UNIVERSITY OF OSLO

Master thesis

A no-code design approach to sitsim development

An inquiry into the dissemination of cultural heritage sites using augmented reality

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Master's thesis in Media Studies

60 ECTS

Department of Media and Communication

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Acknowledgments

In my late twenties, I decided to pursue a bachelor's degree, as I believed it was necessary to get the jobs I desired. I planned to complete my studies while working and then continue my professional life. I am grateful to the Department of Media and Communication staff for demonstrating that investing my time in studying was a wise decision. Within a year as a student, I decided to pursue full-time studies, not because it was hard to study alongside work, but because I enjoyed the hours attending lectures and spending time in the library so much.

Over the last few years, I have researched, developed, modeled, and troubleshooted in order to comprehend sitsim design. In many ways, this has been my way of relaxing, and I've enjoyed every moment. Media design is a perfect fit for me because it allows me to combine practical, hands-on work with my interest in problem-solving through research. I want to thank my MA supervisor Gunnar Liestøl for involving me in his research since my bachelor's degree. He encouraged me to write and publish an article based on my bachelor's research. He invited me to be a teaching assistant in one of his courses and included me in multiple sitsim projects. I'm genuinely thankful for your support, and I hope this thesis is something you can endorse.

During my master’s studies, I worked part-time at HF:Studio, a learning center at the University of Oslo's Faculty of Humanities. Although it meant leaving my favorite office chair at IMK in Forskningsparken and moving to a different one in Sophus Bugges hus, I became increasingly involved in the center. This led to a change in my initial plan to work part-time as I was offered to coordinate the center. As a result, I am writing these acknowledgments one semester later than initially planned.

I want to thank my colleagues at HF:Studio for being both inspirational and my friends. Thank you for the coffee breaks and laughs. I would also like to thank Peter and Sindre for helping me test one of the AR prototypes I developed for my thesis.

I would like to thank my parents and sister Anne for their support throughout my decision to quit my job and pursue my studies; thank you for always being on my team! I am also extremely grateful to my parents for their help in the final weeks of my thesis work when they helped us by taking care of our children, Oliver and Ellinor.

Ending my acknowledgments where they should have begun, I want to express that my family was the main reason for me to pursue an education. Apart from the obvious motivation of studying to get a job, I wanted my son Oliver, who is almost four, and my daughter Ellinor, who is six months old, to have a father with an education; they have been an immense motivation. Thank you both for waking me at 5 with a smile!

I have watched my wife achieve more than I thought was possible in her academic career, almost making it appear easy. However, after years of my own studies, I have come to admire you even more because I have seen all the hard work firsthand. Thank you, Kine, for always being there, believing in me, and being my greatest inspiration. Thank you for reviewing my work and providing me with valuable insights. Your feedback has shown me that I have so much more to learn.

Abstract

This thesis explores the dissemination of cultural heritage sites using augmented reality (AR) and the Situated simulations (sitsim) platform. Sitsim experiences consist of the user's visual perception of the actual physical surroundings and the visual perception of a 3D graphics environment shown on a handheld screen. Currently, sitsim utilizes indirect AR, which is similar to AR, except that it provides virtual elements on the entire display rather than overlaying virtual objects onto the real world. Indirect AR is used due to three main challenges with AR systems: (1) alignment – aligning real-world imagery and virtual elements accurately while the app is in use, (2) occlusion – ensuring that virtual elements are correctly removed when they need to appear behind real elements in terms of depth, and (3) calibration – aligning virtual and real-world elements during development. However, novel technologies, such as the Lidar sensor in the Apple iPhone 12, may provide opportunities to utilize AR within the sitsim platform instead of indirect AR. Furthermore, studies have shown that user testing at early stages helps find desirable solutions for end-users.

This thesis aims to evaluate whether the Lidar sensor has advanced AR technology sufficiently to address the issues of registration, occlusion, and calibration in cultural heritage dissemination. The thesis also aims to improve user experiences through user testing with no-code and low-fidelity prototypes in earlier stages of development.

To investigate technical aspects and user experiences, this thesis involved the development of low-fidelity prototypes. These prototypes were created using three no-code development tools: Unity, Reality Composer, and Adobe Aero. The prototypes were used to gather user feedback in the early stages of the design process and were evaluated using methods from design science and media studies. Insights were gathered through self-participation and user tests with the prototypes, performed via think-aloud methods and unstructured focus groups.

I find that Lidar sensors can enhance AR experiences, especially in indoor settings and when the distance between the device and real-world objects is short. Optimal conditions are seldom achieved in real-world scenarios, suggesting that AR still faces challenges in achieving widespread adoption in cultural heritage applications.

While exploring user experiences with AR, concerns such as the limited field of view and the wish to view the virtual content from other perspectives arose. These limitations with AR come in addition to the three primary concerns that initiated my investigation. Therefore, my findings suggest that indirect AR is a beneficial mode of representation for sitsim.

Acronyms

AI Artificial Intelligence

API Application Programming Interface

AR Augmented Reality

AV Augmented Virtuality

CMS Content Management System

CSCL Computer-Supported Collaborative Learning

FBX FilmBoX

GPS Global Positioning System

GLONASS GLObalnaya NAvigatsionnaya Sputnikovaya Sistema

HMD Head-Mounted Display

HTML HyperText Markup Language

MR Mixed Reality

NCDP No-Code Development Platform

HCI Human-Computer Interaction.

ICT Information and communications technology

iOS Iphone Operating System

LCDP Low-Code Development Platform

LIDAR Light Detection and Ranging.

SDK Software development kit

UI User Interface

USDZ Universal Scene Description Zip

UX User Experience

WWDC Worldwide Developers Conference

XR Extended Reality

Glossary

Situated simulation (Sitsim)

In a sitsim, there are two connected components: the user's visual perception of the actual physical surroundings and the user's visual perception of a 3D graphics environment shown on a handheld screen. The 3D environment shown on the handheld screen relates to the device's positioning and orientation, providing similarity between the real and virtual perspectives. The 3D environment can convey information about the location's past, present, or future. The entire screen is filled with virtual content. Hence, sitsim uses a mode of representation called indirect AR.

Augmented reality (AR)

AR in this thesis is understood adhering to Ronald Azuma's definition (Azuma et al., 2001). AR involves overlaying digital information or virtual objects onto the real world, typically through a mobile device. It allows users to interact with and experience a blended reality that combines the physical and digital worlds.

Indirect AR

Closely related to AR is indirect AR, coined by Wither et.al. (2011). indirect AR provides virtual elements on the entire display, creating a distinct but minor difference between the device's artificial perspective and the user's real perspective. The perspective provided by the indirect AR device moves relative to the user's movement on a location.

Software development kit (SDK)

SDK is a set of tools, libraries, and documentation that developers use to create software applications for specific platforms or frameworks. An SDK provides resources that help streamline the development process by offering pre-built functions, APIs (Application Programming Interfaces), sample code, and debugging tools.

Light Detection and Ranging (Lidar)

Lidar is a remote sensing technology that uses laser light to create detailed 3D maps or point clouds. Lidar is being used in mobile devices like smartphones and tablets. It enables improved depth-sensing, 3D mapping, and various applications like AR and indoor navigation.

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Preface

This thesis investigates the dissemination of cultural heritage sites using augmented reality (AR), with a no-code design approach. Design involves creating something new, and in media design, researchers synthesize their products and study them in the process (Nyre, 2014). Media design is often connected to, yet different from, media innovation. Media innovation involves the analysis of societal and economic changes and developments in the media landscape (Storsul & Krumsvik, 2013). However, one of the main benefits of media design is that it provides valuable insights to understand and analyze media innovations.

When conducting media innovation analyses, one needs to be dynamic and adaptable. Over the last year alone, the industry has undergone numerous rapid changes, like the advent of commercialized Artificial Intelligence (AI) and new products such as Apple Vision Pro, a head-mounted display (HMD) that blends real and virtual environments in front of the user's eyes (Apple, 2023a). The media design approach facilitates comprehension of rapid changes by equipping researchers with tools for in-depth analysis of a field of inquiry. I have worked from a media design viewpoint to investigate the research field of mixed reality, which involves using novel technology to blend real and virtual elements to augment the real world with virtual layers of information.

My aspiration with my thesis was to present something new, an invention. Using new technology, I expected to align virtual elements properly in AR with real-world elements captured by the device's camera. I believed that a new mobile device, released when I started this research project, would solve the technical issues preventing satisfactory mixed reality at cultural heritage sites. These experiences sparked the idea of developing an augmented reality experience situated at a location alongside one of my favorite hikes in Oslo. The illustration in Figure 1 shows how I envisioned the experience – a virtual building that perfectly aligns with the ruins in the actual location. While working on this thesis, however, I have become humbled by the previous work within this field.

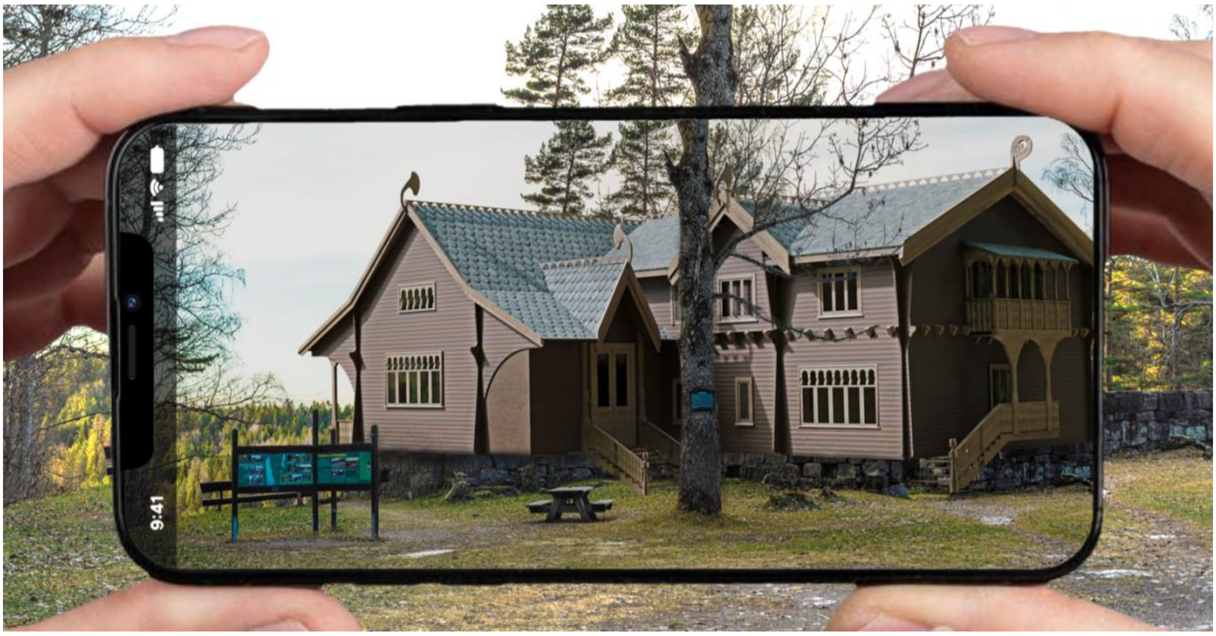

Figure 1: This illustration presents my vision for my project, an augmented reality (AR) experience: a virtual building that perfectly aligns with the ruins in the actual location. Trees and other physical elements would seamlessly integrate into the experience. The illustration has been post-processed in Photoshop to illustrate my aspirations for the project. The example does not accurately reflect the actual results.

As a bachelor's student, I took the course: “Media students as researchers – design in mobile media” (my translation). This course introduced me to the sitsim (situated simulation) platform. Sitsim allows users to better experience and understand Cultural Heritage sites by providing enriched digital content, such as visual reconstructions and narration, overlaid on a Cultural Heritage site (Liestøl et al., 2011). One of the key findings from my first sitsim development was that it is difficult to predict user feedback (Bøe, 2021).

Therefore, I have worked extensively throughout my thesis to get feedback at the early stages of development. My thesis presents a framework to gain insights from prospective users throughout the design process while exploring AR as a mode of representation at cultural heritage sites. I have been fortunate to continue working as a research assistant and teaching assistant with my supervisor, Gunnar Liestøl, alongside my MA studies. As a teaching assistant, I have partaken in teaching students 3D modeling as a part of their coursework. As a research assistant, I have contributed to multiple sitsim developments. These projects have contributed to and paved the way for the research presented in this thesis.

Introduction

Sitsim and cultural heritage dissemination using AR

The sitsim platform uses mobile devices, like phones and tablets, to add a new layer of information to a heritage site, hence augmenting the information that the site provides in itself. This augmentation does not occur one-dimensionally on a screen surface but in conjunction with the user's physical presence at a location (Liestøl, 2011a). Sitsim is founded on an indirect Augmented Reality approach, where the entire screen surface of a mobile device is covered with virtual content that mediates the surroundings where the user points their device.

The most common definition of AR proposes that the augmentation happens on the display surface (Azuma et al., 2001). According to this definition, in AR, the screen shows a mix of the real environment captured by the device’s camera with virtual elements aligned with the real world and registered in real-time in 3D (Azuma et al., 2001).

When sitsim development began, technical limitations were among the main reasons why indirect AR was chosen. The devices at that time did not mix real and virtual elements satisfactorily. The main issue was that the hardware could not compute advanced and realistic graphics. In addition, registration and alignment issues would have prevented virtual content from properly aligning with actual content captured by the device`s camera (Liestøl & Hadjidaki, 2019).

