowed views

**Alternatives:**
1-10 scale.

1: Not likely
10: Very likely

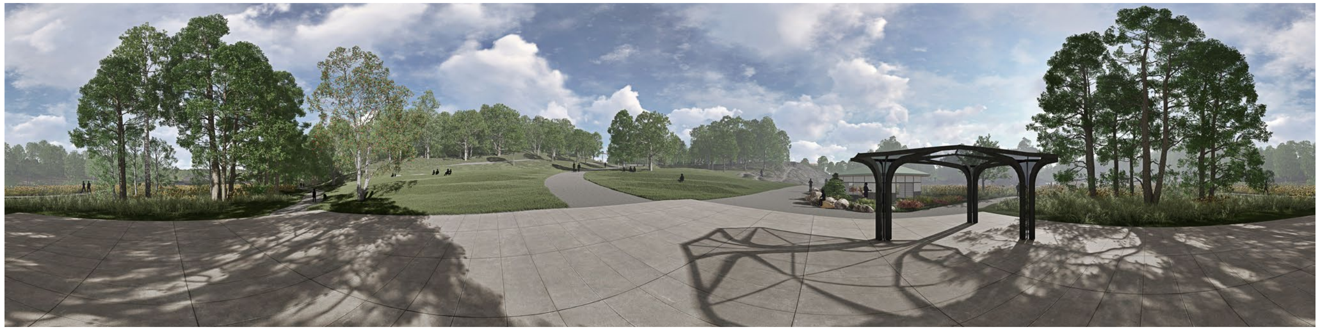


*Figure 61. Sphere 8: Questions related to legibility, topography, lines of sight, focal point, light and shadow (two alternatives with different sun position)*

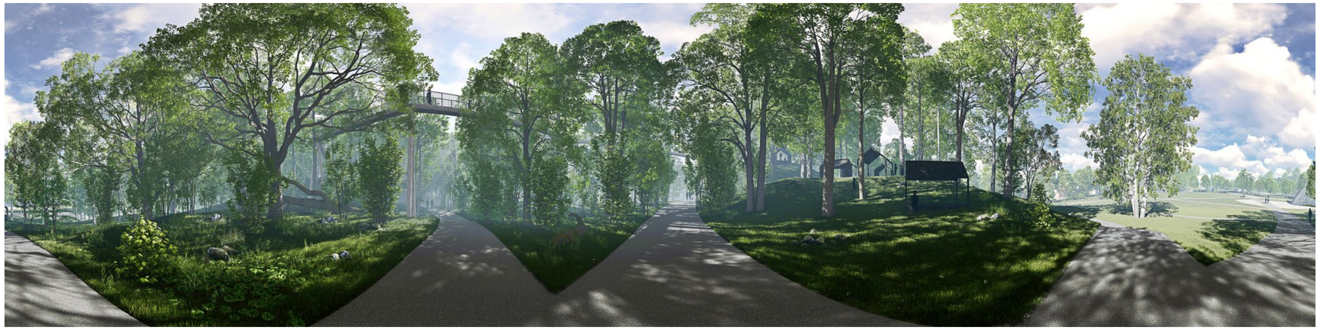


*Figure 62. Sphere 4a/4b: Questions spaces feeling safe & appealing, choice of vegetation and navigation (two alternatives: undergrowth shown/hidden)*

*Figure 63. Sphere 10: Question related to discovering unexpected issues*

*Figure 64. Sphere 3: Question related to external or "borrowed" vistas. (Three versions were presented with varying level of detail/realism)*

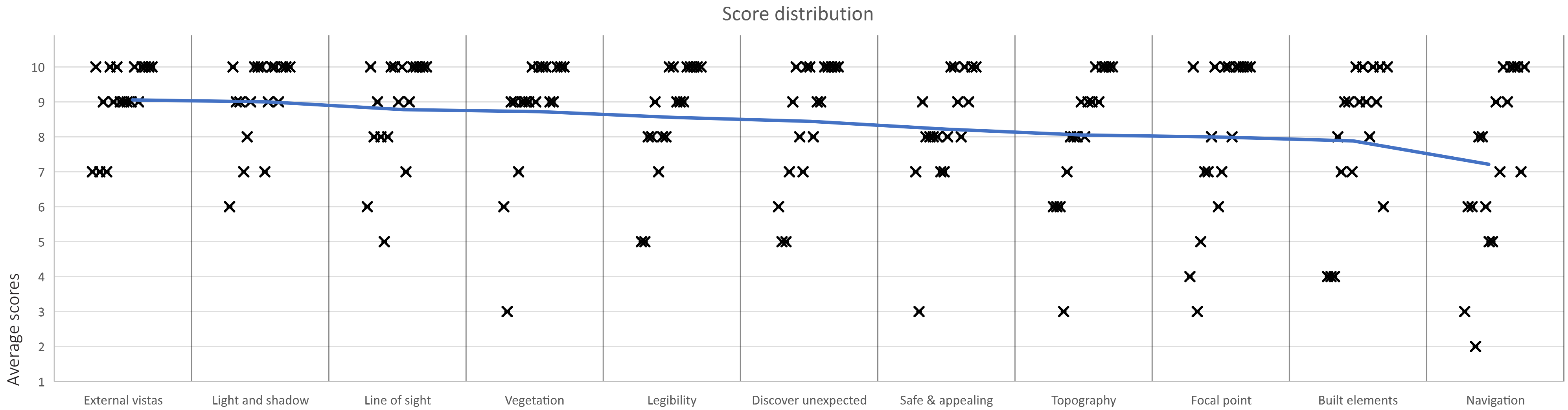



*Figure 65. Score distribution for the suggested uses of VR spheres demonstrated using the case study. Ordered from the most to the least highly rated suggested use.*
*(n=18 respondents)*

q. 12. Evaluate whether spaces are legible and well-defined
Average score: 8

*“It is said that landscape architects see the world from plan view and forget about this. So, this is really useful.”*

*“The larger scale a project has, the more important VR can be. In a landscape like this, it is much more useful than in a small space, like a public plaza. I think this would be extremely useful for our roadworks projects. Reading larger landscapes, seeing how tree plantings affect spatial definition.”*

*“I get a lot of information from reading the plans. This does not help me to understand the scheme.”*

q. 14. Evaluate the visual effect of built elements
Average score: 7.9

*“The world is colored as realistically as possible, so one can see items against their surroundings”*

*“I would not trust this. I would rather have a material sample” (to evaluate materials)*

*“It looks rather artificial, but is better than other tools we have”*

q. 16. Evaluate the visual effect of focal points
Average score: 8.1

*“You can test this aspect (using VR) in ways you couldn’t do otherwise. Except using mental imagery, which improves over the years.”*

*“Great potential. One can see on the plan that the trees might be in the way, but to stand here and look with VR headset is much better.”*

*“This is complex, because it depends so much on what happens in the brain of the designer”*

q. 13. Evaluate the effect of design decisions on site topography
Average score: 8.1

*“You could get this topographical information readily from a section drawing. This probably varies a lot with the spatial understanding of the designer”.*

*“My 3D models do not display much subtle topographical features. This works a lot better, because you have textures, shadows etc.”*

*“I can’t use this to understand how water will run, etc. This is more useful to sell ideas.”*

q. 15. Evaluate the effect of design decisions on lines of sight within site. Average score: 8.8

*“I think I could read this (lines of sight) from a plan. VR could work well to control your assumptions from the 3D model.”*

*“This is a game-changer”*

*“Lines of sight are equally clear when using SketchUp”*

*“What is so great is that you achieve eye height, in relations to the landscape around”*

q. 17. Evaluate the effect of sunlight and shadows
Average score: 9.1

*“Best tool for this purpose.”*

*“Great effect. You can really see it. I think you forget quickly how the sun moves (throughout the day).”*

*“10 - Assuming that the tree height is accurate”*

*“I could have shown this in 2D. But now that you see it so clearly, you (...) don’t feel like sitting there (in the shade)”*

q. 18. Evaluate whether spaces feel appealing and safe or not
Average score: 8.3

*“Everything in Lumion feels somewhat appealing. So this could be, but it is not necessarily an accurate representation of how the vegetation would turn out.*

*“This is the kind of thing you can’t judge from a plan.”*

*“It depends on how much work you put into Into the model. Here, VR can be used to evaluate to a very high degree. A half-ugly SketchUp model would not be as useful.”*

q. 19. Evaluate your choice of vegetation
Average score: 8.8

*“You experience the difference very clearly (With and without undergrowth)”*

*“There are two factors – that the vegetation is 3D (stereoscopic), and that it grows (can be shown in stages).”*

*“You experience the size of trees very clearly, compared with other tools. You also get a feeling of lushness. Which I could also have visualized mentally, but (…)“*

q. 20. Evaluate how users will experience navigation on site
Average score: 7.3

*“A (2D) illustration would have been better for distant elements. The VR presentation lacks information (Limited resolution).”*

*“I have 25 years’ experience of looking at maps. Plans are easier to navigate”*

*“You can’t move around”*

q. 21. Discover unexpected issues before construction
Average score: 8.5

*"What often happens in larger projects is that one loses sight of hills that are way too steep. And becomes expensive to fix. You would uncover that kind of issue in advance if employing a VR model like this.”*

*"It must be ideal – going in and seeing it this realistically. Many things can be read from a plan. My experience is that there are a lot of things that you don’t really envisage. (Using VR) you see exactly how it will turn out."*

*“I can imagine a lot of minor issues being discovered before it is too late”*

q. 22. Evaluate the effect of design decisions on external vistas/ borrowed views. Average score: 9.1

*“You often see your own site and focus on that. Now you can consider the landscape around, which is easily ignored otherwise.”*

*“You can try to imagine things, but here you see it”*

*"There are small details you can get preoccupied with. The eye looks for errors. This is a weakness."*

*“Raises consciousness of what is out there. Great value.”*

## Question 23

(Ignoring time expenditure) which LOD conveys relevant information most clearly during early design stages?

## Question 24

(Ignoring time expenditure) which LOD conveys relevant information most clearly during late design stages?

**Alternatives:**
Realistic, intermediate, abstract

Participants were asked not to take into account assumptions about different time expenditures (as these are difficult to predict), and instead focus on what conveys relevant information most clearly in order to evaluate design decisions.

Most participants found the realistic models more useful, although one third found the abstract model sufficient or superior in early stages of the design process. No partaker preferred the intermediate version for either stage.

*“I find that the abstract representation says more”.*

*"As a tool to make some quick judgement, the abstract model works well - like a hand drawn perspective sketch. But aspects such as play of light and materiality are only clear on the realistic model."*

*“I would have begun with the abstract (VR representation), then gone up from there (as the project progresses)”*

*“For use with clients, I would have been scared to use the detailed version at first. They may get preoccupied with details”*

*“To explain the project, abstract might be better. Perhaps stronger colors on focal points. It can be dangerous to give highly realistic VR models to clients.*

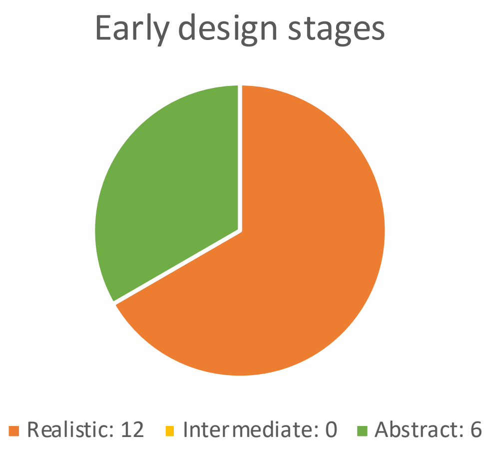



*Figure 66. Preferred level of realism, early stages (n=18 respondents)*

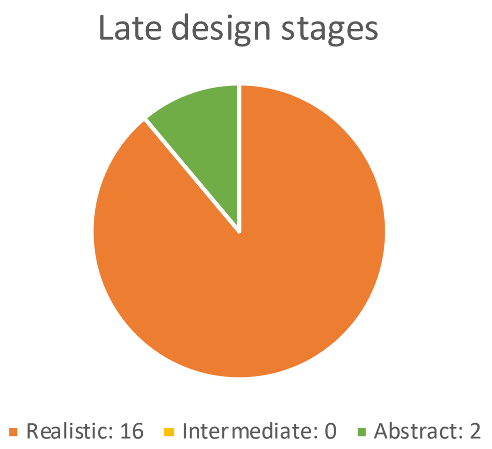



*Figure 67. Preferred level of realism, late stages (n=18 respondents)*

*Figure 68. Realistic*

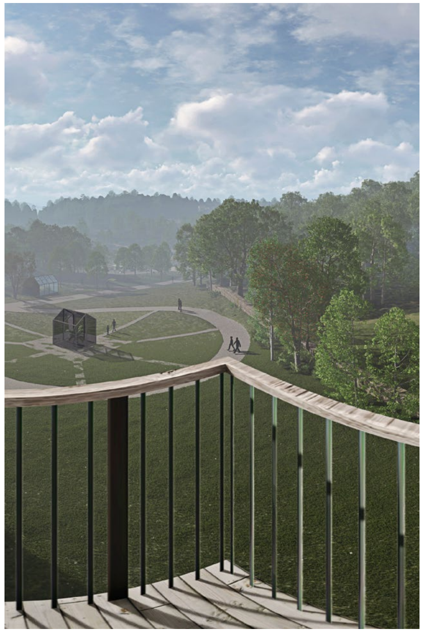


*Figure 69. Intermediate*

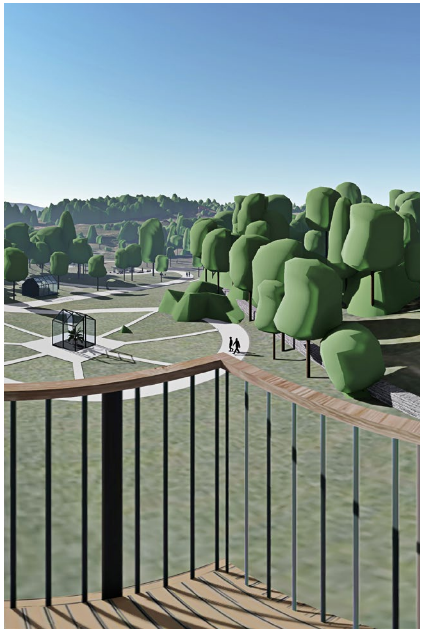
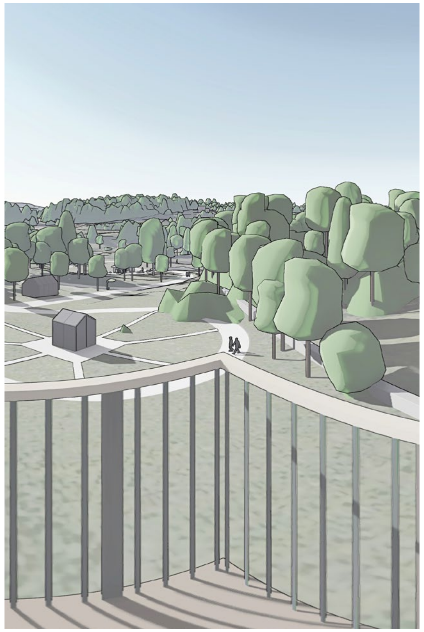


*Figure 70. Abstract*



## Question 25

How relevant do you think these kinds of evaluations are for achieving good design outcomes? (question 12-22)

**Alternatives:**
1-10 scale.

1: Not relevant
10: Very relevant

**Average score: 9.5**

*"Relevant, but I feel like they are forgotten too often"*

*"In this type of project, (VR is) very relevant. For e.g. a kindergarten project, it might be less important."*

*"It is largely what we do (as landscape architects). Lines, spatial definition, scale, experience of space"*

## Question 26

How accurately do you feel that the VR model represents the proposed scheme? (Assumption based on drawings, site photographs, site familiarity and personal experience)

**Alternatives:**
1-10 scale.

1: Not accurate
10: Very accurate

**Average score: 8.2**

*"It depends where. In the forest, I felt that it was less so than by the grass hill, where it felt very representative"*

*"You always end up with an idealized image. It's always like that with illustrations and models. This is perhaps how good it can get"*

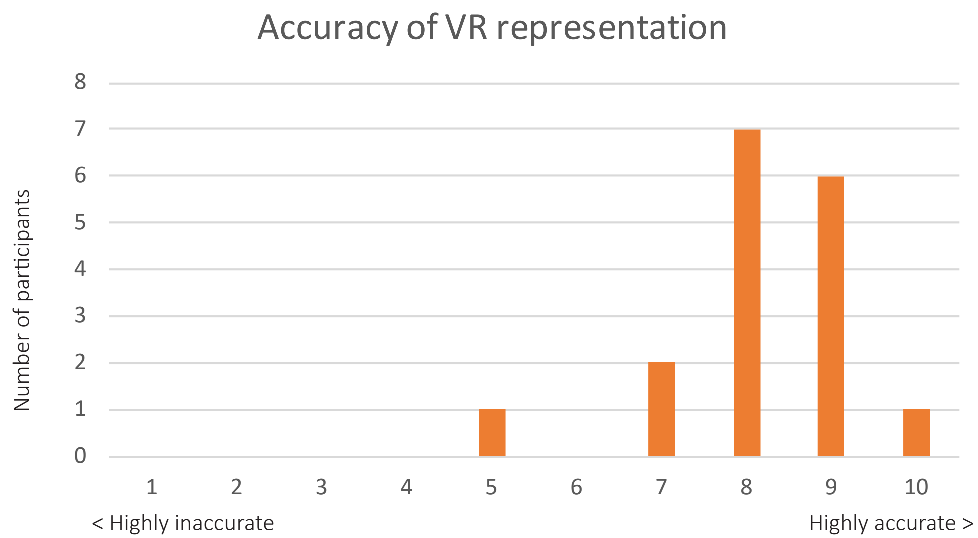



*Figure 71. Perceived accuracy/representativeness of VR model (n=18 respondents)*

## Question 27

(Having experienced VR for the case study) How useful do you expect VR to be in your design process?

**Alternatives:**
1-10 scale.

1: Not useful
10: Very useful

Average score for question 8 “How useful do you expect VR to be in your design process?” **was 7.5.**

After experiencing VR, average score **increased to 8.8**

*“I think it is one of the best tools we can adopt. I find it strange that we haven’t began using it earlier. Engineers have begun using it.”*

*“Even if you are proficient at reading spaces, this gives a lot more. It is like being in the room, instead of reading a plan”*

*“It really depends on the project. For this type of project, it is a 10. For a smaller project, it is less relevant.”*

*“I find it limiting that you can’t move around”*

*“Depends on the user, and those you need to convince. You have to ask – what do you get out of VR, when compared with just watching a screen? You get a much stronger feeling of being in the landscape using this. You forget that you are sitting in a room. However, it is not clear to me that it is more valuable than watching (the 3D model) on a screen”*

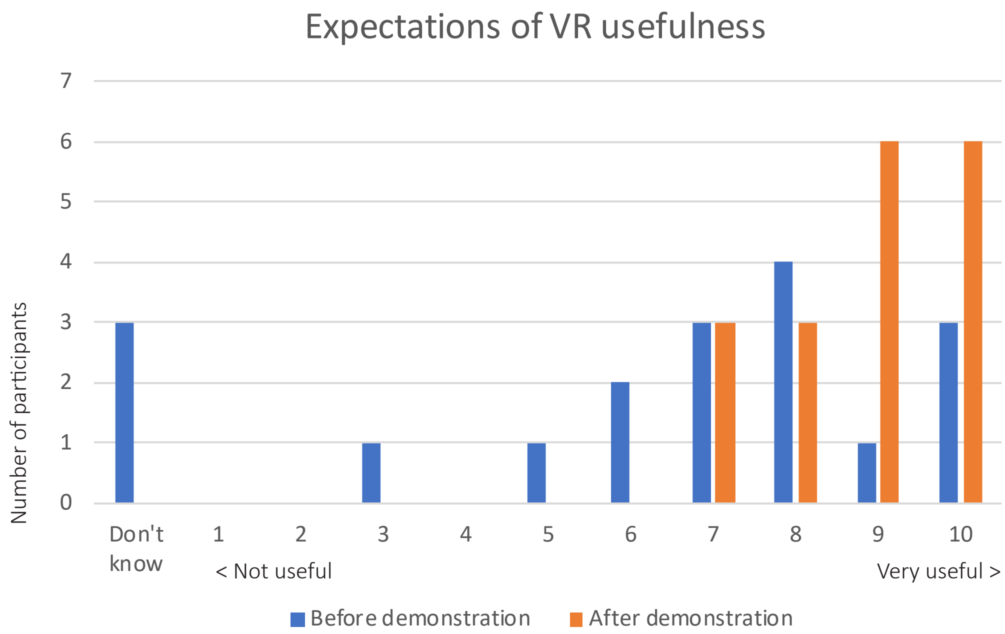



*Figure 72. Expectations that VR can be useful during design process, before and after demonstration (n=18 respondents)*

## Question 28

Is VR likely useful for sharing your vision with colleagues unfamiliar with a project for feedback?

**Alternatives:**
1-10 scale.

1: Not useful
10: Very useful

**Average score: 8.2**

*"I understand the (botanical garden) project much better after seeing it in VR. It is impossible to get the same images into the head from looking at plans and sections"*

*"It depends on which colleague I share the project with. For someone I don't know too well, it is very useful."*

*"(Using VR to collaborate) You can give feedback (on the project) directly. Otherwise, you have to imagine everything from the drawings. Even we (landscape architecture) can't really do that."*

*"We make visualization of all kinds of projects, but where things are slightly problematic, they tend to show an aerial perspective. What is interesting is seeing it in human scale."*

*"For single viewpoints, it is very useful. However, I miss moving around"*

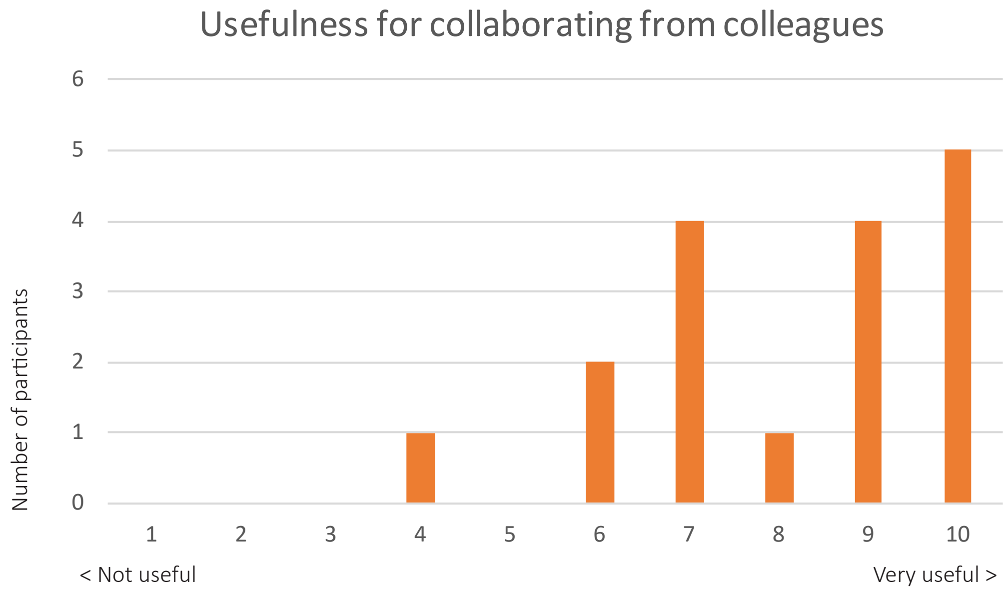



*Figure 73. Expectations that VR can be useful for sharing your vision with colleagues. (n=18 respondents)*

## Question 29

How easy was it to communicate with me while wearing the Samsung Gear VR headset?
(e.g. to locate a specific focal object)

**Alternatives:**
1-10 scale.

1: Not easy
10: Very easy

**Average score: 9.1**

## Question 30

Is VR likely to lead to a better outcome of the design process?