Panel A: AR Panel B: indirect AR

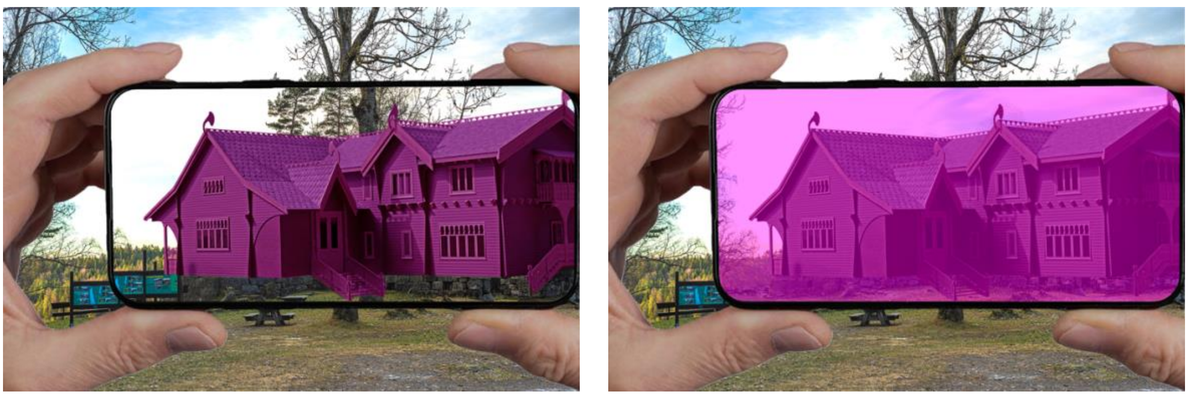

Figure 2: Panel A illustrates Augmented Reality (AR). The background shows the real world, while the device displays the real world as captured by the camera with virtual elements marked in pink. Panel B shows the real world in the background, and the device displays all virtual elements marked with pink that resemble elements of the real world.

Another major issue with conventional AR is the inability to adequately remove virtual content when a real object, as captured by the camera, appears in the spatial location where the virtual object should be placed (Figure 3) (Kasapakis et al., 2016). In AR, virtual content usually appears on top of anything the camera captures. This means that, for instance, if a person walks in front of a virtual object, the object will still appear on top of the person. This can sometimes impair the AR experience (Apple, 2023c). When an AR system removes a virtual element partly or entirely, this is called occlusion. Occlusion means that the virtual element is not rendered on the screen.

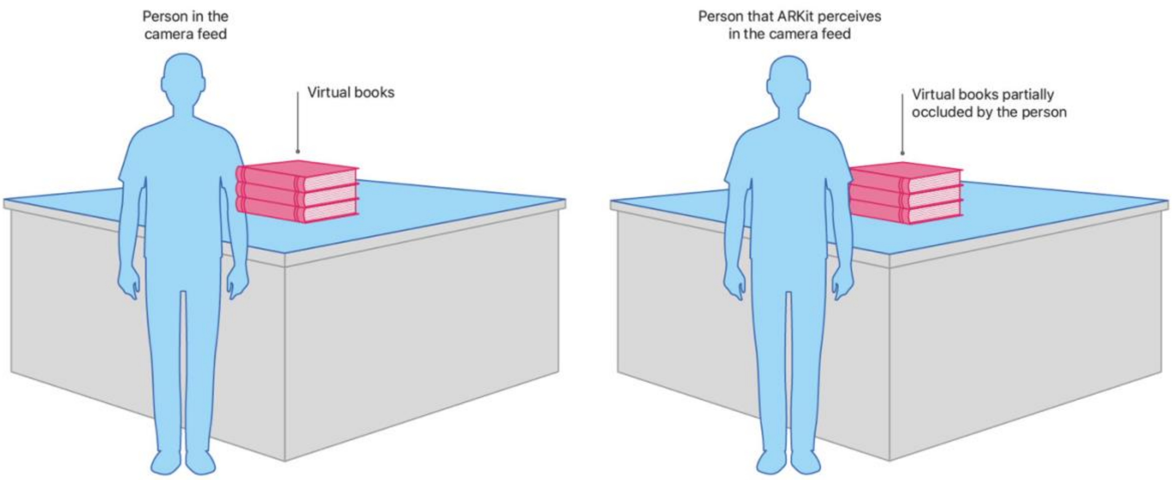

Figure 3: Virtual content overlays anything in the camera feed by default. However, this can sometimes lead to breaking the illusion of the AR experience. For instance, if a person passes in front of a virtual object, the object will be drawn on top of the person (Apple, 2023c).

Shortly after conducting my first sitsim test on location, the iPhone 12 was launched. It was equipped with a novel sensor technology known as a Lidar sensor that measured depth in the environment in front of a mobile device. This was promoted as a sensor that could reduce alignment and registration issues and improve enhanced occlusion abilities. Consequently, my research aims to explore the relationship between indirect AR and AR in the representation of cultural heritage. I aim to understand if the technology has matured sufficiently to expand sitsim into AR, and to investigate what scenarios would still be best experienced in indirect augmented reality.

This thesis reports findings from several sitsim developments that address various parts of my research questions. I also conducted a case study to tackle the aforementioned issues frequently discussed in the literature regarding AR dissemination of cultural heritage. This case study proposes a method for developing AR prototypes using a no-code approach. The thesis draws on media studies and design science to answer my research questions, making it interdisciplinary.

Research background and extent of study

I propose a method for developing and testing AR-app prototypes, potentially contributing to developing the sitsim genre and design processes. The proposed approach will reduce the development time of low-fidelity AR-app prototypes compared to conventional sitsim development methods. Developing spatially aware AR apps for mobile platforms often requires significant development resources. However, app prototypes can be created without extensive programming knowledge using no-code development platforms (NCDPs) with graphical user interfaces. Using NCDPs reduces resource costs for prototype development, thus further expanding the possibilities for progress in the engaging sitsim genre.

My approach follows methods from design science while being grounded in the humanities and Liestøls synthetic-analytic approach (Liestøl, 1999). The synthetic-analytic approach involves developing a synthesis based on genre conventions from preexisting media forms or genres and analyzing the innovation based on humanistic methods.

As a case example, I have developed a prototype based on conventions from the sitsim platform on a cultural heritage site at Sarabråten in Oslo. The prototype explores whether AR has matured sufficiently for cultural heritage applications, particularly concerning alignment and occlusion issues. This question is addressed by testing three apps developed using various AR composing tools: Apple Reality Composer, Unity, and Adobe Aero. Initially designed to answer a research question about typical issues in AR for cultural heritage, the experiment also investigates whether using NCDPs is a feasible method for solving problem statements in the early stages of sitsim development.

Why is this important?

To understand and analyze media texts in this fast-paced technological landscape, one should have the technical understanding to understand what drives media innovation (Fagerjord, 2015). At the same time, technology advances at such a rate that the problems you are working on are likely already solved if you do not have a fast turnaround. Hence, to make actual contributions to a field of research, one needs to discern good ideas from bad ones quickly.

Research questions

With my thesis, I aim to address the following research questions derived from collected problem statements and arguments:

1. Has the Lidar sensor advanced AR technology sufficiently to address previous issues with alignment, occlusion, and calibration in cultural heritage dissemination, making the advantages of indirect AR less relevant?
2. How could no-code approaches and low-fidelity prototypes be used to get answers to problem statements at earlier stages of sitsim development?

These research questions work in conjunction throughout my thesis because I could not have answered question number one without the tools developed through question number two. At the same time, I could not have analyzed whether the advantage of indirect AR is less relevant without the extensive technical understanding provided by synthesizing products on my own.

Methodological approach:

To answer these questions, I propose a methodological approach combining elements from design science with the synthetic-analytic method grounded in media studies. These method choices are influenced by Lars Nyre's media design method (2014). The first stages of the research design involve investigating shortcomings with cultural heritage dissemination using AR. Further, genre conventions from sitsim are identified and used as benchmarks for the prototype development. I also suggest methods to explore alternative ways of gathering user feedback. I provide an example from a future workshop to investigate user feedback at early development stages.

For my case example, I perform user testing on location. To gather user feedback, prototype tests are conducted using humanistic evaluation methods (Fagerjord, 2015), such as Think-aloud and focus groups. Think-aloud methods involve vocalizing users' thoughts and actions while interacting with a system, providing valuable insight into their decision-making processes, frustrations, and needs (Fagerjord, 2015). Focus groups allow users to express their opinions in a more structured format. In addition to the answers I get from users, I report on my findings utilizing self-participation methods (Brattli et al., 2023).

By combining these data collection methods (Design science/human-computer interaction studies, synthetic-analytic methodology, think-aloud methods, self-participation, and qualitative focus group), I provide a framework that also can be used for future sitsim developments. The provided framework has offered me useful feedback at the initial stages of sitsim development, which can be valuable in larger projects developing high-fidelity prototypes and subsequent release candidates.

Theory and literature review

Historical overview of extended reality

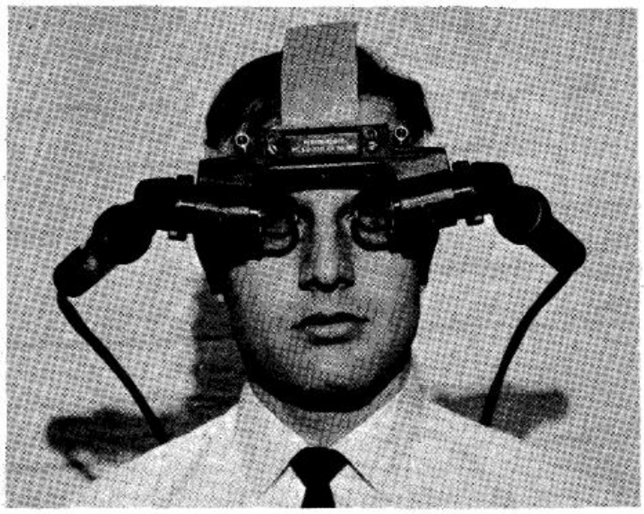

Figure 4: Ivan Sutherland's Ultimate Display concept (Sutherland, 1968).

AR technology has its roots in the 'Ultimate Display' concept, which was first introduced in 1968 by Ivan Sutherland, a famous computer scientist also known as the "father of computer graphics" (Engberg & Bolter, 2020; Sutherland, 1968). He developed the first head-mounted display (HMD) system, which connected the physical and digital worlds.

A few decades later, Boeing researcher Tom Caudell officially coined the term 'Augmented Reality' while developing a method to assist in assembling wire harnesses in aircrafts (Engberg & Bolter, 2020). His utilization of holographic overlays for projecting digital images into 3D space represents one of the fundamental applications of AR.

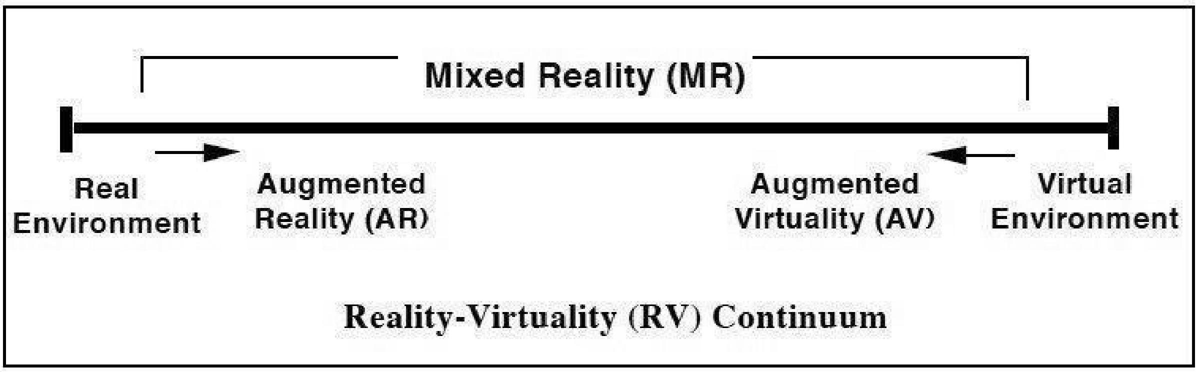

Figure 5: Milgram and Kishinos Reality-virtuality continuum (1994).

An attempt to define a taxonomy of the range of experiences between unmediated reality and completely immersive virtual experiences was made by Milgram and Kishino (1994). The existing forms between these extremes were termed mixed reality (MR) environments. Thus, mixed reality was conceived as the different continuum points at which real and virtual objects were merged, AR being one such mode of representation.

The understanding of the term AR was further enhanced through the work of Ronald T. Azuma (2001). Azuma's AR definition helps explain the different aspects and layers of AR. It is based on three key characteristics:

1. **Combines real and virtual:** AR involves blending real-world and virtual elements. It does not entirely replace the real world with a virtual one (like Virtual Reality); it adds or overlays virtual components such as images, sounds, or other data to our real-world environment.
2. **Interactive in real-time:** The second point of Azuma's definition is that AR is interactive in real-time. It means that the virtual elements added or overlaid in the real world dynamically adjust and react to the changes in the environment or the user's interaction. For example, as a user moves his mobile device, the virtual elements also change their positions.
3. **Registered in 3D:** Lastly, AR objects are registered in three dimensions, meaning they appear to exist in our real-world space. They are not merely two-dimensional images but appear as actual objects with depth and occupy space.