**Alternatives:**
Yes, no, don't know

*"At least with the current work methods. Before, one visited the construction site more frequently and could made decisions on-site. Nowadays you just hand over the data. It is important to know in advance what it will look like"*

*"You get more predictability. What is often difficult, even with a lot of experience, is scale. When you watch a plan: how will this be experienced? You get a better impression of that here (using VR)"*

*"Lots of great projects are completed without VR – one can do without. I don't feel like the design will improve. Perhaps it will improve for people with less experience. People with more experience can more easily imagine the result mentally."*

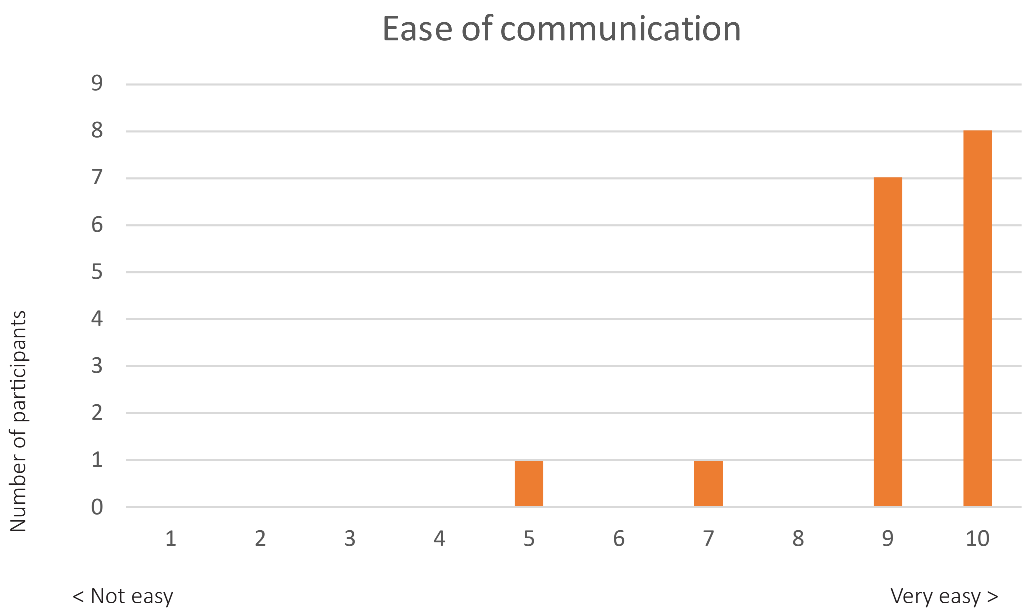



*Figure 74. Ease of communication while wearing the VR headset. (n=18 respondents)*

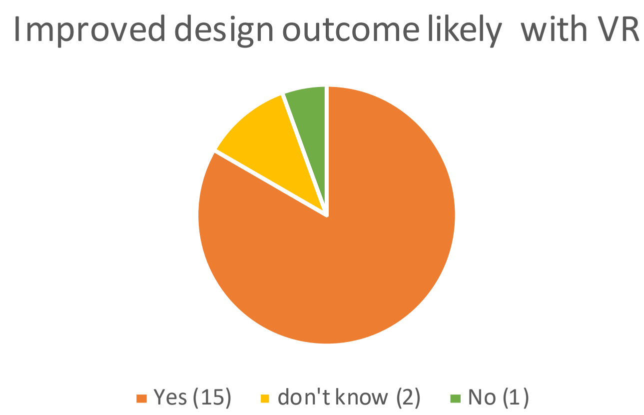



*Figure 75. Perceived likelyhood that use of VR will lead to outcome of the desing process. (n=18 respondents)*

The case study project has 300 work hours available for the current phase (early design stage). 45 hours of those were expended creating the 3D model.

## Question 31

Would you consider this time well spent? (In a typical project of this nature)

**Alternatives:**
1-10 scale

1: inefficient use of time
10: Very efficient use of time

**Average score: 9.3**

## Question 32

An additional 6 hours were spent setting up and creating the 10 VR spheres viewpoints

Would you consider this (additional) time to be well spent? (in a typical project of this nature)

**Alternatives:**
1-10 scale

1: inefficient use of time
10: Very efficient use of time

**Average score: 9.4**

Most participants found the time spent on creating the 3D model and VR spheres highly efficient, compared with alternative uses. Several participants pointed out that users less proficient with 3D modeling tools would likely expend a lot more time.

> *"We should be working with 3D models anyway. I don't find 45 hours to be a lot."*
>
> *"45 hours is unrealistic for many users"*

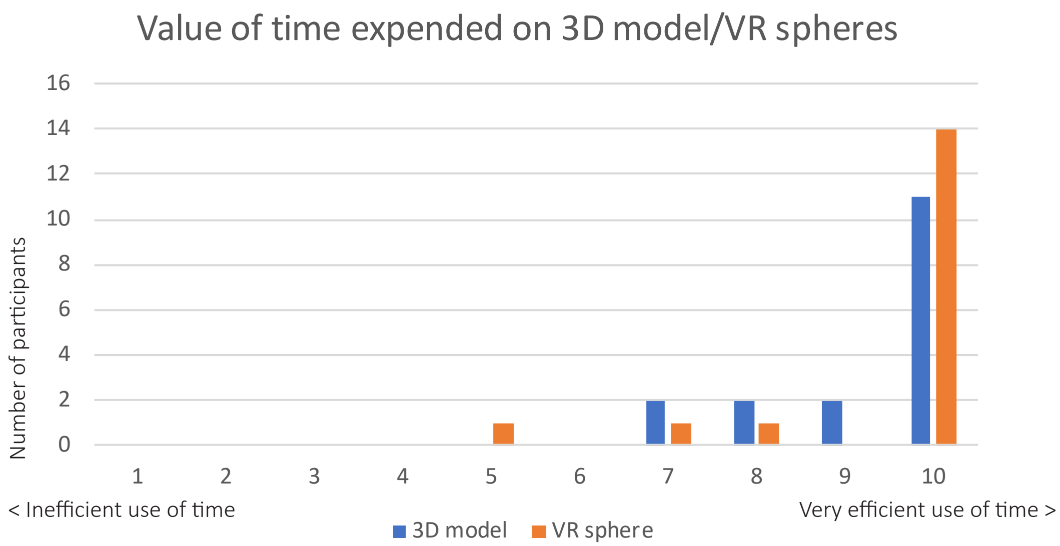



*Figure 76. Value of time spend on 3D model creation and VR sphere rendering (n=18 respondents)*

## Question 33

Is use of VR tech likely to increase overall time spent on project?

**Alternatives:**
Yes, no, don't know

*"If you use BIM modeling, it should not make a big difference. It depends on what the client is asking for."*

*"I think it will be easier to make decisions, and it will help project leaders understand. For example, road engineers"*

*"If I was to do this myself, I fear it would increase overall time expenditure"*

*"It will likely increase a bit, but you get that back in the final result. It's not like you would normally sit for 45 hours and study the lines of sight. You just wouldn't think that hard about it. Although time expenditure is increased, VR adds more value"*

*"Not if we alter workflow a bit. The way we work now, I think I will increase time expenditure."*

*"I think it will reduce overall time spent, as you can make decisions faster during the process."*

*"for small projects with limited time it is not worth it. For projects of this type (case study), it is very valuable"*

*"You often don't discover issues before construction. In that sense, I think you can save time on it (VR)"*

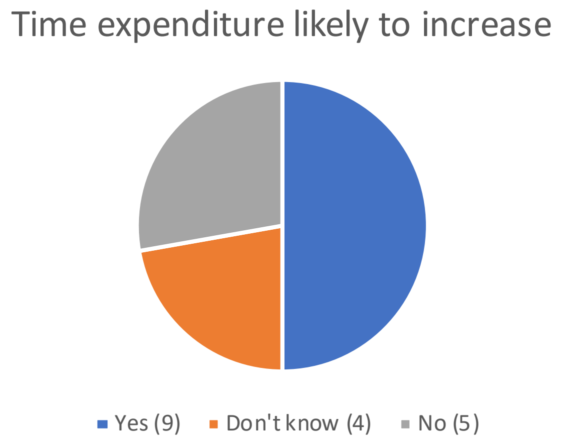



*Figure 77. Value of time spend on 3D model creation and VR sphere rendering (n=18 respondents)*

## Question 34

What are the main barriers which might keep you from adopting VR technology? (if any)

Explanations are categorized and counted below.

Don't know the methods/programs yet:
10 mentions

Prohibitively time-consuming to learn:
4 mentions

Prohibitively time-consuming to use:
3 mentions

Lack of client demand:
1 mention

Lack of specialists to do the work:
1 mention

## Question 35

Did you find the experience nauseating or uncomfortable?

12 participants answered "no". No participant answered "yes", but 6 added a comment indicating some level of discomfort, e.g. related to strained eyes or vertigo (from watching the viewing platform VR sphere).

## Question 36

Did you find the exploring the VR spheres a pleasant experience?

**Alternatives:**
1-10 scale

1: not pleasant
10: Very pleasant

**Average score: 9.3**

## Analysis of correlation

In general, evaluation of VR as a design tool was high, but did not correlate much (positively or negatively) with factors such as experience level, design process, work methods and methods used to evaluate design decisions.

Only a single participant stated that they sometimes used simple/linear design processes, so correlations between current design processes and evaluation of VR usefulness are probably not meaningful.

Landscape architects with more experience were slightly more likely to rate the VR model accurate/representative (Figure 78).

Users who make no use of 3D tools were somewhat more likely to believe that adding VR to their workflow would improve their ability to evaluate design decisions (Figure 79). It should be noted that the sample size is small.

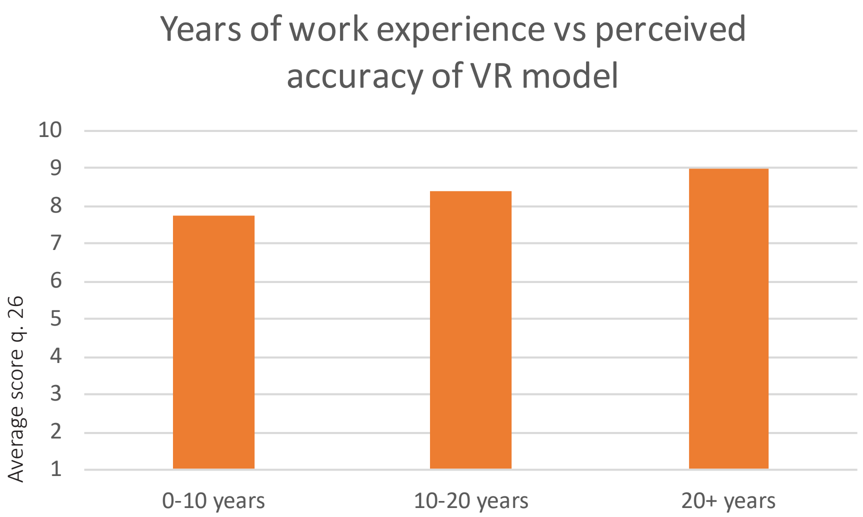



*Figure 78. Experience vs perceived accuracy of VR model. (n=18 respondents)*

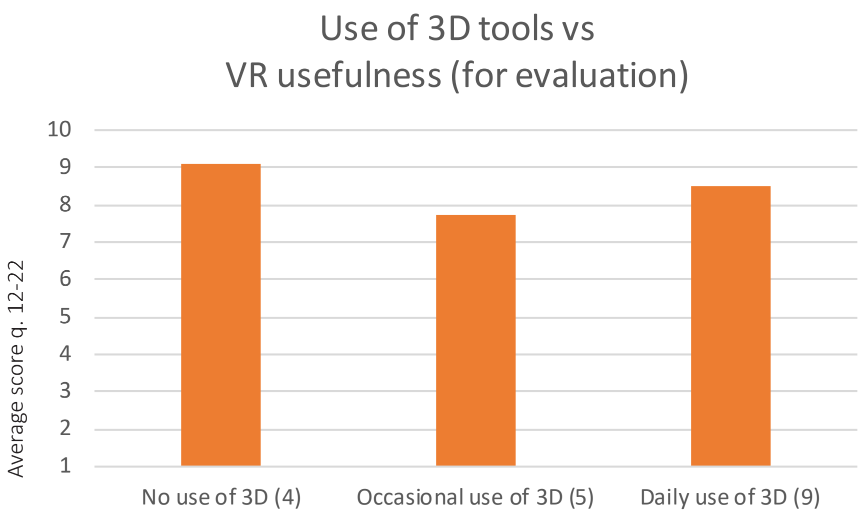



*Figure 79. Use of 3D tools vs average scores of VR usefulness in question 12-22. (n=18 respondents)*