An important note is that Azuma's AR definition underlines that for any system or technology to qualify as AR, it should adhere to all three aspects (Engberg & Bolter, 2020). When referring to AR, I will address the term following Azuma's definition.

An extension to the term mixed reality, more frequently used in today's literature, is Extended Reality (XR). Extended reality is a term that encompasses all environments and interactions that combine both the real and virtual worlds (Engberg & Bolter, 2020). Extended reality applications have significantly impacted the presentation of cultural heritage at various locations (Bekele et al., 2018).

Extended reality in digital cultural heritage dissemination

The emergence of sensory media and handheld digital devices (e.g., phones and tablets) equipped with various sensors provides new possibilities for dissemination. These sensors can register multiple input types, including movement, orientation, and rotation, among others (Liestøl et al., 2012). The use of sensory media to create innovative solutions for disseminating cultural heritage is referred to in the literature by several different terms, such as Cultural Computing (Haydar et al., 2011), Spatial Computing (Geronikolakis et al., 2020), Virtual Heritage (Bekele et al., 2018), and Digital cultural heritage (Kremers, 2020). However, recent literature has gathered around the term digital cultural heritage. Digital cultural heritage is a broad term including digital content worth preserving and the technologies utilized to disseminate cultural heritage (Kenderdine & Cameron, 2007). Using extended reality to disseminate cultural heritage sites involves telling stories that may have otherwise gone untold.

We create stories when we interact with places, objects, and people. Most of the time, these stories remain untold and must be made evident to the public. Technology has made it easier to understand and remember the stories related to cultural objects and sites. It helps make abstract concepts and meanings related to cultural objects more visible, making them understandable to visitors (Fanini et al., 2023). This enhances visitors' experience and helps them recognize and remember things that might have gone unnoticed. The potential of technologies, such as AR, to improve this understanding of our shared cultural heritage is immense, but there are still some challenges to overcome. In the following, I discuss three main challenges: registration, occlusion, and calibration.

One of the main issues in the dissemination of cultural heritage with AR is the registration problem, where virtual objects fail to align precisely with real-world objects (Marto & Sousa, 2018). Azuma pointed out these issues as early as 1997 when he described even minor registration errors as easily detected by the human eye (Azuma, 1997). When the real and virtual layers fail to register correctly, the illusion and experienced realism are impaired. An example of a registration issue is when there is a discrepancy between the movement of the device and the movement of the virtual element. This issue commonly occurs in a Cultural Heritage site, for example. when a part, such as a building, fails to align with a real-life object, such as a ruin. The user will sense that the element is just glued on, breaking the illusion of realism.

Another frequently reported limitation of AR in Cultural heritage representation is connected to issues with occlusion (Kasapakis et al., 2016). When a virtual element overlays a physical object present in the space between the device and where the virtual object should be placed, the illusion of the virtual component being connected to the location is broken (Tian et al., 2019). To solve this issue, the device needs to understand depth to occlude, i.e., remove the part of the virtual object that should be covered by the physical object, referred to as occlusion culling (Figure 3).

A third issue with AR in cultural heritage dissemination is calibration (Fanini et al., 2023), which means the process of ensuring virtual objects align correctly with camera imagery when starting the experience on location. This refers to both calibration in the development phase and for the user. If the user must perform multiple tasks to ensure the virtual objects align with the location, this can break the experience. From a developer's point of view, this is a job that always needs to be performed, and it can be a discouraging task because it requires a combination of multiple sensors in the device to work together and provide consistent results. In my thesis, I only investigate calibration from a development viewpoint.

Sensory media

The improvement of smartphone technology at the beginning of the 21st century played a significant role in transitioning AR from an experimental technology to a widespread consumer product. Companies like Apple and Google accelerated the development by incorporating AR capabilities into their mobile operating systems through Software Development Kits (SDK), such as ARKit and ARCore. These advancements enabled consumer-grade mobile devices to interpret and augment the world around us, thus making AR technology more available. The technology was popularized through games like Pokémon GO and later through different "lenses" in Snapchat (Druga, 2018).

The most prominent sensor for creating AR experiences on location is the Global Positioning System (GPS). Similar to the situation with cellular service, the accuracy of GPS positioning depends on, among others, satellite availability, the phone's location, obstructions to its view of the sky, etc. A recent development in device positioning was the introduction of Dual Frequency GPS (Goodwin, 2022). Apple has implemented a dual-frequency GPS in the iPhone 14 Pro, which utilizes so-called L1 and L5 bands to achieve higher accuracy. The L5 band has more power and can detect unwanted reflections, resulting in the potential for centimeter-level GPS accuracy on the latest iPhones. However, there is still a discrepancy between potential precision and real-world accuracy due to the abovementioned variations. iPhone positioning has developed extensively over the years, utilizing a sensor fusion of different internal components, such as Wi-Fi, GPS/GLONASS, Bluetooth, magnetometer, barometer, and cellular hardware (Apple, 2023b). These data points are gathered on-device and provide a location that apps can obtain through the *Core Location* framework, which is a part of the iOS SDK. The sensor fusion, i.e., the combination and amplified results of combining different sensor inputs, could be expanded by adding Lidar.

Lidar is an essential technology to consider for AR due to its ability to use laser range probing to create accurate environmental reconstructions as point clouds (Kuzma, 2022). However, this technology has challenges. In certain situations, Lidar may not be effective in accurately tracking or distinguishing moving objects (Postica et al., 2016), which is a problem with mobile devices that are constantly in motion. Using Lidar can also cause noise that provides inefficiency in occlusion (Kuzma, 2022). However, it is worth noting that Lidar can still provide high accuracy and effectiveness in reconstructing static environments.

AR and indirect AR

Sensory media was the foundation when Professor Liestøl at The University of Oslo designed sitsim to supplement a location with a virtual layer representing the location's past, present, and/or future. Sitsim allows individuals to better experience and understand significant sites by providing enriched digital content such as visual reconstructions and narration. As a user points their smartphone or tablet at a certain point within the site, the sitsim platform provides a 3D reconstruction of the location on the device's screen. In essence, it empowers users with a visual journey through time.

The sitsim platform displays only virtual elements on the display surface, the virtual environment appear relative to the *in situ* unmediated reality of the user (Liestøl, 2011b). Hence, sitsim uses the mode of representation identified as indirect AR (Wither et al., 2011). When coining the term indirect AR, Wither and colleagues argued that indirect AR provided better alignment or registration between virtual elements due to the technical limitations of the current hardware. The advantage of indirect AR is that it creates a slight discrepancy in the perspective of the virtual environment, which makes additional discrepancies harder to distinguish when visually aligning with the real environment.

Sitsim development

In the autumn of 2008, the development of the "situated simulation" or "sitsim" began. The first prototype was designed for the second-generation iPhone (Liestøl, 2013). It included a reconstruction of the Oseberg Viking Ship, which was buried in 843 CE and excavated in 1904. The prototype had basic navigation and information access features (Liestøl, 2009). It was decided through the design and development processes that off-the-shelf hardware should be used, meaning there would be no proprietary combination of hardware elements, and only all-in-one terminals would be employed (Liestøl, 2013).

Apple's iPhone was chosen as a hardware/software platform due to the launch of the iPhone Software Development Kit. In March 2008, Unity3D announced support for exporting games developed in their platform to native iPhone applications. (Liestøl, 2013). The purpose of the software is to extract GPS data from the device, perform the required calculations to use the data in Unity, read the sensor output from the device's accelerometer, gyroscope, and magnetometer, and fuse the sensor data to provide Unity with the necessary information to align the view in the simulated environment with that of the actual physical world (Liestøl et al., 2011).

In 2010, a prototype of a sitsim from the Forum in Rome was developed, tested, and evaluated. This simulation included a reconstruction of the Roman Forum in 29 BC and 44 BC and employed four distinct dates. New features were added, including an internal web browser, user-generated links with a comment function, and hardware and software improvements (Liestøl, 2013). In 2012, the Roman Forum simulation was redesigned and published in Apple's app store (Liestøl, 2013).

Since 2013, the sitsim platform has seen several significant developments. The platform has been used to present a simulation of the plans for the new national museum in Oslo (Liestøl & Morrison, 2015) and for disseminating climate change (Liestøl et al., 2015). The platform has been adapted to the Android platform in addition to the iOS platforms, using the Unity game engine's support for multiple platforms (Liestøl et al., 2011). There have furthermore been improvements relating to different point of views in the simulation (Liestøl & Morrison, 2013). One of the outputs of the project has been a sitsim AR editor for Unity, developed to make sitsim development easier (Liestøl, 2019). I have contributed to recent platform developments with a solution for creating engaging applications for historical photographs by combining mobile augmented reality and gamification (Bøe, 2021). All these improvements have made the sitsim platform an engaging framework for spatial storytelling.

Spatial storytelling

Spatial storytelling is a narrative technique that engages a user within a mediated environment where discovery through exploration advances a non-linear narrative, and where space is the essential communication medium (Hameed & Perkis, 2018). It is inspired by immersive theater and environmental storytelling and is a method that shifts focus onto space, turning to the narrative potential of locations and places in our everyday life (Hameed & Perkis, 2018). By integrating spatial storytelling techniques into AR, designers can provide a unique storytelling experience, blurring the boundaries between the real and virtual worlds. AR enables users to interact with virtual objects and characters in their surroundings, enhancing their engagement with the story.

Research methodology

Media innovation and media design in the context of cultural heritage.

Media innovation is a field of research that involves the application of various scientific methods and theories to understand and explain changes and developments in the media landscape (Storsul & Krumsvik, 2013). This includes studying the influence of various factors, such as technology, user behavior, etc.

In the context of cultural institutions, media innovations have expanded museum exhibits beyond physical buildings, allowing access from anywhere on mobile devices and online (Stuedahl & Vestergaard, 2018). Thus transforming museums “into social institutions accessible from ‘everywhere’ and to ‘everybody’”, i.e., a distributed museum (Stuedahl & Vestergaard, 2018). Media studies provide a critical language for digital cultural heritage content, but researchers can better understand how these inventions are developed by delving into the underlying design principles and techniques.

This calls for a shift towards focusing on the creation process or synthesis (Liestøl, 1999; Nyre, 2014) rather than solely analyzing the end product or service. Adopting an interdisciplinary and practice-based approach, incorporating perspectives from fields such as human-computer interaction and interaction design, is essential for building a solid foundation of alternative media design research (Stuedahl & Vestergaard, 2018). This approach facilitates a more profound comprehension of media innovations and establishes a deliberate and methodical approach to media design. By adopting this method, we can better understand how media innovations operate and develop a structured and systematic approach to designing media products.

Media studies – synthetic-analytic methodology

Sitsim development is typically developed based on a synthetic-analytic methodology, which is an approach that involves using conventions from existing genres and media forms to create new ones (Bøe, 2021; Fagerjord, 2012). This draws on the understanding that new media remediates old media forms, making the new feel familiar and understandable (Bolter & Grusin, 1999). Development is typically done utilizing novel digital technology. The researcher begins the method by analyzing a design problem and formulating a solution (Fagerjord, 2012). After proposing a solution, the researcher creates an example (usually a prototype) to illustrate it. This example is then evaluated and compared to previous theories to determine whether the theory has been reinforced or if it can be improved or extended. The latest analysis is used as the basis for a new synthesis. The methodology involves a cyclical process whereby a new synthesis is developed based on analyses of feedback from previous iterations (Fagerjord, 2012).

"The philosophers have hitherto only interpreted the world in various ways,
The point, however, is to change it."

Karl Marx.

Design science - human-centered design principles

The field of media design has been greatly influenced by the design principles of human-computer interaction (HCI) or interaction design. These design traditions have been prevalent in information science departments under various titles since the 1970s (Nyre, 2014). An important aspect of technology development is user involvement. The Scandinavian tradition of Participatory Design (PD) during system development dates back to the 1970s. (Sanders & Stappers, 2008). In the early 1980s, the Utopia Project involved users in the early stages of development through interaction with low-tech prototypes, encouraging suggestions and critical thinking among test users. (Sanders & Stappers, 2008). The idea with these low-tech prototypes was to get early user feedback.

Participatory design and co-design

In their review of participatory design methods, Sanders and Stappers identified a shift from traditional user-centered design, where researchers lead the process and view users as passive recipients of information, to a co-design process where users are actively involved in the entire design process, including the development of research design (Sanders & Stappers, 2008). Co-design could be linked to the way sitsim has been developed, since Liestøl has involved students as researchers in the development of the platform (Bøe, 2021; Engmark, 2013; Orkelbog, 2012). Not because students necessarily should be considered users of the developed product but because students could provide insights into a design process that would otherwise go unnoticed.

Design thinking

Design Thinking is an approach to problem-solving that helps find desirable solutions for end-users (Leifer et al., 2011). Design thinking offers an alternative research approach by adopting a human-centered design principle. Design thinking, particularly research-based design, relies on a shared, social construction of understanding with the people who will later use the tools (Leinonen & Durall, 2014). Product design involves analyzing qualitative data from participatory design sessions and making design decisions related to the prototypes (Leifer et al., 2011). Through this approach, design thinking allows for the creation of tools that are not only based on research but are also tailored to the needs and contexts of the users. I utilize this flexibility to build a framework, especially for sitsim development.

Design thinking typically involves the following steps:

1. **Empathize:** Understand the needs and perspectives of the people you are designing for. This can be accomplished through self-participation in the design problem.
2. **Define:** Clearly define the problem or opportunity you are trying to solve.
3. **Ideate:** Generate a wide range of possible solutions to the problem.
4. **Prototype:** Create low fidelity, i.e., simple versions of the most promising solutions.
5. **Test:** Gather user feedback on the prototypes and refine them until you have a solution that meets their needs.

Human-computer interaction studies provide valuable methods for design, but a good argument for interdisciplinarity between media studies and design science is the latter´s sometimes simplified views of the user.

Audience-making - who is the user?

Audience-making refers to how industries perceive their audience (Sundet, 2021). The involvement of users in the design process involves the creation of a user, which is problematic because there is no “naturalized group” that represents users. As a result, there will always be a disparity between the real audience and the industry's understanding of the audience's (Sundet, 2021). The audience-making theories are based on Raymond Williams' idea that “there are no masses, only ways of seeing people as masses” (Williams, 2003). These ideas are essential in media design because they shape media production by influencing how audiences are perceived.

For the scope of my case study, I have not made any inquiry into who typically visits Sarabråten. Apart from self-participation exercises witnessing visitors on the location. The way I perceive my audience might affect the design process, and because I don’t know who the audience is, I develop and design toward an imagined audience. This still contemplates a way of seeing people as masses; however, asserting my imagined user makes it easier to be transparent about how my ways of seeing the audience have affected design choices.

I contemplate my imagined user based on McKercher’s attempt at a classification of cultural tourists (McKercher, 2002). McKercher divides cultural tourists into categories based on the experience sought and “the importance of cultural motives in the decision to visit a destination” (see: Figure 6).

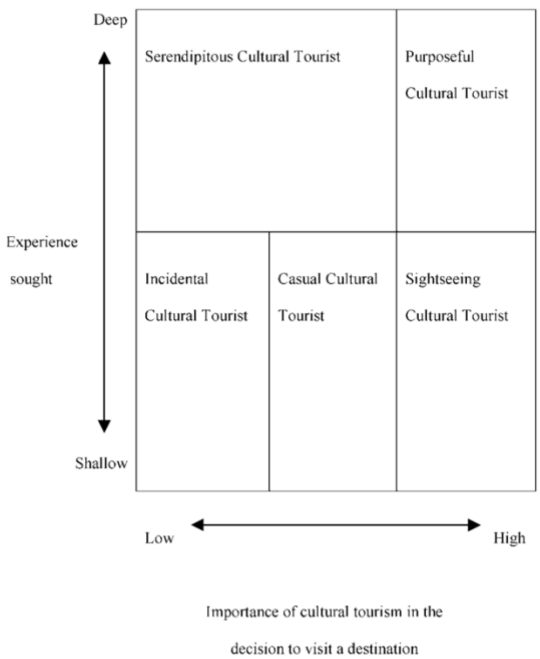

Figure 6: McKercher’s classification of cultural tourists (McKercher, 2002).

Figure 7: The information billboard at Sarabråten, where the parent learns that an AR-app is available.

The prototype developed in the thesis aims to engage visitors who request a shallow, i.e., popular-science-oriented dissemination. My imagined audience is a parent who reads the information billboard posted on the location (Figure 7) and is made aware of the possibility of witnessing the building through AR. The parent is motivated to show this experience to his/her kids, hoping they will better understand the interesting history he/she just read on the billboard. Hence, my imagined audience is adults and their children.

My methods in summary

In addition to being grounded in humanistic theory, my study seeks to understand and empathize with the user (Brandt, 2006). Such comprehension is founded on (2) Meinel et al.'s design thinking research (Leifer et al., 2011) and principles from Human-Computer interaction studies.

Based on these interdisciplinary methods for gathering insights, I present a no-code method for developing functional prototypes designed to investigate AR for use in cultural heritage dissemination. I evaluate these prototypes based on humanistic evaluation methods (Fagerjord, 2015).

Based on my participation in relevant sitsim developments, I have gathered findings that support various aspects of my research questions. The value of early-stage user feedback is exemplified through work with a simulation of a sinking ship around the islands of Alonnisos and Peristera during the 5th century BC (Liestøl, 2022; MAREBOX, 2021 - Unpublished manuscript.). This sitsim also gave me valuable insight into the benefits of indirect augmented reality related to different point of views. To test AR through the development of no-code low-fidelity prototypes, I have developed my case study on Sarabråten. I have also conducted off-location tests at a location with good test conditions to test how accurate AR has become in modern mobile devices in optimal conditions. The accuracy of the Lidar sensor in mobile augmented reality was also investigated through my experience of modeling and testing a sitsim reconstruction of a coastal fort in Portugal (Liestøl, in press, will be published in 2024).

The purpose of presenting these projects is to substantiate their impact on my research, and show examples of viable use cases for indirect AR. In conjunction, my methods chapter can be read as an overview of how a long-term design process is influenced by technological advancements and insights gathered along the way. Although I strive to present a circular understanding of the design process, it was experienced differently, more along the lines of the illustration on the right in Figure 8.

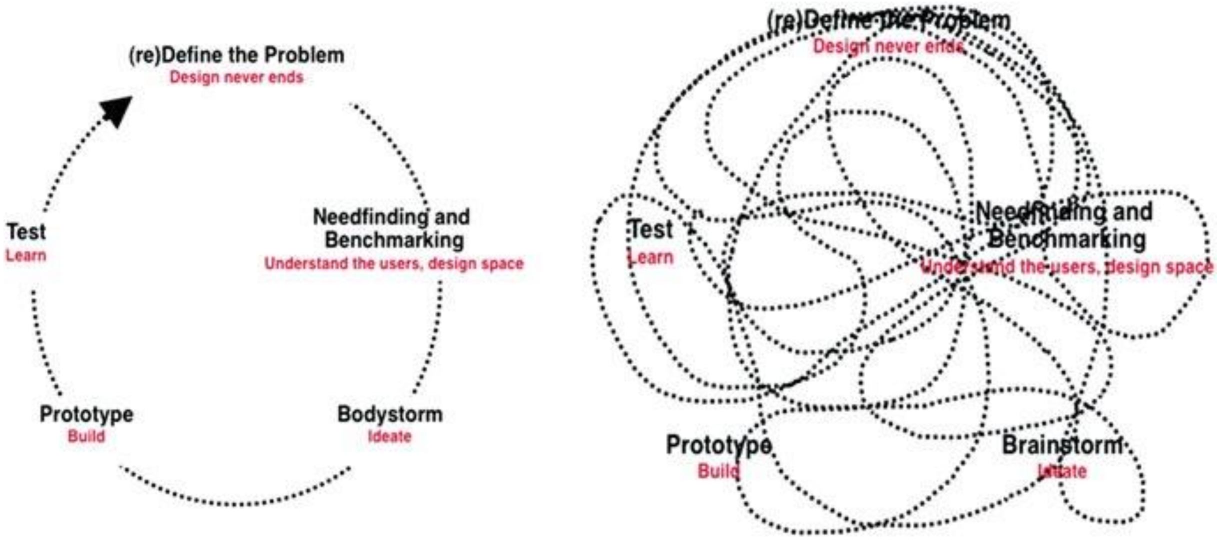

Figure 8: Design thinking has five stages often shown in a simplified diagram, but in reality, it's more complex. Choosing the right points to move to next is a skill that takes practice (Leifer et al., 2011).

Method: a design thinking approach to sitsim development

Comprehending media design.

In 2020, I had the opportunity to test the sitsim platform on location in Lofoten as the final course of my bachelor's degree. In this course, the students were invited to partake in the project "Connected Culture and Natural Heritage in a Northern Environment" (CINE) led by Museum Nord (2017-2020).

The location used to be a bustling fishing village with around 200 fishing huts (rorbuer), but now, an old "væreierbygning" is the only remaining trace of what once was (Bøe, 2021). As a part of the design process, I spent months investigating and creating various models to be implemented into a sitsim application that showcase this location throughout different periods. When I finally arrived on-site to test the app in practice, I was surprised in many ways. Having already worked with high-res photogrammetry models, I found the landscape familiar. I already had extensive knowledge of the area from modeling and placing elements into the 3D-captured terrain. During the modeling process, I created fishing huts, a spissbåt (a type of boat), and even modeled and animated human characters from an old photograph (Figure 9). At the time, I wanted to test how an old photograph could be remediated as a 3D-modeled animation sequence (Bøe, 2021).

I was surprised that my simple models were reported by test users. Without fully comprehending it, I had already completed my first circle in the sitsim design process.

Figure 9: Example of how a sitsim looks on-location, notice that all the elements on the screen are virtual. The modeled boat and fishermen where my contributions to the project. Photo: Gunnar Liestøl

Design never ends, but where does it begin?

"Design is a funny word. Some people think design means how it looks. But of course, if you dig deeper, it's really how it works."

Steve Jobs

My first Sitsim development showed me that it is challenging to presume and predict user experiences. After the test phase of the Sitsim experience in Lofoten, survey results showed that an overwhelming percentage of users found my 3D-modelled characters credible, contrary to my presumption. The feedback was valuable, but it took my research in a different direction than anticipated. This contradiction led me to investigate other methods for user feedback and prototyping at earlier stages.

The presented method is modeled on a design thinking framework (Brattli et al., 2023; Leifer et al., 2011) with the insight that the design of low-fidelity prototypes involves short development cycles to obtain immediate feedback from users (Leinonen & Durall, 2014).

Understanding the problem – identify and define.

The first step in the design thinking process is empathizing with the product's potential users. This involves gaining insights into their experiences, emotions, and motivations through research activities such as interviews, observation, and participation (Brattli et al., 2023). The aim is to understand users' perspectives, pain points, and aspirations, which helps uncover unmet needs, identify patterns, and recognize underlying problems (Leifer et al., 2011). This sets the stage for the subsequent steps, enabling designers to gather knowledge and insights to inform problem-solving and idea generation, resulting in solutions that genuinely address the users' desires (Brattli et al., 2023). The initial phase of a design thinking process relies on identifying problems, but what if the user needs to be made aware that there is progress to be made?

The advantage of the synthetic-analytic approach to design is that ideas are grounded on a deep understanding of a research field, providing possibilities that may not be apparent to the typical end user of future inventions. This methodology involves developing iterations of a media product by employing conventions from preexisting genres. These iterations are informed by humanistic theory (Fagerjord, 2012; Liestøl, 2013). According to design thinking, such understanding gives you a "*head-start*," which could cause you to jump to a solution before thinking the problem through (Brattli et al., 2023). I will argue that these two ways of thinking in the initial stages of the design process are unified because identifying problems in the literature can still be user-oriented, and the literature can answer things prospective end-users would not be able to grasp. At the same time, taking a step back and empathizing with the prospective user might give insights into trifle matters that the literature will overlook, but that will make a massive difference for the user.

Identifying a problem through literature – the case of Sarabråten

After nearly fifteen years of research, a typical limitation for sitsim development has been tied to technical aspects, such as processing power, sensor inaccuracies, overheating, etc (Liestøl et al., 2021; Liestøl & Hadjidaki, 2019; Liestøl et al., 2011). One of the most recent articles I read when I started my investigation into sitsim was an article that "proposed an interim solution that can improve precision and prepare for the forthcoming interfaces and potential of AR based on real-time 3D capture" (Liestøl & Hadjidaki, 2019). This article argued that the current mobile devices lacked specialized hardware to accurately align virtual 3D elements with 2D imagery from the camera.

Shortly after my initial work with the sitsim platform, the mobile device with such specialized hardware was released. When Apple introduced the iPhone 12 Pro and Pro Max models in October 2020, they included a Lidar sensor as a significant upgrade (Matthews, 2020). At that point, I had read numerous articles describing the issues of registration and alignment that made AR challenging to apply in cultural heritage applications (Bekele & Champion, 2019; Bekele et al., 2018; Wither et al., 2011). After acquiring the new iPhone equipped with novel sensor technology, I wanted to investigate whether the Lidar sensor could improve the experience of conventional AR by eliminating registration issues where the virtual elements fail to align with imagery from the camera.

Defining the problem

When a clear solution to a problem you have been thinking about arises, The design thinking methodology recommends adapting what in Zen Buddhism is known as *Shoshin*, which means "beginners mind" (Brattli et al., 2023). In this case, having a beginner's mind simply means addressing the problem with an open mind and investigating multiple aspects of the solution before moving further. This involved investigating arguments other than technical issues supporting an indirect AR approach in sitsim experiences.

An analog to the more hands-on approaches provided by design thinking is analyzing user feedback from earlier relevant studies. One study shows that users typically hold their phone tilted slightly downward when walking around with it. By tilting the view of the virtual experience fifteen degrees the indirect AR experience was deemed more user-friendly because it meant the users could walk around more relaxed (Liestøl & Morrison, 2015).

Another study investigates the experience of an incongruity between the location of the mobile device and the virtual environment by sending the virtual camera to a different location to give the user a different perspective from that in which the user is standing, providing multiple points of view. (Liestøl & Morrison, 2013). This was also applied successfully when the virtual camera was sent down to the seabed to show a shipwreck at ancient Phalasarna in Crete (Liestøl et al., 2021).

Even though the literature presented clear examples of the benefits of using indirect AR, I was still interested in investigating the value of AR as adhering to Azuma's definition. Hence, I needed a suitable heritage-site to conduct my experiments.