# Summary of findings

Average score given for quantitative questions are summarized in Table 2.

| | | Score | Yes | Don't know | No | Realistic | intermediate | Abstract |
|---|---|---|---|---|---|---|---|---|
| q. 5 | VR concept familiarity | | 18 | 0 | 0 | | | |
| q. 6 | VR personal experience | | 14 | 0 | 4 | | | |
| q. 7 | VR professional experience | | 1 | 0 | 17 | | | |
| q. 8 | VR expectations of usefuless | 7,5 | | | | | | |
| q. 10 | Case study site familiarity | 2,6 | | | | | | |
| q. 11 | Case study project familiarity | 3,3 | | | | | | |
| q. 12 | VR to evaluate legibility | 8,6 | | | | | | |
| q. 13 | VR to evaluate topography | 8,1 | | | | | | |
| q. 14 | VR to evaluate constructions | 7,9 | | | | | | |
| q. 15 | VR to evaluate lines of sight within site | 8,8 | | | | | | |
| q. 16 | VR to evaluate focal points | 8,1 | | | | | | |
| q. 17 | VR to evaluate light and shadow | 9,1 | | | | | | |
| q. 18 | VR to evaluate safe & appealing spaces | 8,3 | | | | | | |
| q. 19 | VR to evaluate choice of vegetation | 8,8 | | | | | | |
| q. 20 | VR to evaluate navigation on site | 7,3 | | | | | | |
| q. 21 | VR to evaluate to discover unexpected | 8,5 | | | | | | |
| q. 22 | VR to evaluate external vistas | 9,1 | | | | | | |
| q. 23 | Preferred LOD early stage | | | | | 12 | 0 | 6 |
| q. 24 | Preferred LOD late stage | | | | | 16 | 0 | 2 |
| q. 25 | Relevance of issue 12-22 | 9,5 | | | | | | |
| q. 26 | VR model representativeness | 8,2 | | | | | | |
| q. 27 | Updated VR expectations of usefuless | 8,8 | | | | | | |
| q. 28 | VR usefulness for collaboration | 8,2 | | | | | | |
| q. 29 | Ease of communication despite headset | 9,1 | | | | | | |
| q. 30 | VR likely to lead to improved design outcome | | 15 | 2 | 1 | | | |
| q. 31 | Time on 3D model well spent | 9,3 | | | | | | |
| q. 32 | Time on VR model well spent | 9,4 | | | | | | |
| q. 33 | VR Likely to increase overall time expenditure | | 9 | 4 | 5 | | | |
| q. 35 | Was nausea induced | | 0 | 6 | 12 | | | |
| q. 36 | Was VR demonstration pleasant | 9,3 | | | | | | |

*Table 2. Summary of quantitative findings*

# 8 DISCUSSION

The first section discusses findings related to each of the research questions. The main research question is treated last, as it largely follows from the sub-questions.

The second section is a critique of the methodology used.

## Sub-questions

### Can VR assist in evaluating a design proposal?

> *What often happens in larger projects is that one loses sight of hills that are way too steep. And becomes expensive to fix. You would uncover that kind of issue in advance if employing a VR model like this."*

This question focuses on the list of potential uses for VR in chapter 4, page 18. Responses to the demonstration (question/q. 12-22) indicate that in the perceptions of the 18 professional landscape architects surveyed, the introduction of VR into the workflow is likely to improve participant's ability to evaluate design decisions and solve issues that are important to achieving good design outcomes (q. 25). Both average score across all questions and comments from participants support this assertion, although there are significant individual differences. 4 participants gave average scores of 7 or lower across all questions, indicating that introducing VR is in many cases not likely to improve their ability to evaluate design proposals. The primary reasons given were that other tools (e.g. SketchUp) were sufficient, and that mental representation based on simpler representation can be superior to VR.

**Variation between themes**
The score was expected to vary significantly between the different themes. However, the lowest average score was 7.3 (q. 20), suggesting that no irrelevant uses were included in the survey.

The most highly rated among the proposed uses was for evaluation of vistas/borrowed views. Both factual aspects such as visibility/line of sight, as well as aesthetic evaluation of the vista in question, are important considerations.

Evaluation of light and shadow was the second highest rated suggested use. Although powerful tools exist to predict e.g. how much sunlight a spot will receive, participants were generally impressed by the accuracy and realism of VR sun studies.

The least popular use for VR was to evaluate how users will experience navigation on site (q. 20). Based on the comments given, this can probably be explained largely by the lack of mobility with VR spheres, which is afforded to other forms of VR. Furthermore, limited display resolution makes it difficult to see distant details, e.g. to locate a car parking or exit sign.

When asked whether these types of considerations are relevant to the design outcome (q. 25), the average score was 9.5, indicating that these questions are very important considerations.

### Can VR facilitate collaboration during the design process?

> *"(Using VR to collaborate) You can give feedback (on the project) directly. Otherwise, you have to imagine everything from the drawings. Even we (landscape architecture) can't really do that."*

Because of their training, professional landscape architect can be highly proficient at visualizing a design proposal in their minds, in addition to representing it in drawings. However, collaboration often requires colleagues less familiar with a project to understand the current proposal, e.g. to help evaluate design options. Understanding topography, the intended effect of vegetation, materials, site context etc. in detail can be time-consuming. It is hypothesized that VR can be particularly useful for this purpose.

Half of the participants found VR very useful (9 or 10) for sharing their vision with colleagues less familiar with the project (q. 28). 3 participants suggested that experienced designers are equally or more likely to understand the scheme better using other methods, such as plans, 3D models, and renderings.

**Communication between individuals**
Early pilot tests revealed that communication could become problematic when wearing HMD VR goggles. Prior research has pointed out that users of HMD VR are visually isolated from their surroundings, a real limitation when collaborating (Desai et al., 2017). For this reason, cardinal directions were added to the bottom of each VR render sphere. With some practice, verbal communication improved quickly, and this was not a significant issue during the interviews. Participants ranked HMD VR headset 9.1 in terms of smooth communication (q. 29). However, some friction should be expected, especially in the beginning. For example, 2 of 18 participants intuitively pointed their hand physically to draw attention to specific objects experienced in VR during the interviews, momentarily oblivious that this object was not visible to others.

This suggests that although HMD VR users are isolated from their surroundings, this limitation is possible to partially overcome with some training.

**Communication within groups**
Because only one person could experience the VR spheres at a time, additional methods of representation was required for group discussions over the case study. This could be plans, illustrations or models shown on-screen or printed on paper. These methods of representation are very different from immersive VR, which limited efficient communication with the person wearing HMD VR.

Presenting the VR spheres on-screen similar to *Google Street View* can alleviate this limitation, and this method was successfully used in the case study to allow multiple designers to discuss the same VR sphere.

Services such as IrisVR Scope (used to transmit and communicate VR spheres to the mobile devices) can display VR spheres through a web browser link, with no additional steps required. While the viewing direction in the browser window will not automatically match the head-mounted display, it can easily be inferred, e.g. by describing reference objects or cardinal directions.

**Collaboration over distance**
The case study demonstrates that VR can potentially facilitate collaboration over distances. VR spheres with instructions

for use with Google Cardboard were sent from Ås in the East to Bergen in the West of Norway, to facilitate collaboration on the case study across the country. Links with updated VR spheres were sent over email routinely, and this effort was not experienced as problematic by either side.

**Collaboration across fields**

2 participants in the survey commented that VR was likely to help practitioners of other fields better understand typical landscape architecture considerations when experiencing the project in VR, e.g. if "before/after" VR spheres were presented.

## Do certain design processes, methods, design fields and project types benefit more from the introduction of VR?

> *"The larger scale a project has, the more important VR can be. In a landscape like this, it is much more useful than in a small space, like a public plaza. I think this would be extremely useful for our roadworks projects. Reading larger landscapes, seeing how tree plantings affect spatial definition."*

As confirmed by the survey, work method employed by landscape architects varies a lot. Under what circumstances is VR likely to be preferred?

**Design process**

Prior research suggests that design process has a significant impact on design outcome. The design process can differ significantly between individuals, groups or projects.

It was expected that designers with a more linear process were less likely to find VR helpful, as they do not engage in much exploration and evaluation, which VR can facilitate.

The interview revealed that the surveyed professional landscape architects are quite aware of their own design process, and that all 18 prefer using highly iterative and/or explorative design processes (q. 1). No correlation was found between positive evaluation of VR usefulness and preferred design process.

**Ability to visualize**

> *"You could get this topographical information readily from a section drawing. This probably varies a lot with the spatial understanding of the designer".*

To synthesize and evaluate ideas, mental imagery is constantly employed during the design process. Ability to generate effective mental imagery varies between individuals (Purcell & Gero, 1998). This variation is largely explained by the level of design experience.

5 participants commented that VR is more likely to be of benefit to designers who are less experienced, which limits their ability to generate accurate mental imagery to visualize the project. However, no direct correlation was found between level of experience and assessment of VR usefulness to evaluate ideas.

**Work method**

Landscape architects are widely seen as being less technologically advanced than colleagues in similar fields, such as architecture and engineering (Li et al., 2014). This was largely true of the surveyed landscape architects, as only half of the 18 participants make use of 3D tools daily, while 16 use 2D CAD daily. Architects and engineers in the same firm use 3D modeling tools primarily.

Users who made no use of 3D tools (q. 2-3) were somewhat more likely to respond that VR would likely improve their ability to evaluate design decisions (q. 12-22), especially when compared with those who make only occasional use of 3D (Figure 79 on page 65). These small differences could be statistically meaningless, due to the small sample group. However, this suggests that preferred work method is not a strong predictor of expected VR usefulness.

It is interesting that none of the 18 participants in the survey make significant use of physical models, even when digital 3D models are not employed (q. 2-3). Physical models are in some ways analogous to VR representations, as they are both experienced intuitively and in 3D. However, physical models are difficult to incorporate into a larger workflow, as they are slow to create and cannot easily be used to generate sections, details, visualizations etc.

**Design field**

Most of the research on practical applications of VR has focused on fields such as architecture, engineering, and city planning, with limited attention paid to landscape architecture (Yan, 2014). As design process, work methods and ultimate goal are not identical between the various design and planning fields, potential uses of VR are also likely to vary.

Experience from the case study suggests that that VR spheres might be more appropriate for landscape architecture, while navigable VR models are likely more relevant in other fields such as architecture, particularly for interiors. Due to limitations in computer processing power, navigable VR models tend to work best where the 3D point/polygon count is limited, i.e. where geometry is not too complex. Buildings interiors are typically much simpler than landscapes, especially when detailed topography, vegetation and distant areas are modeled. Orientation/navigation is central to good architecture, and fixed vantage points might be very frustrating. If exterior landscapes are modeled at all, a lower level of detail indicating what the view from various rooms will be might be sufficient.