Location choice

After two sitsim developments where I had limited access to the location in advance, I wanted a more readily available location for this test. I knew that answering my first research question would pose technical challenges; hence, it was essential to have an accessible location. I have used the area around Nøklevann in Østmarka, a forested area east of Oslo, a lot for hiking. And I have always been attracted by the beautiful location of Sarabråten. At the location, there is a ruin from an old building and a poster raised by the special interest group "sarabråtens venner" (Rogstad, 2016). The ruin is a remnant of an old dragon-style villa raised by Thomas T. Heftye. The place has served as a vacation spot for famous cultural figures. Durile researching, I found historic photos of Henrik Ibsen, Hans Gude, Aasmund Olavsson Vinje, and Ole Bull (**Senje**). There are also records of royals, such as Crown Prince Carl (later King Charles XV) and King Oscar II, having visited the location (Lokalhistoriewiki). Sarabråten was also where "Norsk Turistforening" (The Norwegian Trekking Association) was founded and where the country's first scout troop was formed (Saugstad, 2016).

There are loads of exciting stories to tell here, and since the history dates to the late 19th century and early 20th century, good records are available. In sum, this is a perfect location to test dissemination of cultural heritage using AR.

Define problems through self-participation.

I have already touched upon the notion that design never ends, but it is also difficult to define whether it has a clear beginning. The initial stage of the design thinking method is to emphasize with the user to understand the needs and perspectives of the people you are designing for. Nevertheless, as identified by Gadamer, there is never a *tabula rasa,* i.e., a clean slate in human understanding (Gadamer et al., 2012). Even when trying to adopt a "beginner's mind," it is difficult, if not impossible, to refrain from your presuppositions. Still, even if you have gone through the design process of sitsim applications several times and think you understand the user, there is immense value in investigating the location through the eyes of a prospective user.

In developing a simulation that relies on a location's spatial environment, not having access to that location can present challenges. However, if you have access to the location, self-participation is a helpful method in the initial stages of development. This approach involves actively engaging in the project to gain a deeper understanding and insight into what needs to be addressed in the later stages of development (Brattli et al., 2023). When I was in the initial stages of my Sarabråten project, I had prior experience both as a user and a developer of sitsim; I still went to the location multiple times before even starting my development process.

Figure 10: Aerial photography of Sarabråten. The ruin from the Dragon-style villa is the most visible.

Sarabråten is situated on a hiking path that encircles Nøklevann. You can approach it from the north or south, as both paths pass the ruins, visible when you look towards the west. Walking towards the ruins, you will see a sign that welcomes visitors (Figure 7). This location is a popular hiking destination, and I have observed that it's often crowded during my visits, mostly on weekends.

An exercise I did early in the process was to walk around the area while filming with my phone to try to address any issues walking in the area with a phone. An issue with AR experiences is that you can get so involved in the experience that you forget where you walk. I documented this walk on video, which also serves as documentation for later development stages. My most noticeable observation was related to the number of visitors at the location. People walking in front of the camera can be a problem in AR because virtual elements will overlay people in the frame (See Figure 3), breaking the illusion of AR. Another potential usability issue I discovered was that some steep parts in the terrain might pose challenges if a user walks backward when looking at the simulation.

I gained multiple insights for my case study through self-participation on-site. In the following, I elaborate on how I have worked with user-centered design without access to the location at early development stages.

Participatory design - the case of the Alonnisos Peristera shipwreck

The first major project I worked on during my master's program had external funding and a clear objective. This also meant that I had very specific responsibilities going into the project. At the same time, I was conscious of my first experiences from the project in Lofoten, where user feedback diverged from my expectations. As the location was in Greece, I could not visit during development. I needed a different approach to gain insights. I wanted to rule out users' problems with the perception of the representation I worked on. In the following, I present an applicable solution to this problem grounded in participatory design methods. The presented case exemplifies the second stage of a design process, where one needs to identify needs.

The project "MAREBOX – Underwater culture " investigated "new expressive modes of conveying experience and knowledge about the submarine cultural history and heritage of Europe." (MAREBOX, 2021). As a part of this project, I was invited to participate in developing a sitsim reenactment of a ship descending between the Greek isles of Alonnisos and Peristera in the 5th Century BC.

In 1985, a Greek fisherman discovered a large classical shipwreck near the island of Peristera in the Aegean Sea. (Hadjidaki, 1996). In 1991, archeologist Elpida Hadjidaki initiated a survey to investigate the site (Hadjidaki, 1996). The shipwreck resides at a depth of 25 meters, making it inaccessible without diving. Hence, this was a suitable use of the indirect AR mode of representation where the virtual camera is moved from where the user is standing. In this project, we investigated different viewing modes (e.g., top-down view, diving view, close-up view) since the experience was supposed to be experienced from shore and the sea. In addition, we utilized genre conventions from movies to portray jumps in time since the entire voyage would have been uninteresting to watch.

After a thorough investigation into relevant source material and interviews with the archeologist, I completed some design mockups that were used for a future workshop, combined with an exploratory game to get feedback from prospective users. At this stage, I needed user feedback to address questions of realism. Since I could not access the location, I arranged an experiment to gain user insight off-location[1].

Exploratory design game – the delta game

The delta game involves assigning different roles to participants, who work together to accomplish a shared task. The game aims to foster collaboration and teamwork among the participants (Brandt, 2006). Brandt suggests that incorporating game rules into participatory design exercises can provide valuable insights, even if users won't be directly using the product or service in question (Brandt, 2006).

In this experiment, the participants were given roles that have specific functions in the development a sitsim, particularly related to realism (designer) and authenticity (anthropologist and archeologist). The idea was that these roles would provide more honest and open insights, as they would answer as their designated role rather than as themselves. In this experiment, the delta game was combined with a future workshop.

[1] I have reported on some of the insights from this experiment before in an unpublished exam (MEDK4200 Mediebruk og brukerinvolvering at OsloMet). I find the example worthy of mentioning here in a brief excerpt based on a new angle of incidence. The work with this simulation was completed after the exam.

Future workshop method – an exploratory as-if world

A future workshop consists of three phases, (1) The critique phase identifies problems, which are grouped into areas. (2) In the fantasy phase, participants come up with innovative and creative ideas for the future of the product based on the issues they identified in the previous phase. (3) In the implementation phase, participants will identify obstacles related to their ideas and discuss how they can be overcome to achieve their goals (Brandt, 2006).

The participants were given a brief introduction at the start of the experiment. They were tasked with working together as a group of experts to assess a university student's work. The work was in its early stages; their feedback would help improve it.

The material they were given to assess was what Lars Nyre refers to as a dummy (2014), which in this case were initial mockups of a ship (Figure 11) sinking outside of the Greek islands of Alonnisos and Peristera around 500 BC. All participants were introduced to their roles during the plenary, so they knew what each person was responsible for. They were instructed to write on the whiteboard and the direct contribution written on the whiteboard was accompanied by notes taken by me during the workshop.

Figure 11: Screenshots of three scenes in the sequence, with the third showing the ship being struck by lightning.

Figure 12 Photograph showing the workshop in progress. The camera in the far right of the image shows the whiteboard to the Zoom participant. Present participants can easily interact with the digital participant.

Participants followed the game format and rules well, with few interventions. The workshop became self-regulating, indicating the format's effectiveness in promoting collaboration. Although the Delta game is not a competition, game-like behavior was observed, such as eagerness in writing on the whiteboard and feedback based on assigned roles.

The new insight provided by the experiment.

I gained valuable insights from the experiment, which helped us complete the simulation - our main objective. However, I also gained insight that has relevant for the research question related to the relation between AR and indirect augmented reality. When using the sitsim platform to convey a narrative that, for instance, shows different weather circumstances, you also gain some advantages with indirect AR through more dynamic storytelling. I coded the feedback I received from the workshop based on the roles in the delta game and many design-related suggestions would have been impossible to achieve with AR, e.g., more dynamic skies, changing the direction of the waves, adding reflections to surroundings as the lightning strikes, etc.

Build a prototype – The Sarabråten case.

After collecting data in the initial stages, the next step is to develop a prototype. However, at this point, I had gathered loads of data and identified various problem areas related to my initial investigations. Therefore, I needed to carefully analyze all the available choices and decide what to develop to answer my problem statement. At this stage, I was starting to see more clearly that AR isn't necessarily the best mode of representation for cultural heritage dissemination. Still, I wanted to explore further to see how it would work in practice.

Ideate – generate ideas to solve your problem.

At this point, I was full of ideas, I wanted to make an experience showcasing the different works of the architect throughout the city of Oslo. I found several historical photographs of important cultural figures and considered the possibility of continuing my work by remediating historical photographs into 3D simulations. I wanted to animate Sara, the pedal-wheel boat that once commuted guests to Sarabråten. I considered using different viewing modes to distinguish between an indirect AR experience and an AR experience. I found sources stating that the old "Stabbur" at Sarabråten was moved to Kongsberg, and I considered including this in my simulation using photogrammetry, etc.

Converging ideas

Since I had many ideas, I saw no use in generating more. If I were struggling to ideate at this point, design thinking methods would recommend brainstorming or brainwriting activities with prospective users to generate ideas (Brattli et al., 2023). My challenge was to converge all these ideas into a prototype that answered my problem statement and research question.

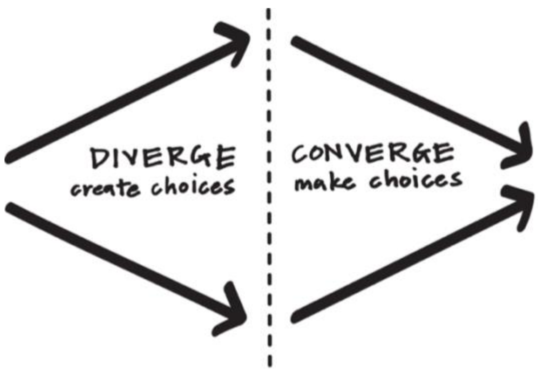

Figure 13: At this point in the process, I needed to identify different solutions to the problem statement and identify the best choice to solve it. (IDEO)

This meant I needed to move from the quantitative phase of diverging ideas into the qualitative phase of converging them, as illustrated in Figure 13 (Brattli et al., 2023). In essence, this involves a phase of "killing darlings" and going from an uncritical frame of mind in the idea-generating stages to a more constructive frame of mind. According to Tim Brown, you identify good ideas at the point of intersection between an idea's desirability, viability, and feasibility (Brown, 2008).

For the aspiration of this thesis, my main concern was feasibility. AR development is time-consuming and costly, and I needed to be able to accomplish my ideas without a budget and with limited time. Since I was involved in several projects that helped me shed light on my research question in various ways, I went with an idea that involved low-fidelity prototypes to address the concern of registration, occlusion, and calibration in AR. Still, I wanted the prototype to adhere to the main traits of the sitsim platform. I wanted to create a historically situated simulation in a significant location, and the simulation needed to be registered in real-time in 3D. To perform an extensive test of the three issues identified in the literature review, I also wanted to test different development platforms to understand if this played a part in the results.

Research into historical sources

A quintessential part of modeling and factual storytelling is good documentation. Hence, I gathered a substantial amount of documentation. In the initial stages of development, I was still unaware of how much I could achieve with the simulation. Hence, I had a broad scope in these initial stages. Hence, I have leaned substantially on two primary sources of information, the book: “Sarabråten – godset i skogen” (Saugstad, 2016) and digitaltmuseum.no.

I gathered textual information, maps, and photographs. Much of the source material is scans of handwritten material, but I have not transcribed or worked with the original documents since my aim is widespread dissemination to a general audience. I coded the gathered material using NVivo to manage the material. The material was coded into the following categories based on what content the material presented: Architectural information, material information (e.g., types of wood, stone etc.), stories of people and guests, Poetic representations of the area, and other interesting information. While working with the material, I developed flexible categories as I was uncertain about what I was looking for and what I would find.

Documentation as a basis for modeling – The dragon-style villa.

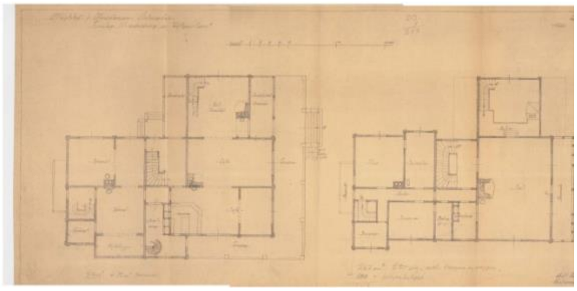

Figure 14: A floor plan exists, but this is dated 1922 (after the building was torn down.)

The villa was raised in 1897 as an upgrade to the building that was on the location from 1856 (raised by Thomas Heftye's father) (Saugstad, 2016). There are written documents detailing the estate for insurance purposes, but unfortunately, no architectural drawings are available for the villa ("Dragestilvillaen,"). However, a floorplan exists, but this is dated 1922, after the building was torn down (see Figure 14).

Figure 15: The most detailed image of the Dragon-style villa.

There are several good-quality photographs from Sarabråten and the dragon-style villa (see Figure 15). The Heftye family still owns multiple photo albums from the years the dragon-style villa was in their possession ("Heftyes fotoalbum fra Sarabråten,"). Six of these albums have been digitized and made publicly available through the image-sharing platform Flickr (*Sarabråtens venner Flickr album*). The gathered material was sufficient to develop a low-fidelity prototype to address my research question.