Conversely, landscape architects might benefit more from realistic representation facilitated by VR spheres, even though VR spheres do not support navigation through the model. More open (outdoor) spaces increase visibility, which makes it easier to make assumptions of how orientation might be experienced even without moving- especially if there are multiple vantage points, e.g. every 25 meters along a path. Furthermore, affective response (more accurately simulated by realistic models) is often central in landscape architecture project such as parks, while it might be secondary to other concerns for many architecture projects. Interaction of topography, vegetation and built elements with line of sight or vistas are particularly important within landscape architecture and may be more difficult to picture without VR.

Landscape architects face unique challenges when employing VR, especially if aiming for realistic representation. Botanically plausible vegetation is difficult to reproduce and can be taxing on computer hardware. Important considerations for landscape design range in scale from construction details to distant vistas. Creating accuracy and realism across all scales can be particularly demanding.

**Project type**

*"In this type of project, (VR is) very relevant. For e.g. a kindergarten project, it might be less important."*

It is hypothesized that projects which are most likely to benefit from the introduction of VR in the design process are complex, large-scale landscape architecture projects, where there is a wide array of interacting factors to consider, and multiple design team members or specialists, which require a shared vision. VR is likely particularly useful when affective response is more important than purely practical considerations.

This view was supported by 3 participants, who commented that projects similar to the case study were more likely to benefit from the introduction of VR than other types, e.g. where affective response is less important, scale/complexity is smaller (such as small urban spaces and kindergartens).

## How does VR differ from alternative methods of representations?

*"I understand the (botanical garden) project much better after seeing it in VR. It is impossible to get the same images into the head from looking at plans and sections"*

Virtual reality has the potential to represent a detailed scene with an accurate field of view, head tracking and stereoscopic vision. This was theorized to have significant practical implications, as it more closely resembles the experienced of users after the project is finalized.

*"My 3D models do not display much subtle topographical features. This (VR sphere) works a lot better, because you have textures, shadows etc."*

Moreover, realism and depth perceptions have important implications for affective response. Prior research suggests that lush and appealing environments, a sense of mystery which encourages exploration, legibility and organized visual complexity are predictive of visual preference.

Achieving these sentiments using more traditional methods (e.g. hand drawing or digital rendering) often requires a lot of work. However, these feelings (sense of lushness, mystery, legibility etc.) are facilitated by the immersion afforded by stereoscopic HMD VR.

The landscape architects' responses seem to largely support these assertions. 14 of the 18 participants commented that the experience is very different from traditional forms of representation, and mentioned aspects such as spaces, materiality, scale, context and light conditions.

*"You experience the size of trees very clearly, compared with other tools. You also get a feeling of lushness. Which I could also have visualized mentally, but (...)"*

**Accuracy in representation**
Research on VR and other forms of visualization has often emphasized that digital representations can be as misleading as they are informative (Hansen, 2013). Participants were expected to be somewhat distrustful of the accuracy and representativeness of the VR model, with more experienced practitioners expressing higher levels of skepticism.

The average score for representativeness (8.2) suggests that most participants found the VR model to be a credible representation of the scheme (q. 26). Surprisingly, the most experienced landscape architects gave a somewhat higher score than the least experienced practitioners (Figure 78 on page 65). However, 2 participants warned that the apparent level of realism could be misleading.

## How can VR be part of an effective workflow?

*"Not if we alter workflow a bit. The way we work now, I think I will increase time expenditure."*
*(Answer to question 33)*

Creating detailed and extensive 3D models can be very time-consuming. If the 3D model used for VR is exclusively created for experimenting with design options, it is likely to suffer from the same fate as physical models: a potentially useful tool standing outside of the daily workflow, and therefore never employed by practitioners. Consequently, VR should be well integrated with the overall design workflow.

**2D vs 3D**
The 3D model was based on a 2D CAD drawing, demonstrating that working entirely in 3D is not a prerequisite. Although SketchUp is very effective at modeling, it is not particularly good at maintaining quality and flexibility as the model goes through many alterations, and it is often faster and easier to model "from scratch" than to make further alterations. Besides, SketchUp is not optimal for storing a hierarchy of information, with different levels of detail. However, SketchUp can import AutoCAD files efficiently, while maintaining physical positions and information about layers.

For these reasons, using 2D CAD such as AutoCAD as foundation for the overall scheme works well. Modeling landscapes in 3D using other widely used programs (e.g. Autodesk Revit) while using AutoCAD plans as the foundation has also been proven an effective method.

This more gradual shift to 3D, which maintains 2D CAD as foundation is perhaps more likely to be successful than transferring entirely to 3D, for two main reasons:

1. Large numbers of landscape architects still work exclusively in 2D CAD and are likely to continue doing so for some time.
2. No 3D modeling program has proven effective at meeting all the varied needs of landscape architect- from schematic design to detail design development, for a large range of project types and scale.

**Efficient modeling**
An important lesson from experimenting with various programs for the preparatory work and case study is that flexibility and compatibility with other programs are the most important criteria when trying to integrate software into an effective workflow. For this reason, SketchUp (along with powerful plugins) was chosen as primary modeling program.

To efficiently create large, detailed models, it is recommended that most parts of the model, and especially the site context are modeled implicitly rather than being "hand-crafted". Good material libraries containing high-resolution textures and 3D models, presets for rendering and widespread use of keyboard shortcuts can drastically increase workflow productivity.

**Overall workflow**

If a 3D model is planned for generating VR spheres, it could be beneficial to create the model early in the process and use it throughout the project. As pointed out by a participant in the survey, a detailed model of the site and context can be used for site analysis the same way as Google Street view is often used. The same model can be used to experiment with early design options, perhaps using the more abstract representation, focusing on "larger" aspects such as lines of sight and spatial definition. As the design process progresses and level of detail increases, focus on VR can shift over to smaller elements, such as materials and construction details. The same 3D model naturally lends itself to architectural visualizations and animation, and analyses such as sun study. If created accurately enough, section cuts or detail drawings can also be extracted, and perhaps processed using 2D CAD. Users can also calculate quantities, such as surfaces and volumes, e.g. for cost estimation. However, there is a significant risk that a 3D model could become a time sink, or focus too much on the least impactful, late phases of the design process. If a model is planned with too many different uses in mind, requirements for accuracy can potentially hamper immediacy and creativity.

## When is a high level of detail and realism more desirable?

*As a tool to make some quick judgment, the abstract model works well - like a hand drawn perspective sketch. But aspects such as play of light and materiality are only clear on the realistic model.*

If used internally during the design process, it is important to consider what a VR model aims to achieve, and who the target group is, to select an appropriate level of realism.

An important finding is that most surveyed landscape architects preferred the realistic models for all stages of the design process, if asked to ignore any difference in time expenditure (q. 23-24). Realistic models make evaluation of both factual and affective aspects easier, as more information is available to the designer. As pointed out in some comments, detailed and realistic models can often be somewhat misleading. However, experienced designers are likely capable of taking this uncertainty into account when developing the project.

This was expected, and fits well with some prior research, which suggests that designers are more easily able to understand spaces presented in VR when techniques such as textures on surfaces, high level of detail and advanced lighting are employed to evoke realism (Loyola, 2017).

Some considered the abstract model sufficient for some purposes, or even superior. This disparity could reflect varying ability to create mental imagery to fill in details.

2 participants preferred realistic representation during early stages, and more abstract model during late stages. This is because they regarded aesthetic evaluations as more central during early design stages, with more practical considerations (such as construction details) during later design stages. 2 other participants added that they would prefer to show abstract models to clients or external parties and non-designers, to avoid misleadingly realistic representations.

*"For use with clients, I would have been scared to use the detailed version at first. They may get preoccupied with details"*

It is interesting that no participants preferred the intermediate level of realism over the realistic and abstract representation. Apart from the simplified vegetation, the intermediate VR representation contains the same amount of information as the realistic representation, but lacks all the subtle details which add realism, such as 'normal maps' and atmosphere. 2 participants commented that shape outlines from the abstract model improved depth perception and understanding.

The preference for realistic and abstract representation could partially be explained by the prior research concerning visual preference and realism: Both high realism and some level of novelty is known to correlate with visual preference. It is possible that the abstract representation peaked "novelty", while the intermediate model peaked neither "novelty" nor "realism".

Realistic representations are more likely to evoke feelings of lushness/water, generate a sense of 'mystery' and display high levels of organized complexity, all believed to increase visual preference. This could also have influenced survey participants to choose realistic representation over alternatives.

**Time expenditure**

Abstract models are less time-consuming to create, and therefore likely preferable in many cases, such as early stages when design exploration should be high. However, if implicit modeling is widely employed, the difference in time expenditure may be trivial. Placing out individual trees is not necessarily slower when placing realistic rather than abstract trees. When working in the case study, two important factors made the realistic model more time-consuming to work with:

1. Creating realistic textures that were mapped correctly onto surfaces was somewhat time-consuming, especially blending together high-resolution aerial photography with site plan and other ground textures.
2. Complex geometry made the model less responsive, slowing down the entire process. This was particularly noticeable when inserting realistic vegetation.

Finally, it is important to consider what the model will be used for. A representative model is likely useful to ensure that a team has the same understanding of the design intentions. Evaluating details such as materials, precise lines of sight and choice of vegetation is more practical when using a realistic model, while an abstract model can be sufficient for overall scale and spatial definition.

*Once you find an error, the brain starts looking for more mistakes. you get obsessed with details. This can stop the (constructive) discussions (...). For this reason, it is important that the model looks perfect.*

An unexpected observation was made by 2 participants, as well as the project leader: if a VR scene is presented with a high level of realism, small errors become very conspicuous, and can become the focus of attention. Observing a small error, e.g. levitating objects or unrealistic terrain caused by flawed surface generation led participants to begin looking for more errors. This was not deemed an issue for the abstract model. At least for some users, high levels of apparent realism necessitate high levels of accuracy, while abstract models do not. If VR is employed to generate only parts of a scene, or some errors are deliberately ignored to save time, abstract representation could be preferable to avoid misdirected focus on these errors.

## Is currently available "low-threshold" VR-technology useful?

> *"I think it is one of the best tools we can adopt. I find it strange that we haven't began using it earlier. Engineers have begun using it."*

The case study and survey demonstrate that the currently available, low-threshold technology is fully capable of producing functioning VR models that can be useful during the design process. Although most aspects of VR technology can be improved, no single step/group of steps can be expected to significantly improve the capability of VR spheres in the near future.

This viewpoint has been suggested by prior researchers, who claim that VR technology has recently reached a threshold which is likely to plateau somewhat (Arnowitz, 2017).

However, the combination of higher resolution smartphones and improved VR sphere rendering resolution is likely to gradually enhance the experience of working with VR spheres in coming years.

## Are benefits of using VR likely to outweigh the costs?

> *"(time expenditure) will likely increase a bit, but you get that back in the final result. It's not like you would normally sit for 45 hours and study the lines of sight. You just wouldn't think that hard about it. Although time expenditure is increased, VR adds more value"*

Prior research on VR has often focused on the opportunities of VR technology, and paid less attention to significant costs incurred, such as additional time expenditure. Will potential benefits of employing VR be worth this cost? Can complementary uses of the 3D model offset the cost?

Most participants in the survey suggested that creating a detailed and realistic 3D model and VR spheres was an effective use of limited time (q. 31-32) and would likely improve design outcome (q. 30). However, 9 of the 18 participants believe that overall time expenditure is likely to increase (q. 33), while 5 believed it would stay the same or be reduced, and 4 were unsure.

This indicates that although VR has potential to improve design outcome, it is often unlikely to pay for itself through faster decision-making and improved collaboration alone.

2 participants commented that clients would likely be willing to pay for this increase, or even begin to demand VR for projects, despite higher cost.

> *"45 hours is unrealistic for many users" (q. 32)*

Additional time expenditure for generating VR can be reduced or eliminated if the model is used for multiple purposes, as outlined in the discussion concerning workflow. However, it should be stressed that an ineffective workflow for generating 3D models can easily turn a project into a time sink. Proficiency in digital tools and flexibility/adaptability are important to make good use of VR technology in a cost-effective way.

Detrimental health effects when experiencing VR is also a factor, although most participants did not suffer from any significant ill effects (q. 35). VR spheres high are less likely to trigger these than some alternative VR technologies, as navigation is impossible, and framerate is high. All participants, including those who experienced some detrimental effects found the VR demonstration a pleasant experience (q. 36).

## Why is VR not widely adopted within landscape architecture?

> *"Landscape architects already have a lot to master. It is a broad field. We can't master everything."*

Some prior research indicates that few landscape architects are likely to have used VR in their work. This held true for the surveyed group, as only 1 of 18 participants had used VR for professional work before, for a single project.

This thesis has proposed that there can be clear benefits to using VR within landscape architecture, which can arguably offset the cost, at least when used for appropriate projects with an efficient workflow. If so, why are apparently few landscape architects adopting the technology?

It was hypothesized that practitioners of landscape architecture have low expectations of VR technology. However, the survey suggests that these expectations were rather high (q. 8, average score 7.5), and do not explain low adoption rates. However, this score did improve somewhat with the demonstration (q. 30, average score 8.8) suggesting that more widespread knowledge about VR is may increase adoption rates. 4 participants expressed that VR is not widely seen as useful for landscape architecture.

> *"I think it is because landscape architects lag behind when it comes to use of 3D tools."*

The most popular explanations for low adoption rates (q. 9) were that VR is too recent for widespread implementation, and that landscape architects are generally slow to adopt new technology. Some mentioned that knowledge about VR is lacking, and that the technology might be too time-consuming to learn or to use.

When asked what barriers could hold participants back from adopting the technology themselves (q. 34), 10 mentioned not being proficient with the appropriate software, while 4 mentioned VR likely being prohibitively time-consuming to learn or to use. Lack of value to the project was not mentioned.

In general, this suggests that technological barriers are the main reason for low adoption rates, while lack of knowledge about VR technology and potential uses seem secondary issues.

These comments also confirm the widely held view that landscape architects often lag behind similar fields when it comes to adopting advanced tools.

This could suggest that VR is not likely to become widespread soon. However, it is not necessary for every designer at a practice to have in-depth knowledge of a tool to benefit from its implementation. Specialists in 3D modeling and VR can be brought into projects when needed, as was done for the case study. For this reason, adoption rates of VR tech could change quickly, especially if landscape architecture education focuses more on advanced digital tools.

On the other hand, landscape architecture is a very broad field, and practitioners are expected to have in-depth knowledge of a long list of topics ranging from natural science to communication and design. This list keeps getting longer, with large topics such as landscape resilience, native ecology and accessibility on the rise. Several survey participants expressed frustration over the large numbers of digital tools they are already expected to learn, often without receiving formal training. Perhaps the underlying reason for slow adoption of VR is that landscape architects are expected to be generalists, while VR demands some specialization.

# Main research question

## What is the potential of VR to improve the design process within landscape architecture?

> *"You get more predictability. What is often difficult, even with a lot of experience, is scale. When you watch a plan: how will this be experienced? You get a better impression of that here (using VR)"*

Background literature suggests research concerning practical application of VR is lacking (Portman et al., 2015). This thesis proposes that there are at least two important potential uses for VR during the design process: evaluation of design decisions, and collaboration between design team members.

Both uses require effective methods of visualization. Virtual reality differs from alternative methods of visualizing landscapes in significant ways and may increase the number of factors that are considered.

The survey suggests that for many users, VR is likely to help visualize a proposed scheme in a manner more realistic and representative of final user experience than alternative methods. This can assist in evaluating design decisions, which can be based on accurate information presented realistically and intuitively. It can also be used to communicate ideas and create a shared vision when collaborating.

Improvements to the design process can lead to improved design outcomes, which in turns has the potential to improve the experience of the physical environment.

However, low immediacy when working with VR presents important limitations. High levels of iteration and exploration the crucial early phases of the design process should not be slowed down and hampered through the introduction of VR.

> *"We are trained to use and communicate using simpler methods. The technology can become a hindrance."*

Creating and testing design options using VR is significantly more time-consuming than most alternative methods. Furthermore, externalizing thoughts while experiencing VR presents a problem, as even hand-sketching is impractical while wearing HMD VR headset. For these reasons, VR more suitable as a supplement to, rather than a replacement of traditional methods of externalizing, evaluating and sharing design ideas.

# Critique of methodology

**Selection of participants**

The group selected for the survey might not be representative of all landscape architects. Prior research suggests that larger, multidisciplinary firms such as Norconsult are more likely to make use of 3D modeling tools (Hassan et al., 2014). Furthermore, self-selection bias may lead participants to be more positively inclined towards VR, as indifferent invitees are more likely to turn down the invitation. However, this effect is likely limited as 18 of the 24 invited subjects decided to participate in the survey. Although 18 participants is not a small group for in-depth interviews, it may be too small for uncovering a meaningful correlation between factors, which might contribute to positive or negative evaluation of VR.

**Examples VR spheres**

Only one example VR sphere was provided as demonstration to evaluate each potential use of VR – e.g. for assessing line of sight, visual complexity etc. It is likely that the particular example provided had some influence on positive or negative evaluation of a suggested purpose. For example, VR sphere 4a/4b might have been a poor example to demonstrate the potential of VR to better understand navigation. Furthermore, overall affective response of each sphere can have influenced the score. Most participants expressed unique delight over experiencing VR sphere 3, with provides a distinctive vista from a platform elevated high above the ground. This could partially explain that question 22 received the highest average score (9.1). Although presenting more than 4 VR scenes as examples would have been preferable, it was deemed impractical due to time constraints.

For these reasons, score comparison for questions 12-22 should be treated critically. However, most participants were apparently able to evaluate the various alternative uses beyond the specific example given, as suggested by some insightful comments and analogies when providing explanations for the given score.

# 9 CONCLUSIONS

This thesis investigated the opportunities and limitations of using VR to alter the design process within landscape architecture.

The primary focus was on benefits and drawbacks of immersive VR for evaluating and sharing design ideas under various circumstances. To shed light on this, the thesis explored common design processes and intrinsic difference between VR and alternative methods of representation.

The thesis also explored several practical considerations, such as workflow integration, cost-efficiency, and current/expected adoption rates.

Adiabata (the redesign of a botanical garden) was selected as case study to address research questions. This case study reflects the type of projects which is hypothesized to benefit the most from the introduction of VR, based on prior research. The case study permitted exploration of the technology within a realistic situation and measurement of time expenditure.

After completing work on the case study, A survey was conducted of 18 practicing landscape architects. The survey further investigated the research questions and re-examined findings from prior research and the case study.

The main finding was that VR can potentially be useful to designers during the design process, rather than merely for presenting finished products. Under the right circumstances, VR can alter the design process, likely leading to an improved design outcome and physical environment. However, important pitfalls can easily increase cost and potentially hinder a creative design process.

The current low-threshold technology used was acceptable for practical use and is unlikely to make dramatic progress in the near future. Practitioners interested in VR should consider making use of the current tools, rather than wait for new technology to be developed.

Virtual reality has particularly interesting potential when used in large, complex landscape architecture projects where affective response is central, and many designers/engineers are collaborating.

Some will find VR useful to evaluate their own design decisions, while others will not benefit as much. This variation can be partially attributed to the level of experience with design and proficiency in generating mental imagery.

Introduction of VR is likely to help create a shared understanding of a project efficiently. This may be particularly useful to help other involved parties, e.g. road engineers, to understand landscape architecture considerations.

If VR remains outside of a larger workflow, it is likely to share the same fate as physical models, which generally suffers from limited use during the design process. Detailed and accurate 3D models useful for VR can be employed during the site analysis stage and can be used for various purposes throughout the project.

One of the main advantages of VR is that the presentation form feels highly realistic. If this is combined with a realistic model, VR has a unique potential to present proposals in a convincing and faithful manner. However, abstract models are often sufficient and are likely to save time. It is important to reflect on what considerations VR is attempting to uncover, and who the target individual/group is, and what supplementary uses the 3D model might have.

Although VR models are time-consuming to create, it seems likely that the cost can be worth benefits, especially if the 3D model has synergistic uses. Despite being potentially cost-beneficial, adoption of VR technology has been limited. History of relatively slow 3D tool adoption within landscape architecture could suggest that this is likely to remain the case in the future. However, surveyed practitioners seem to have somewhat high expectations of VR, and the technology could become more widespread if firms can take advantage of a few VR specialists.

More research on VR for landscape architecture can be beneficial to the field, including other applications of VR during the design process. A larger and more diverse group of landscape architects from both small and large firms is preferable to the relatively homogenous group interviewed for this thesis. Using several different case study projects will reduce the chance that the specific details of the case study inadvertently affects the results.

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# TECHNICAL DISCUSSION

The research questions for this thesis addresses general questions regarding the feasibility of VR for landscape architecture, and do not encompass a how-to guide. Description and discussions regarding realistic and efficient 3D modeling may be useful to the thesis target group, but will likely become outdated as software and techniques evolve quickly. For this reason, a discussion of technical aspects of the case study is included in this final section.

This section does not describe every step in detail, and is targeted at an audience familiar with the fundamentals of 3D modeling.

## 3D modeling- description

It should be emphasized that there is no “default” way to model in SketchUp. The techniques presented below are the result of personal experimentation with various alternative methods, in order to uncover efficient procedures. The various elements of the digital model are:

1. The terrain surfaces, including bodies of water
2. Constructions such as buildings, pavilions and steps.
3. Vegetation, rocks and other natural elements
4. Size cues/animation: humans, animals, cars.
5. Atmosphere, weather etc. (added when rendering)

Although roads and paths intuitively might intuitively belong to the category of “built elements”, they were usually created by draping/projecting a texture over the terrain surface. This saves time and makes it easier to alter the model.

During early stages, I experimented with photogrammetry for modeling and texturing terrain accurately (Figure 80). This technique has been used in the video game industry to generate detailed models quickly and is used in Google Earth for modeling accurate models of important regions, such as cities (e.g. Oslo and Bergen).

Although photogrammetry has large potential to generate models for use with VR, the technique has important drawbacks, which are assessed in the next section. For these

*Figure 80. Photogrammetry rocks on the forest floor.*

reason, photogrammetry had limited use in this project, but was used to generate some natural elements, such as clusters of moss-covered rocks placed on the forest floor.

The main steps used to create each element of the model are presented below.

**Terrain surfaces**
The terrain consists of two elements: The mesh surfaces, and textures mapped onto the surfaces.

In order to remain efficient and light, the surface contains 3 levels of detail, which are placed on different layers: The site area, the surrounding areas (up to 2 km away) and distant areas (about 6 km away from site). Contour line accuracy range from 1 meter interval on the site, to approximately 10 meters interval for distant regions.

The terrain surface model is assembled from three different sources: Topographic laser data from Norwegian mapping authority for surrounding and distant areas, SOSI (standard geospatial) data from Bergen municipality for the site itself, and the altered contour lines within the site from the design team/ AutoCAD.

The topographic laser data was downloaded as GeoTIFF format from hoydedata.no, and was converted to a 3D mesh using Adobe Photoshop CC.  Two versions are available, and both were used: One which had vegetation removed (DTM), and another version (DOM) where vegetation is retained (Figure 81). This made it possible to show distant forests and forests in low detail, e.g. to avoid a smooth horizon line on forested

*Figure 81. Meshes showing vegetation based on laser data used for distant forests (e.g. horizon lines) and for accurate placement of tree models close to site. Aerial photography displays lower resolution on left side (further from the site) to increase optimization.*

hills. Meshes showing existing trees were also used to place tree models at approximately correct sizes/heights around the site, then were hidden. These 3D meshes were exported from Photoshop to SketchUp using COLLADA format.

SOSI data (existing contour lines) and new contour lines from the AutoCAD site plan were merged together in SketchUp and used to generate surface geometry on the site.