Development and Implementation of AR App Prototype

To answer whether technology has matured enough to expand sitsim into conventional AR. I decided to create a low-fidelity prototype of the dragon-style villa and anchor the building to the ruins present on location at Sarabråten.

The level of realism I aspire to

According to Engberg and Bolter (2020), the primary objective of computer graphics in video games and VR is to achieve perfect photorealism. However, Bolter et al. argue that it is impossible to achieve perfect realism in any media, as all forms of media fall short of duplicating reality (2021).

In a previous study, I assessed why users perceive 3D models in a sitsim to be realistic despite apparent fallacies in their realism (Bøe, 2021). One possible explanation is that the sitsim experience provides a double description experience, where multiple information sources converge to produce a new type of information that differs from either source individually (Bøe, 2021; Hui et al., 2008). Bateson's theory of Double Description is integral to my modeling, as it explains why the experienced realism of the models will be higher because they are experienced on location. This is crucial because mobile devices require omitted details to run the 3D model without dropping frames. Hence, I designed a simplified model of the villa.

3D modeling

3D modeling is creating a three-dimensional representation of an object or scene. This is achieved by using a modeling tool to place points, known as vertices, on coordinates along the three-dimensional axes (X, Y, Z). These vertices can be connected to form surfaces or faces, which can then be combined to create more complex models. When multiple faces are connected, they form a 3D mesh, which can be made more realistic with a material.

Two primary methods for creating a 3D mesh are (1) using 3D modeling software or (2) photogrammetry. With 3D modeling software, various tools are available to help place vertices in a way that achieves the desired result. On the other hand, photogrammetry involves taking pictures of an object from multiple angles and using computer software to generate a 3D model.

Although photogrammetry can result in highly realistic models, it has some drawbacks. Photogrammetry models can be very detailed and contain many vertices, which can cause performance issues on mobile devices. Additionally, if you need to model something that no longer exists or is imaginary, you must use traditional 3D modeling techniques.

The prototype in this project was entirely modeled using traditional 3D modeling techniques. Modeling is done using the open-source modeling software Blender version 3.6 as shown in screenshots in Figure 16.

Texturing and Optimization.

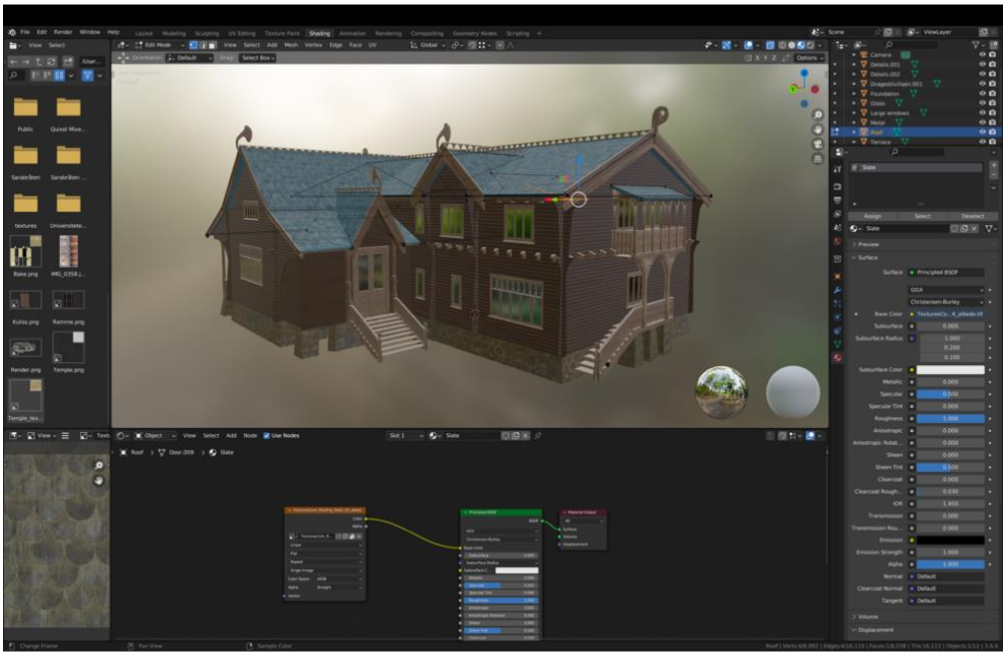

Figure 16: Image from the modeling process of the dragon-style villa.

When creating models for mobile platforms, it is essential to consider the balance between photorealism and playability. While adding extra vertices can enhance the simulation's detail and photorealism, it can also cause the display device to drop frames, negatively impacting the user experience. Consequently, 3D modeling involves optimizing models to utilize textures effectively. There are two main ways to optimize a 3D model: (1) reduce geometry (i.e. vertices) that do not affect the end result substantially. And (2) using textures to simulate the experience of extra geometry (i.e., normal maps, height displacement maps, etc.). See Figure 17 for an example of different textures that can affect the end result of a 3D model.

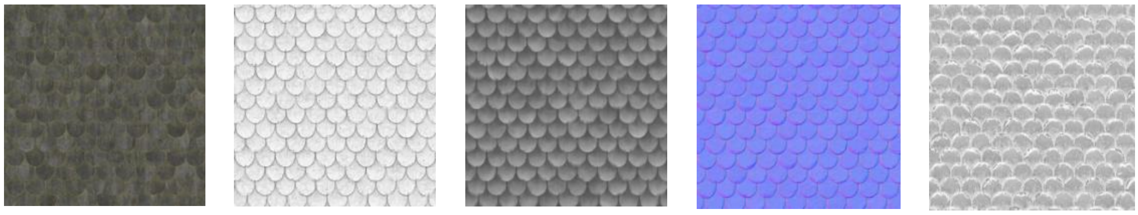

Figure 17: Presentation of the most important texture-types that constitute a PBR-material.

Physically Based Rendering (PBR) texturing is creating digital two-dimensional images that store surface and color information that will be projected onto a 3D object. The different textures affect different aspects of the model, such as shadows (ambient occlusion), reflectiveness (roughness), base color (diffuse/albedo), re-detailing of simlipified meshes (normal), etc.

UV mapping refers to creating a 2D representation of a 3D object. This representation is used to apply textures and materials to the surface of the 3D object in a way that accurately represents the intended design (Disguise, 2023). The 3D model's materials are projected onto a UV map using U and V axes to describe 2D images. To apply a material to a 3D model, it must first be flattened into a UV map where each face of the mesh is assigned a specific coordinate. The texture is then projected onto the model based on the map (see Figure 18).

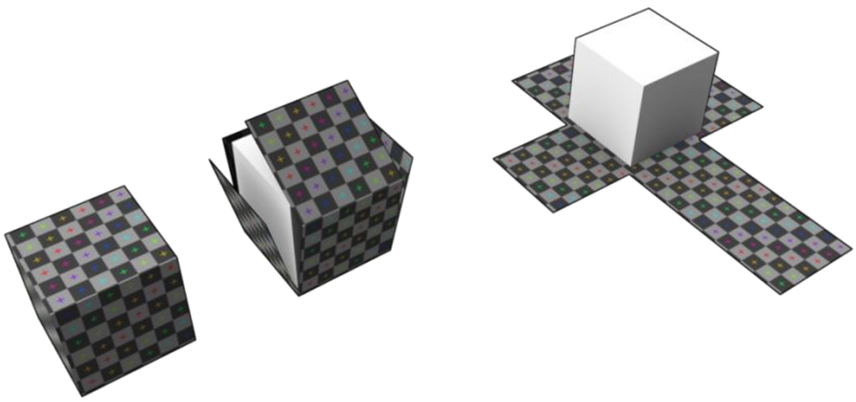

Figure 18: A 3D cube is flattened to a 2D representation, creating a UV map (Disguise, 2023).

When placed together, the textures form a material that the 3D software can use in combination with lighting data and the surrounding area to calculate shadows and reflections in the material. The textures in Figure 17 are used to generate the roof of the dragon-style villa, and when combined in a PBR material, they look like the image in Figure 19.

Figure 19: "medieval slate stone rooftiles" fetched from textures.com.

Source-material

The best sources to model historical objects are blueprints or detailed drawings. Unfortunately, the original architectural drawings from the dragon-style villa are lost. The best available source material I have is, therefore, the historical photographs (Figure 15) These were gathered and placed relative to each other in Blender as reference material.

When creating building models that need to reflect the real world, the first step is to take accurate measurements. It is crucial to ensure that all dimensions are precise to achieve the desired level of accuracy. I have been provided with accurate real-world measurements in the other sitsim developments referenced in my thesis. These are provided either from a drone photogrammetry model (Lofoten and Alonnisos Peristera) and/or a Leica Geosystems total station[2] (Fort of Paimogo). For the Sarabråten case, I only had the aerial-view photo (Figure 10) combined with reference measurements I took with a laser gauge (Bosch Zamo ll). I overlayed the floor plan (Figure 20) on this material to get the best possible reference for modeling.

[2] A total station can measure angles and distances electronically and process trigonometrically to produce a survey of a location that provide 3D views of measured data Geosystems, L. (2023). Leica FlexLine TS10 Manual Total Station. https://leica-geosystems.com/products/total-stations/manual-total-stations/leica-flexline-ts10.

Figure 20: Aerial view with floor-plan overlayed.

Hovedbygningen paa Sarabraaten,

som Akers kommune for 5—6 aar siden solgte til trælasthandler Saatvedt, nedtages nu for at føres til Kongsberg og tjene som privatbolig for bygningens nye eier. Akers kommune har senere angret paa afhændelsen af dette vakre og solide bygverk, som der knytter sig mange minder til. Nogen nødvendighed for bygningens fjernelse af hensyn til Nøklevandets forurensning forelaa vistnok ikke. Kommunen har forsøgt at faa gjort handelen om igjen, men disse forsøg er kommet for sent.

Figure 21: Notice in Aftenposten about the sale of the torn down Dragestilvilla to timber merchant Saatvedt (March 22, 1919)

There were discrepancies between the floor plan and the foundation that form the ruins. I interpreted this as the floor hanging outside the foundation and being supported by pillars. I find support for this in the remaining pillars on the northern wall.

The dragon-style villa was deconstructed around 1920 because Aker commune was worried that it was a potential source of pollution to the drinking water (Saugstad, 2016). The timber was sold to a merchant (see: Figure 21). I researched dragon-style buildings around the Oslo area, hoping to find something that resembled the building, even hoping it had been reconstructed. I later realized that this research had also been performed by the author of the book about Sarabråten with no luck (Saugstad, 2016). There is no information about what happened with the building after it was deconstructed.

For reference, I visited “Norsk Folkemuseum” multiple times to see a building drawn by the architect Holm Munthe that, based on the historical photographs, appears to share many features with the villa at Sarabråten. I used this building as a reference when modeling details that are difficult to distinguish in photographs (see Figure 22 for examples).

I have reference photographs of the west, south, and east walls, this means I have no information about the last wall. Since this is currently just a prototype, I have left this part as a simple wall with windows, and a protrusion with a roof (I can see the roof in one of the photos). There are also several details that are left out, because I had to prioritize implementation into the AR development platforms. For example, I didn't have the time to add chimneys to the model. The developed models that are ready for implementation can be seen in Figure 23.

Figure 22: Photo on the left shows ornament on the waiting hall, displayed in Norsk Folkemuseum (Photographed from the ground, hence slightly distorted). Render on the right shows the 3D-ornament from the recreation.

Figure 23: The completed dragon-style villa model, rendered from Blender.

Registration and Lidar scanner – the case of fort of Paimogo

Before I was ready to start implementing the models into an AR development environment, I visited Portugal to test the Fort of Paimogo sitsim experience, where I had modeled the fort and optimized the photogrammetry model of the surrounding area[3]. The unity package I developed was sent to the team at the game development company Tag of Joy. Tag of Joy has been involved in creating and implementing sitsim experiences for many years.

The Tag of Joy team faced a challenge when developing this sitsim - accurately aligning the virtual 3D environment on the screen with the real world using ARKit 4 and Lidar scanner technology. The Lidar sensor was needed for this simulation because large parts of the experience occurred inside the fort, where there is no GPS signal. Fortunately, the iPhone 13 Pro's second-generation Lidar scanner is incredibly precise (Tamimi, 2022), making it a more reliable on short distances than GPS. Tag of Joy developed an addition to the sitsim framework that made it possible to scan and deploy new world maps from within the sitsim app. These world maps were used by the Lidar sensor to detect where the user was throughout the experience. However, we could not scan a complete world map before the first test. As a result, we had to send test users along a pre-determined route. Still, we experienced minor discrepancies in alignment between the simulated and real environment, believed to be caused by moving natural light in combination with steady artificial light. This test was somewhat discouraging for the tests I was planning, as it highlighted the difficulty in aligning real and virtual environments, still it was a proof of concept that Lidar can provide alignment in conditions where the GPS coverage is poor.

We conducted a test at fort of Paimogo. Fifteen participants were involved. Each tester was provided with an iPad or iPhone and accompanying headphones. All users started their tour at the southern entrance of the fort and were instructed to follow a predetermined path. The predetermined path was a necessity at this stage of testing to get the tracking to work as intended. After testing, all the participants answered a survey.