Once surface meshes had been generated and placed, textures were mapped on the mesh surface. These textures simulate the surface properties of the landscape, such as grass, gravel paths and asphalt roads. The texture on the surface meshes was merged together from three sources: The new site plan, general high-resolution textures (e.g. grass and asphalt) and existing aerial imagery. To avoid trees being shown in both plan and 3D, these were hidden from the site plan. Appropriate high-resolution textures were added to each surface according to their color code, e.g. grass texture over all light green regions of the site plan.

Using aerial photography as terrain texture presented a particular problem: cast shadows (e.g. around trees and houses) are visible on aerial photographs, which means shadows will be shown twice on the ground when the model is rendered with a light source. This was resolved by identifying all shadow areas using smart selection tools such as "selection by color range", and brightening these areas, then partially replacing these pixels with surrounding textures using "content-aware fill" in Photoshop CC or generic grass textures.

Normal maps were generated from the resulting textures. Normal maps simulate uneven surfaces, resulting in more realistic light and shadow on textured surfaces. This technique works particularly well landscape imagery, and is essential to give uneven surfaces some appearance of realism at all scales.

**Water**
Water simulations used an alpha mask (transparency layer) on textures using Photoshop, which is identified by Lumion and rendered separately. In these areas, reflectivity and glossiness was altered to creative a reflective surface, modified by normal map displaying wave patterns. This was faster and less demanding than dividing the surface meshes between water and land areas, which can be particularly problematic when the shoreline is highly fractal and shown in high level of detail, while mesh resolution is low.

**Updating the landscape**
Although SketchUp can be very effective for generating geometry, SketchUp models are notoriously difficult to alter. To change the topography, new and updated contour lines in limited areas are imported from AutoCAD, and the previous terrain is deleted within a defined area. A new mesh is generated in this area, using the updated contour lines.

Most updates of the landscape only affected the textures mapped onto the surfaces, e.g. paths and roads. Updates to the textures are quickly accomplished in Photoshop and automatically updated.

**Built elements**
Existing buildings were generated using the SOSI data, which consists of a few lines representing roof edges and ridge. A mesh surface is generated between these lines and copied twice. The first surface is extruded down through the terrain surface, to generate walls. The second mesh is slightly enlarged and extruded up by 40cm. This creates a slight roof overhang, which appears more realistic. These steps can be used to generate large numbers of houses simultaneously.

Roofs and houses were given colors based on their appearance in Google Earth, using a limited color palette. These colors are later replaced by generic roof and facade textures, which subtly suggests high level of detail.

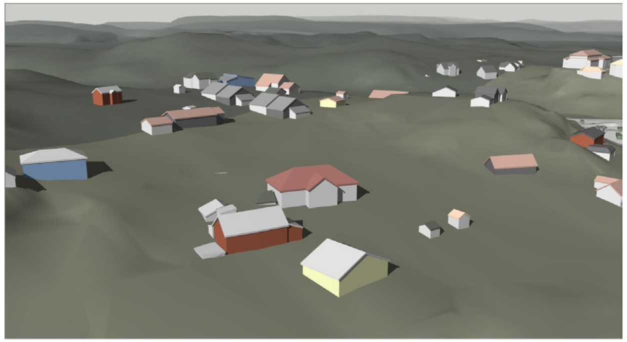

*Figure 82. Generation of houses before adding generic facade textures.*

**Vegetation and natural elements**
Individual trees and rocks were placed in Lumion. Lumion supports mass placement and can handle much higher polygon count than SketchUp before slowing down. Grass is automatically generated on areas with pre-selected textures.

**Size cues**
People, animals and cars originated from the Lumion default library, and were placed individually. People and animals were colored entirely black, as realistic people can draw attention away from important aspects. Furthermore, 3D people in Lumion are sometimes experienced as slightly disturbing, likely due to the "uncanny valley" effect.

**Atmosphere/weather**
The final steps were fine-tuning atmospheric effects, color balance, contrast, weather settings and shadow effects in Lumion before rendering the VR spheres.

# 3D modeling- discussion

## Achieving realism

As discussed previously, there are important benefits and drawbacks to high levels of realism. In order to examine these, and as a technical challenge, the case study aimed at high levels of realism.

In the context of VR, realism is achieved through combining a life-like 3D model with realistic rendering and immersive presentation.

**Meshes**
For a somewhat open site like the botanical garden, creating a life-like 3D model means combining high level of local details with extensive size, so that distant areas (e.g. the horizon line) appears correct.

Creating realistic "physical" shapes (meshes) was for the most part straightforward to anyone familiar with 3D modeling, especially when it comes to human-made elements, which tend to display highly Euclidian geometry. However, vegetation posed a real challenge, described in the section concerning preparatory work. Trees display strong fractal properties, which are difficult to model accurately. As trees are so ubiquitous, unrealistic trees are easily recognized, either consciously or subconsciously. 3D models of trees that are realistic, lightweight (small file size) and cover all relevant species was not easy to come by. Lumion 8.3 contains a large library of tree models, but levels of realism, customization and relevant species is limited. Several popular software platforms created for this purpose (e.g. Speedtree) are effective means to create somewhat abstract trees, but this becomes increasingly challenging and limiting as one aims for higher levels of realism. In the end, trees were modeled "manually" using SketchUp and Photoshop. This is not an ideal solution for most users. However, tree generation software is making huge advances, with very interesting projects such as "The Grove" *3D tree growing software*, which is based on deep botanical understanding.

**Colors and textures**
Once "physical" surfaces/meshes are created, realistic textures and colors are added to every surface. Finding appropriate color hues was generally easy, especially with site pictures as

reference. However, selecting the appropriate luminosity for each color was surprisingly difficult. Inappropriately light or dark color on grass, trees, skies or other objects becomes very conspicuous, and conveys a “digital” appearance. Correcting the luminosity on one texture (e.g. grass) often leads to other textures appearing wrong. Although this aspect was improved through experience during the preparatory and case study work, it remains an obstacle to achieving high level of realism quickly.

**Rendering**

Having modeled and textures the site, appropriate rendering settings are necessary to achieve realism. A commonly overlooked aspect is atmospheric fog, which generally renders distant colors colder and reduce contrast. Low sun during sunrise and sunset has the opposite effect on hue, rendering distant areas in the general direction of the sun warmer.

Rendering at highest quality effects and highest resolution can be time-consuming. In general, high resolution should be prioritized over high effect quality, to achieve high level of detail and sharpness, even at the cost of e.g. realistic lighting.

## Modeling efficiently

Creating a 3D model for this project presented several challenges, which are common for project of similar category and scope. To present all the useful information, the model needs to be simultaneously large in extent and high in detail and accuracy. In order to achieve this efficiently, large parts of the model need to be “generated” rather than “hand-crafted” (known as implicit modeling). It was also important that the model could be altered and updated easily, as the design changes, or multiple design options are proposed.

**Photogrammetry**

Although photogrammetry has interesting potential to generate models for use with VR, the technique has important drawbacks. Most importantly, making alterations to a photogrammetry-generated model was difficult, as original textures on surfaces are not preserved easily. Secondly, current photogrammetry technology struggles with vegetation. Thirdly, the various elements of the landscape (terrain surface, natural elements, build elements) are not separated objects and therefore not easy to alter independently. Fourthly, creating accurate photogrammetry models requires good photographs from various viewpoints, which is not practical for large areas such as Milde (unless drones are employed). Finally, good topographical/GIS data was available for this project. For these reason, photogrammetry had limited use in this project, but was used to generate some elements during the preparatory work, which were recycled for the case study.

**Emergent modeling solutions**

Unfortunately, no complete package for efficiently generating original and proposed landscape geometry exists. Software tend to be specialized for one aspect of the landscape, such as roadworks, construction details or buildings. These programs tend to have limited flexibility, and important limitations for use with landscape architecture.

The primary program chosen for modeling the case study was SketchUp. The combination of flexibility and large user base has made this simple and intuitive program very powerful, as large numbers of plugins have emerged, which can be used to model almost any shape. Flexibility when importing/exporting models, as well as key mapping of any tool or setting (keyboard shortcuts) facilitates highly effective workflows.

Photoshop was extensively used to create or merge textures, and even to generate 3D terrain meshes from GIS data, which was imported to SketchUp.

SketchUp, Photoshop and the plugins used were not created for the purpose of generating models within landscape architecture. However, no other solution was found which enabled creation of highly detailed, yet extensive models more efficiently. It is interesting that their usefulness emerges from the flexibility of these programs, not the intention of the developers.

However, this “emergent usefulness” also means that finding an effective workflow demands more from the user.

## Sharing and presenting VR spheres

Both Samsung Gear VR and Google Cardboard were used during the case study, while Samsung Gear VR was used for the survey. Cardboard has the advantage of being lightweight and having a trivial price tag. However, the improved gyroscope of the Gear VR reduced “drifting” (FOV movement independent of head tracking), which can cause some dizziness. Furthermore, the Gear VR lenses cause less distortion of the visual field, resulting in a more immersive experience. Google Cardboard is adequate for many users, and can easily be brought to external locations, meetings etc. However, Samsung Gear VR is preferred when both are practical. Both Scope by IrisVR and the native 360 Photos app that come with Gear VR were adequate for presenting the VR spheres.

# APPENDIX I

## Technical terms

### Virtual Reality (VR)

Virtual Reality is a broad term, which encompasses computer-generated simulations of real or imagined landscapes. (Beier, 2000)

### Immersive VR

In the context of Virtual Reality, immersive VR refers to technology which lets users experience a simulated landscape. Techniques such as head tracking and stereoscopic vision are used to increase the feeling of immersion. Common use of the term “Virtual Reality” usually refers to this narrower definition. Use of the term “VR” in this thesis will refer to immersive VR. (Beier, 2000)

### HMD VR (Head-mounted display-based virtual reality)

A range of technologies have been developed for immersive, computer-generated simulation. Among the most promising and widespread technologies are head-mounted displays, devices which contain a display strapped over the head, or held up in front of the eyes. The display is split into two smaller screens, which are presented to each eye separately using built-in lenses. Head-tracking allows the user to look around and experience the simulated world. Common HMD VR technology can be further divided in two types – specialized devices, and smartphone-based devices.

### Smartphone-based HMD VR

Mobile-based devices such as Google Cardboard and Samsung Gear VR are in effect smartphone-holders with lenses, which present each eye with one half of the smartphone screen. Samsung Gear VR is more costly, heavy and cumbersome than Google Cardboard, but offers improved head-tracking through built-in gyro sensor and accelerometer, somewhat wider field of view and more some useful apps. Google Cardboard is inexpensive, almost weightless and compact. Both of these and similar solutions are considerably cheaper than any specialized hardware with built-in display. Anything presented using Mobile-based VR must be rendered using the built-in GPU unit, which is considerably weaker than most computers. Future solutions may potentially be able to transmit visual data quickly from computer to phone using cable or WIFI, overcoming this limitation.
A current limitation of mobile-based VR is the smartphone resolution. Around 2017-2018, VR resolution of smartphones such as Samsung Galaxy S8 with Gear VR is comparable to that of Oculus Rift. Although modern smartphone display resolution appears extremely high with the naked eye, the lens magnification makes their limited resolution noticeable. Smartphone resolution may not continue to improve much, as the pixel density (PPI) is already higher than what many users can perceive when not wearing VR. Specialized tech, on the other hand, will likely continue to increase in resolution. For this reason, the potential for high realism and detail may be higher with specialized products. However, it is possible that smartphones continue increasing their PPI further to stay competitive for VR applications, if the GPU keeps up with increases in resolution.

### VR spheres/ Spherical stereoscopic renderings

VR spheres is the primary technology explored in this thesis. A computer-generated model is pre-rendered on a computer, using rendering software capable of producing stereoscopic 360 output format. The resulting JPG-file is a dual (stereoscopic) *cubic* or *equirectangular* projection. This jpg-file can be quickly transferred to a smartphone and presented with HMD VR. The main limitation of this technology is navigation within the model. Some programs such as Lumion allow numerous VR spheres to be created relatively quickly, so a form of navigation can take place through “teleporting” from one vantage point to the next, e.g. every 25 meters along a path.