[3] I have reported on some of the insights from this experiment before in an unpublished exam (MEVIT4896 – Vitenskapelig assistansearbeid). I find the example worthy of mentioning here in a brief excerpt because it supports my argument and has influenced the course of my research.

The test at Paimogo showed me how complicated the calibration process of an AR experience is, despite having two seasoned developers on-location, the calibration still proved difficult.

Trying out different procedures.

In software development, the deployment phase is the activities that make software available for use. I have extensively researched previous sitsim builds (packages that include all available resources, such as scripts, models, materials, etc.) Still, without the needed coding skills, deployment with the current framework is a significant task than I can achieve alone.

A Sitsim AR Editor has been developed for Unity in 2019. Although a helpful tool for no-code development of sitsim experiences, this tool is unfortunately outdated for the purpose of my inquiry. The editor prerequisites older software and hardware, not equipped with the necessary sensors to perform the tasks I wish to accomplish. Hence, I worked based on packages from newer sitsim experiences, trying to distill the necessary scripts to build a basic prototype, but with no luck. The current sitsim framework was too complex to grasp without the necessary coding skills.

I had the opportunity to get assistance from the Tag of Joy team to deploy into the current sitsim framework. However, for reasons I will discuss in a later chapter, I wanted to complete a prototype without any assistance from professional developers.

The sitsim framework was developed using Unity, a game engine with which I had considerable experience. I had no problem deploying the AR experience into an app, but I struggled to calibrate the 3D models to align with the real-world location. I faced multiple issues, including the lack of real-world data I could connect my models with.

Earlier in this chapter, I stated that working with detailed photogrammetry models in developing the Lofoten sitsim made me acquainted with the area, even before visiting. With the limited resources of an MA project, these data types were unavailable to me. This made the development difficult because trying to align my model in Unity was useless when I got to the location; my prototypes did not work as intended. The process was increasingly difficult because my location is a 3.5-kilometer roundtrip from the closest parking lot. Hence, each time I needed to iterate, I had to return later.

A new release of Google's ARCore suddenly provided a viable tool to assist in this calibration, since it introduced a feature called Geospatial Creator. Google Geospatial Creator enables AR development on the foundation of 3D-photogrammetry models from Google Earth (Google, 2023b). Suddenly, I had access to detailed real-world data, making the calibration of 3D models relative to the environment much more accessible.

I tested the tool off-location, placing the dragon-style villa on the University of Oslo campus. And quickly regained faith, the positioning worked well (see Figure 29). However, I had the same issues when I returned for testing on-location. I have not managed to assert a reason for these issues, but considering there are poor GPS signals, almost no cellular service, and no WIFI at Sarabråten. I suspect this is causing the issue.

Figure 24: Screenshot on the top left showing Adobe Aero struggling to determine device location. After a while location was determined, however the registration was off. After recalibrating, the upload/download process until I could test a new app took 30 minutes due to poor cellular service, which made the process of calibration impossible since it required many iterations.

Despite countless efforts illustrated with Figure 31, I couldn't get GPS-positioned experiences to work properly on Sarabråten. Still, my good results with Google Geospatial off-location made me want to use it for off-location control tests under good conditions. Google Geospatial was released for multiple development platforms. Consequently, I began exploring various platforms for augmented reality development and opted to create the Sarabråten experience off-location across two development environments to compare potential differences. In addition, I built an on-location version of the experience where the registration was performed entirely by Apple ARKit with a Lidar location anchor. In the following, I elaborate on the deployment phase of the different experiences.

Unity – Google Geospatial

I initially chose Unity as my preferred platform because it simplifies the migration into the actual sitsim framework. The Google Geospatial framework proved to be a viable tool for prototyping.

Geospatial SDK would probably install fine on an existing project, but to compare similar experiences, I started an entirely new project. I started by installing all the necessary dependencies as explained in Google's quick-start guide (Google, 2023a). Following the guide, the necessary coordinates are fetched from Google Earth and typed into the appropriate fields in Unity. After importing the 3D model as an *FBX-file* from Blender (with separate texture files), the model can be scaled, rotated, and moved to align it with the real-world location. Unity is a powerful game engine where materials, lights, reflections, etc. can be adjusted for the desired appearance. For the sake of this prototype, I wanted the most basic experience to make it comparable with the alternative development platforms.

Therefore, after placing the model correctly in the environment and applying textures, I deployed the experience to a test app. Since Geospatial is a Google ARCore SDK, I needed to make minor adjustments to deploy for iOS (I use an iPhone for testing). I followed a tutorial to export an iOS-build (Valecillos, 2023). After exporting the package, I opened it in XCode 15 (an Apple developer account is needed), a development tool for Apple devices. With minor adjustments, I could build the app to my iPhone for testing.

Adobe Aero and Google Geospatial

The Geospatial SDK has also been made available in a closed beta program for Adobe Aero. Adobe Aero is a user-friendly no-code environment to create and publish AR experiences (Adobe, 2023). I applied and was approved for the beta program, which is currently (November 2023) a free beta-version. Adobe Aero required a *GLB* file from my modeling software; this file also includes textures; hence, the model appears just as exported from Blender without any changes to textures inside Adobe Aero (see Figure 25).

Having worked with Unity for three years, Aero is user-friendly. After placing the object in the environment, it is as easy as pressing share; you are then provided with a QR code to scan on your smartphone to test the application (the Adobe Aero app must be installed). I performed some initial tests at the university campus with good calibration accuracy (see Figure 29). In my results, I elaborate on these tests as a control test for registration in good conditions.

However, promising the initial tests were, unfortunately, the results were quite different on location at Sarabråten. On-location, the calibration was off by between 10 m on the vertical axes, meaning it was placed above the correct location, poor cellular service made it impossible to calibrate on location, because calibration involved uploading and downloading a new version to Apple Cloud for each iteration (see Figure 25). Hence, Adobe Aero was used for control-tests of registration/alignment under good conditions at UiO Campus.

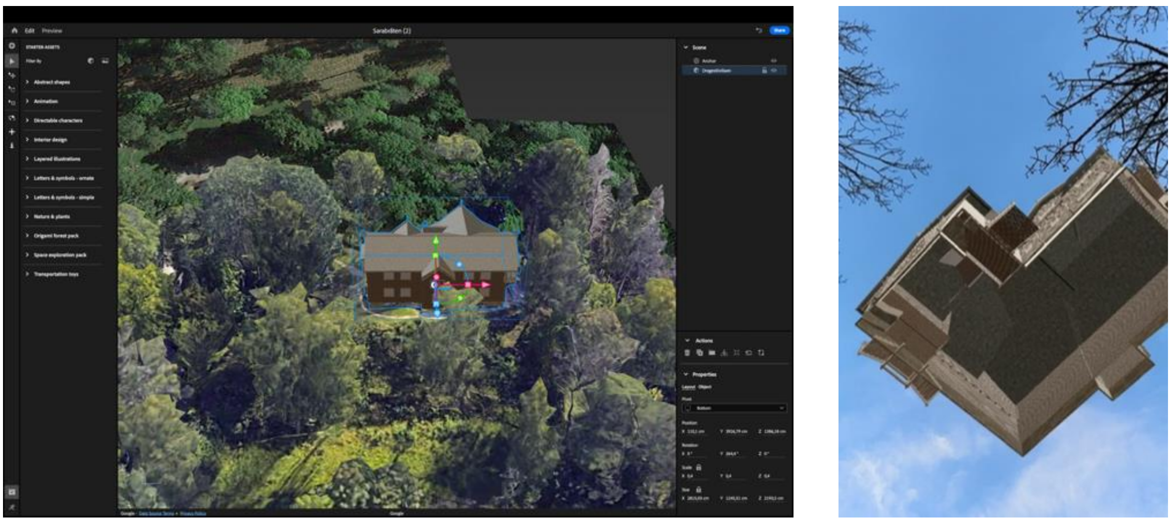

Figure 25: Despite promising results in my initial test, the results on-location were unsuccessful. Screenshot on the right show the Dragon-style villa hovering over its intended position.

Apple Reality Composer

Apple's AR development environment is the last development platform I wanted to test. Reality Composer is a free app for the iPhone that can be used to create AR experiences. Unfortunately, there are no GPS location anchors available in Reality Composer. This means the villa at Sarabråten needs to be anchored to a real-world object or positioned manually every time; however, as shown above, GPS signals at the location were poor, so this actually proved to be Reality Composer's biggest strength. To start with Reality Composer, I first needed to export my model in a Universal Scene Description format. USD is a framework designed to exchange 3D computer graphics data, the framework was originally developed by Pixar and made open source in 2016 (cgchannel.com, 2015). USDZ files are zipped (i.e. packaged) files containing all necessary information to compile a complete 3D environment, I.E., 3D-mesh, textures (compiled into materials), audio, video text, and image data.

Conversion into *USDZ* was accomplished with an Apple software called *Reality Converter*. This program converts *GLB* files to a format *Reality Composer* can read. After successfully importing the model into the app, the app is easy to use with simple step-by-step instructions. The setup at Sarabråten was anchored to the remnant of the column once supporting the stairs leading up to the main entrance of the building. From that anchor, the villa was adjusted and placed in the correct location using the transform tools within the app. This means this app enables calibration on-device, making it easier to perform calibration on location without cellular service.

The alignment was solved by creating models that cover the real-world surroundings, what has been called quasi-mixed reality (Liestøl & Hadjidaki, 2019). For the Sarabråten case, this was solved by modeling the foundation of the building, what are now the ruins, and calibrating the model so that it is placed outside of the ruins.

This AR-experience was used for on-location tests with a test group.

Other NCDPs

My selection of development platforms should not be considered a comprehensive review of No-code development platforms. I considered multiple platforms throughout my initial research. Other relevant platforms worth mentioning are Niantic Lightship, 8th wall, Meta Spark, Snap Lens Studio, webXR.tools, etc. These were ruled out either because the tools were costly (8th Wall, webXR.tools), marketed primarily towards game development (Niantic Lightship), or because they targeted specific social media platforms (Meta Spark, Snap Lens Studio). I have not come across a comprehensive review of AR composing tools. Hence, my choice of development platforms was made for the following reasons. Reality Composer was chosen because it is an Apple tool, and I had the presumption that Apple used its best available SDKs and APIs on its own app. Adobe Aero was chosen because it had what I considered the best location anchoring of the free AR authoring tools because of Google Geospatial. I chose Unity because sitsim is developed on this platform, which provides some advantages when migrating a functional prototype to the sitsim framework.

Measures to maintain consistency between development platforms.

I have selected the standard settings to ensure consistency across all three development platforms. I planned to compare the tools on location. Hence, I have made the following delimitations for the most consistent appearance; these delimitations proved unnecessary since I couldn't compare them directly against each other. Still, these delimitations explain some design choices and are therefore mentioned.

- Basic materials with diffuse/albedo maps are used.
- I have not modeled the inside of the building.
- I have utilized a plain white material for windows.
- I have made no adjustments to lighting or reflections in the platforms; this means that the platform, not artistic choices, causes observed differences.

Evaluation methodology.

At this point, I had two functional off-location test apps (Adobe Aero and Unity) and one on-location solution (Reality Composer) developed to investigate whether AR had surpassed abovementioned shortcomings in cultural heritage dissemination. I have already addressed the shortcoming related to calibration, which have become easier on locations with good GPS service.

To test whether the Lidar sensor had advanced AR enough to address registration and occlusion issues, I conducted a controlled off-location test to investigate during good conditions. This test was conducted by placing physical markers on the ground on the corners where the simulated models were placed and walking around arbitrarily to check whether the registration drifted.

After extensive testing off-location, I already had clear results and a good assertion about what my test users would report. Hence, I needed to verify my findings through actual user testing to rule out that people outside my field of research experienced it differently than I did. I performed this test with the Reality Composer solution at Sarabråten.

I recruited two testers among my co-workers for the on-location test. Since I primarily needed people from outside my field of research to verify my findings, I decided it would be sufficient with fewer testers. Jacob Nielsen argued that conducting elaborate usability tests is a wasteful use of resources. He argued that the most effective results can be obtained by testing no more than five users, and that there is diminishing marginal utility after three tests. Instead, he recommended conducting as many small tests as the budget permits (2000).

Table 1: Code table Sarabråten think aloud user test.

Name	References
Dissemination	1
Immersion and presence	2
Method introduction	1
Negatives related to AR	3
Occlusion related	8
Pro Indirect AR	9
Registration issues	6
Relevant quotes	10
Suggestions for improvement	7
User experience and user interface	3

On the day of the testing, we arrived at the parking lot together and walked to Sarabråten to commence the testing process. For the sake of transparency and because they preferred to be mentioned by name, Sindre Worren and Peter Andreas Kristoffersen were the testers. As no personal information was recorded, the testers were provided with a Røde Wireless Pro microphone to capture the participants' voices during the application testing. These recordings were transcribed using Whisper, OpenAI's speech-to-text algorithm, accessed through autotekst.uio.no. The service is a closed system running only on UiO servers, making it approved for processing sensitive data. After transcribing the data, it was brought into NVivo for qualitative analysis. The material was coded in the flexible categories shown in Table 1.

I performed the test using the "think-aloud" method, where participants are asked to verbalize their thoughts and strategies while performing tasks (Fagerjord, 2015). It is commonly used in testing computer interfaces and assessing emotional impact. The method promises to allow researchers to gain insight into an individual's thought process and how they approach problem-solving (Fagerjord, 2015). I chose this method to get immediate responses on issues that might arise, even small reactions, that might have been forgotten if I had chosen a survey method.