Because the visual image is pre-rendered, the experience is less limited by rendering time. For this reason, models with high polygon count and large numbers of realistic effects such as reflections, atmosphere, shadows, bounced light, high-resolution textures, normal maps can be taken full advantage of.

Once the VR spheres are created, only a common smartphone and simple headset is required for use, permitting more mobility. The VR sphere can also be easily shared to other computers and can be presented in browser window analogous to Google Street View. Many firms already have access to software such as Lumion and Revit capable of producing VR spheres. Because of this, adopting VR sphere technology might not inflict high initial cost, lowering the threshold for adoption.

### Navigable VR model

A computer-generated 3D model is rendered live and displayed on a specialized VR-device. The model is typically rendered using the GPU unit of a computer. Because the model is presented live, the user can freely navigate around the model, and alterations to the model could be experienced immediately. This technology has great potential but suffers from some issues and limitations. Some users experience motion sickness, especially when navigating smoothly rather than by “teleporting” between viewpoints. Level of detail and realism is limited, as complex models quickly cause drops to FPS (Frames per second), causing more motion sickness. Processing complex geometry, realistic vegetation, distant areas etc. is not possible, except with powerful computers and high levels of optimization.

Navigable models currently require specialized hardware such as Oculus Rift or HTC Vive, with a connection to a powerful computer. A mobile phone does not have the processing power to render anything beyond relatively simple models “live”.

Technologies such as Oculus Rift and HTC Vive are essentially head-mounted displays with gyroscope, controls and tracking devices. Tracking devices are set up in a room, and the Head-mounted display is connected to a computer. VR experiences shown on the screen are generated by a nearby computer, preferably with a powerful GPU unit. These technologies are not highly mobile, but flexible in use due to powerful processing. Adoption of this technology is less widespread and purchasing cost of devices is prohibitively high for many potential users.

### Stereoscopic vision

Stereoscopic vision is the ability to perceive depth by presenting two eyes with slightly different images. As HMD VR uses a separate display for each eye, the technology is easily capable of taking advantage of stereoscopic vision. Some individuals lack this ability (stereo blindness) and may not experience the full benefits of immersive VR-technology.

### 2D CAD

2-dimensional computer-aided design: Software used to create precise digital drawings across all design fields, similar to traditional technical drawings. Autodesk AutoCAD and Bentley MicroStation are common examples. (These programs are now also capable of 3D-modeling)

### 3D modeling software

Computer program which allows users to create digital 3D models, such as SketchUp and 3ds Max.

### BIM/Building Information Modeling

Technology used to create digital 3D models where objects, materials and other elements contain parameters or information beyond their "physical" shape and placement. These parameters can be used to model or more efficiently, quickly generate technical drawings, calculate quantities or store relevant information about the properties of objects which can easily be retrieved.

### Photogrammetry

Powerful technique used to generate digital 3D models from photographs of real-world objects, such as cities in Google Earth. Large numbers of photographs are taken from overlapping angles. The similarities and difference between each image is used to calculate the shape of the object. Textures are extracted from the photographs and can be correctly mapped onto the model automatically.

### Equirectangular projection

Common form of projection for mapping a spherical plane to a flat rectangular format, similar to the Mercator projection used on world maps. This projection is used by Lumion to store VR spheres in JPG format.

## Software and smartphone apps used

### Trimble SketchUp

SketchUp is a relatively simple and intuitive 3D modeling computer program used across numerous design-related fields. Due to its low cost, free version for personal use and user-friendly interface, SketchUp has an unusually large user base. The base program is initially limited, but hundreds of plugins increase its modeling capabilities and other aspects. The case study is modeled mainly using SketchUp.

SketchUp is widely used by practicing landscape architects (Albracht, 2016).

### Act-3D Lumion

Lumion is a specialized program for rendering still illustrations, animation and VR spheres from imported 3D models. It is comparatively user-friendly and very fast, but has important limitations and does not generally produce the most accurate and realistic visualizations. For intermediate levels of detail and realism, Lumion's fast rendering speed is a significant advantage over traditional rendering software solutions- especially for VR and animation, where rendering speed are particularly important. Lumion can import a wide range of digital models, including from SketchUp.  The VR spheres created for the case study and used in the survey are generated using Lumion.

Despite relatively high cost, Lumion is somewhat widely used within the field of landscape architecture in Norway. Both NMBU (Norwegian University of Life Sciences) and Norconsult (My current employer) possess licenses for Lumion.

### Adobe Photoshop CC

Photoshop is the dominating software within the field of raster graphic editing. It has a wide range of applications, and some 3D modeling capabilities. Photoshop has been used extensively during the case study, including for creating textures, producing normal maps, generating 3D meshes from depth maps and editing VR spheres.

### Autodesk ReCap

Autodesk Recap is a photogrammetry software, used to generate digital 3D models based on photographs and/or laser scans. Photogrammetry was explored for the case study, and ReCap was used to generate some of the 3D models used in this case study. ReCap replaces earlier software which used to be free of charge but was recently discontinued. The current version is available with a free educational license.

### Autodesk AutoCAD

The case study project was largely developed in AutoCAD. Adjustments to original CAD plans were made in AutoCAD to speed up modeling in Sketchup, e.g. giving contour lines an elevation value.

### IrisVR Scope

Currently among the most popular and user-friendly apps used to present VR spheres. Scope can be used to easily share VR spheres with other users, and to display VR spheres in browser windows. The service requires monthly subscription. Scope works well with Google Cardboard and Gear VR.

### Oculus 360 Photos

Official 360 Photo app for Oculus Rift and Samsung Gear VR, capable of presenting VR spheres on a smartphone easily. Overall less user-friendly than IrisVR Scope but free with Samsung Gear VR.

# APPENDIX II (SURVEY)

| Bakground information | | Question | Alternatives (10: very useful/beneficial/easy) | Participant 1<br>Scores/ choices | comments |
|---|---|---|---|---|---|
| These are some common examples of design processes. (Linear, "black box", iterative etc) | *Question 1* | Which of these, if any, best describes your own process? | Black box, linear, iterative, explorative, complex. | | |
| Here are some common work methods (hand drawing, 2D CAD etc.) | *Question 2* | Which work methods do you use daily? | Hand drawing, physical model, 2D CAD, 3D CAD/BIM, other? | | |
| | *Question 3* | Which work methods do you use occasionally? | Hand drawing, physical model, 2D CAD, 3D CAD/BIM, other? | | |
| Here are some common methods used to evaluate ideas (quick sketch etc.) | *Question 4* | Which of these techniques do you commonly use to evaluate your designs/ideas | Mental img., sketches, sketch model, 2D CAD, 3D CAD/BIM, quick renderings, other? | | |
| | *Question 5* | Are you familiar with Virtual reality? | No, yes/comment | | |
| | *Question 6* | Have you gone through a virtual reality experience before? | No, yes/comment | | |
| | *Question 7* | Have you used VR tools in your design work before? | No, yes/comment | | |
| | *Question 8* | How useful do you expect VR to be in your design process? | 1-10 scale | | |
| | *Question 9* | Why do you imagine VR is not more widely used within landscape architecture? | comment | | |
| | *Question 10* | How familiar are you with the botanical garden at Milde? | 1-10 scale | | |
| | *Question 11* | How familiar are you with the ongoing botanical garden redesign project | 1-10 scale | | |
| Project is introduced, and is VR demonstrated | | | | | |
| Case study project is explained in some detail, using plans and site photographs. 3D model and VR spheres are explained. (This is the current Botanical Garden at Milde, south of Bergen. These plans shows the updated design. In broad stroaks: we are expanding the garden...) | | Limited to project of a similar type and level of complexity - **If added to your current workflow, would this tech likely improve your ability to:** | | | |
| A lot is happening in this space. We wanted to find out whether the space feels chaotic, or is well defined and legible. | *Question 12* | Evaluate whether spaces are legible and well-defined | 1-10 scale | | |
| We explored adding an amphitheatre to a grass slope, and wanted to know what it would look like from this area. | *Question 13* | Evaluate the effect of design descicions on site topography | 1-10 scale | | |
| When looking at the new pavilion design in 3D, we felt that the construction is probably too heavy and should feel lighter. | *Question 14* | Evaluate the visual effect of built elements | 1-10 scale | | |
| In order to guide people towards the entrance and exit, we placed a pavilion by the south entrance. We hoped that it would be visible from the amphi area. | *Question 15* | Evaluate the effect of design descicions on lines of sight within site | 1-10 scale | | |
| When entering through the south gate, we want to draw people towards the "new part", so we added a visual focal point here to get their attention. We wanted to know how visible it might appear, and whether it is obstructed by trees. | *Question 16* | Evaluate the visual effect of focal points | 1-10 scale | | |
| We noticed on the 3D model that planned and existing trees will likely cast shadow on amphi during late afternoon in the summer months, and wanted to evaluate whether they should be kept or removed. | *Question 17* | Evaluate the effect of sunlight and shadows | 1-10 scale | | |
| This is the "childrens forest". We hoped to get a sense of what that area might feel like. | *Question 18* | Evaluate whether spaces feel appealing and safe or not | 1-10 scale | | |
| This forest is very dense and natural today, and not really in use. We wanted to evaluate whether it should be kept this way, or turned into a park-like managed forest. | *Question 19* | Evaluate your choice of vegetation | 1-10 scale | | |
| We were worried that the park north exit might not be obvious at all, especially when coming through from here. Also, we wanted to get a feeling for how inviting the various paths would feel. | *Question 20* | Evaluate well users will experience navigation on site | 1-10 scale | | |
| After dropping a VR sphere in the baroque garden, we discovered that the labyrinth entrance is very difficult to spot from ground level due to being dark and shaded, when the sun is in the south. | *Question 21* | Discover unexpected issues before construction | 1-10 scale | | |
| We are planning a new construction, the elevated tree crown path, and consider whether it should come out of the forest for the vistas, and to bind the park together visually. | *Question 22* | Evaluate the effect of design descicions on external vistas/borrowed views | 1-10 scale | | |
| | *Question 23* | Ignoring time spending - which LOD conveys relevant information most clearly during late design stages | Abstract, intermediate, realistic | | |
| | *Question 24* | Ignoring time spending - Which LOD conveys relevant information most clearly during early design stages | Abstract, intermediate, realistic | | |

VR headset is put aside

| | | | | | |
|---|---|---|---|---|---|
| | *Question 25* | How relevant do you think these kind of evaluations are for achieving good design outcomes? | 1-10 scale, feel free to add comment | | |
| | *Question 26* | How accurately do you feel that the VR model represents the proposed scheme? | 1-10 scale | | |
| | *Question 27* | (Having experienced VR) How useful do you expect VR to be in your design process? | 1-10 scale | | |
| | *Question 28* | Is VR likely useful for sharing your vision with colleagues unfamiliar with a project for feedback? 1-10 | 1-10 scale | | |
| | *Question 29* | How easy was it to communicate with me while wearing the Samsung Gear VR headset?<br>(e.g. to locate a specific focal object) | 1-10 scale (10: very easy) | | |
| | *Question 30* | Is VR likely to lead to a better outcome of the design process? | Yes/no/don't know | | |
| This project has 300 hours for LA forprosjekt, (1000 in total, all phases) 45 hours were spent on creating the 3D model. (not including exploring various methods etc) | *Question 31* | Would you consider it time well spent in a typical project like this? (in a typical project of this nature) | 1-10 scale | | |
| I spent an additional 6 hours setting up and creating about 15 VR spheres (not including rendering during off-time) | *Question 32* | Would you consider this (additional) time to be well spent? (in a typical project of this nature) | 1-10 scale | | |
| | *Question 33* | Is use of VR tech likely to increase overall time spent on project? | Yes/no/don't know | | |
| | *Question 34* | What are the main barriers which might keep you from adopting VR technology? (if any) | comment | | |
| | *Question 35* | Did you find the experience nauseating or uncomfortable? | No, yes/comment | | |
| | *Question 36* | Did you find the exploring the VR spheres a pleasant experience? | 1-10 scale | | |

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