The respondents used my iPhone 14 Pro Max throughout the test and were asked to review the experience from different angles and think aloud as they engaged with the prototype. I had also preplanned that they would need to pass various physical objects so that the app would need to occlude the virtual layer and show the physical object on the screen. I added this control issue to check how users react to this.

Figure 26: Photo from the test at location Sindre is testing, while I observe.

Throughout the test, I followed the testers, looking for any reactions to glitches in the applications to see if they were detected and the testers' reaction to them. I used the following questions to prompt users if they forgot to "think aloud". Sometimes, I provided direct responses or a promise to reply later to questions if I deemed it wouldn't affect their understanding of the app.

- Are you noticing something you are wondering about?
- What are you paying the most attention to?

After the test, the respondents were gathered in an unstructured focus-group situation while walking back to the car, where we continued to discuss the experience.

Figure 27: Peter experiences the the day of testing.

Off-location control tests.

Since I had issues with the two GPS-aligned apps on location, I report on the off-location control tests I performed at the University of Oslo campus. These tests were performed using an iPhone 14 Pro Max. The two apps were designed using Adobe Aero BETA 0.23.4 and Unity v2022.3.11F1. Unity was utilizing the Apple ARKit XR Plugin V.5.10. It was deployed to the device using XCode 15 Beta 3. The app used Lidar to place the building at a horizontal plane, and Occlusion was enabled with the highest available settings, I deployed two versions, one with human occlusion set as a priority and one with environmental occlusion set as a priority. This was done to investigate the best available solution for Occlusion and alignment using NCDPs during testing.

To test registration/alignment accuracy, I first placed the building on a large open space; I then walked around the building with my phone, placing physical markers at each corner of the building. I walked around the area multiple times, both through the building and up and down the stairs, to test how much the placement moved from the original placement. I could have done this more scientifically, with precise measurements along the way, but the objective was to investigate the experienced accuracy and not necessarily real-world accuracy in centimeters. To investigate this, I did multiple tests with the different prototypes, and if I noticed any visual disruptions in the alignment, I deemed it to be insufficient, because it would break the illusion of realism.

Results

In the following, I report on three distinctive findings. (1) My experiences from control tests regarding the main issues of AR in cultural heritage dissemination, i.e., registration/alignment, occlusion, and calibration against the real-world. (2) overview of user feedback during testing on-location. (3) Ease of use in developing and calibrating no-code prototypes and their ability to address previous AR shortcomings by using the Lidar sensor.

1: Control tests of the main issues of AR in cultural heritage dissemination

Using the no-code development platforms, I deployed multiple prototypes to test various conditions relating to AR in cultural heritage dissemination. The presented tests are not meant to compare the different prototypes against each other; the only objective is to investigate whether technology has progressed enough to surpass previous shortcomings in cultural heritage dissemination. Hence, I have not provided accurate real-world measurements since I don't have any applicable tools for this. I will present the best available tool for each issue in the following.

The issue of registration and alignment

During my testing, I have not been able to achieve convincing alignment using core location APIs, there are small discrepancies in alignment even in places with good GPS coverage. Suddenly the models move as much as 50 centimeters on the different axes. This can however be solved on location using quasi mixed reality, where the models are calibrated to be bigger than the real-world element it shall align with (Liestøl & Hadjidaki, 2019).

My tests show that the best alignment results are obtained when I use similar methods to those used in the Fort of Paimogo sitsim. But these methods work best indoors, where the mobile device is always relatively close to a wall. I tested this inside by walking around a room, scanning a world map using the Lidar sensor that generates a point cloud[4] of the room, and anchoring virtual elements to it. With this test I get visually perfect results and no alignment issues. However, doing this on a cultural heritage site in real-world conditions is difficult. This was also one of the problems we faced during the Fort of Paimogo experience. Real-world conditions change rapidly, so the world map had to be rebuilt just before testing.

[4] A point-cloud is collection of points of data plotted in 3D space, using a 3D laser scanner.

This means that world maps may not be applicable on location, at least with the APIs currently available.

The issue of occlusion

The possibly biggest issue in the context of AR is related to occlusion. Occlusion culling is the technical term that describes subtracting parts of a virtual object. I present two different AR development platforms (Unity and Reality Composer) that perform occlusion culling by removing parts of a virtual object when objects are obscured (occluded) by objects in the real world. These solutions work well with stationary vertical objects (like walls, trees, or light posts), but they struggle with uneven objects or those that quickly appear in front of the camera. Also, the range of the Lidar sensor is a problem for larger areas.The Lidar sensor emits a limited number of laser signals per second, resulting in low point cloud resolution and slow updates.

These issues were apparent even in controlled circumstances when my phone was placed on a tripod. In a real-world application at a cultural heritage site, where many people walk around. The illusion of the virtual elements being connected to the real elements of the scene would vanish quickly.

When using Reality Composer to create an AR experience, the user interface in "play-mode" has two buttons - one to stop the experience and another to turn on/off occlusion of the real world. My test results using Reality Composer have confirmed the findings of my literature review, which state that Lidar works best when used on stationary objects. As shown in Figure 29, a stationary wall renders decent results with only slight inconsistencies in opacity. However, when it comes to moving objects, like hands, the results are unsatisfactory even when I attempt to stay still.

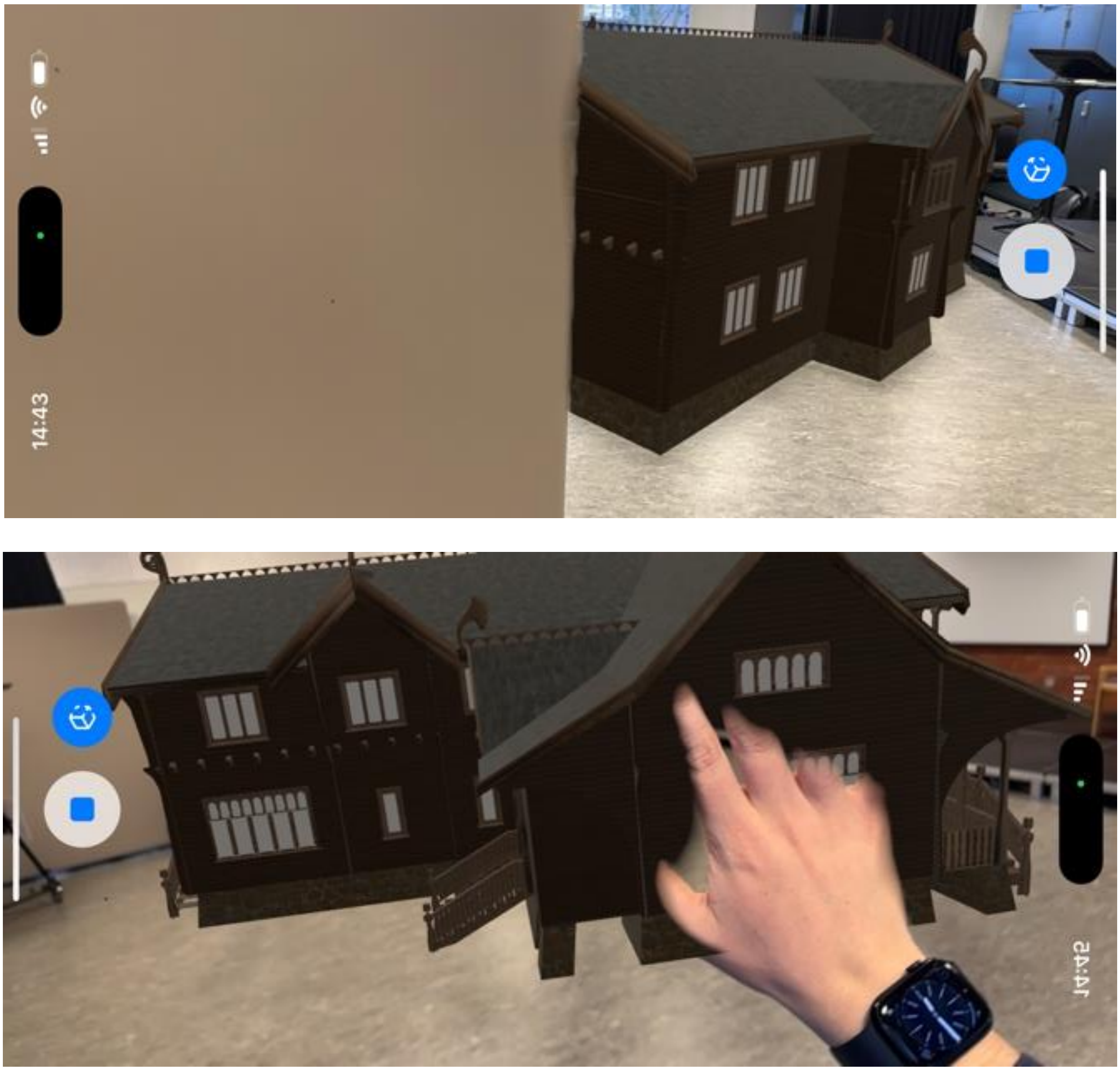

Figure 28: In well-lit environments indoors, Reality Composer performs well with solid edges (image on the right shows a room divider that occludes the virtual layer) but struggles to properly occlude virtual layers when presented with moving objects or complex shapes such as a hand.

The tests I performed with Unity provided somewhat different results. Unity provided the possibility to choose whether the system should prefer either human or environment occlusion culling. Both of these tests provided much better results than Reality Composer, but choosing one priority severely affected the other. Hence, Unity shows that there is potential, for instance through machine learning algorithms that changes priority throughout the experience.

The issue of calibration to the real world-environment

Adobe Aero presents the easiest tool to calibrate AR experiences against the real world. To test this, I made a simple prototype placing cubes and elements in various locations at different altitudes on a big open space at the University of Oslo campus. The resolution of the imagery from Google Earth is low when zoomed in entirely. Still, it is possible to identify smaller real-world elements and place 3D objects on them in the software.

The test showed discrepancies when moving around the area, in the form of registration/alignment issues, prohibiting me from concluding on calibration accuracy. As I walk around, the boxes move on all axes, causing the cubes to shift slightly in either direction. I did a test with the dragon-style villa as well, shown in Figure 29. These images show promising results, but this building also moved around slightly. Some experiences might work with this level of accuracy, but it will be noticeable to users and create a visible discrepancy.

This means that Adobe Aero it is still not perfectly accurate for calibration; it is much better than without Google Earth to calibrate against. However, the user experience provided, would have made it unproblematic to calibrate the elements to the right position if it hadn't been for the fact that the elements move around and become misaligned as the mobile device moves.

Figure 29: The screenshot on the left shows the villa placed at Peter Rokseths plass at the University of Oslo campus. Notice how the building is placed between the two stone walls and how it matches up in the real-world environment in the image on the left (screenshot from iPhone)

Summary of findings from control-tests

The control tests show that there are visual discrepancies in all the tested environments on all the three main issues that I report on. Hence, it is still possible to distinguish issues when using AR to blend the real and virtual worlds.

2: User feedback during testing on-location at Sarabråten

After conducting comprehensive control tests, I thoroughly understood AR performance under optimal conditions. Since I was already aware of the limitations, I had a good idea of how users would respond. However, I still encountered some of the same experiences as in previous tests (Lofoten and Fort of Paimogo), where test users were more likely to be positively astounded than anticipated. This time, feedback was also more direct since I utilized the Think Aloud methods. After the initial calibrations, these were the first (descriptive) responses from both test users, with my translations from Norwegian.

"Ok. That's cool. Now I'm thinking...I mean this impresses me. I thought the textures were perhaps a bit low-resolution. But maybe that is related to what the average phone is capable of processing in an app like this?"

Sindre.

"Nice. Ok. Oh my god, this is insanely cool. It's incredibly good. Yes, this is impressive."

Peter.

Responses from the focus group and think-aloud testing was analyzed in NVivo, to identify the breadth and common features. The findings indicated that the most common feedback fell into four categories: registration/alignment-related, occlusion-related, suggestions for improvement, and "Pro indirect AR," which refers to issues that I know the sitsim framework already resolves through indirect AR. These categories are elaborated in the following.

Registration/alignment-related feedback

Not surprisingly, a large part of the feedback was related to the issues of registration/alignment. Some inconsistencies occur when walking far away from the point of calibration. The respondents were made aware of this and the way to recalibrate by going back to the start. This resulted in several questions throughout testing, asking if they needed to recalibrate.

"Is this a recalibration, or is it... Now I'm standing right up against the wall. Here's the attic."

Peter.

The respondents were at the same time, impressed by the registration alignment when everything worked. It was mentioned that despite expecting errors while walking in lower terrain or further away, the registration still appeared to be correct. One of the testers also expressed surprise at how the phone detected their forward movement, saying he found it quite impressive. An issue was observed where the tester reported that there wasn't a one-to-one connection between certain parts. The experience glitched by around 1 meter at this point, but the tester stated that he still understood which parts should be connected.

Occlusion-related feedback

"It hasn't been taken into account that there are benches here."

Sindre.

I had two preplanned possible issues that I wanted to witness the tester's reaction to, one of them being the benches at the western wall. One of the respondents addressed this as a concern. Stating that it appeared weird when the building overlayed the benches. When discussing this afterward, he claimed that this pulls him out of the illusion, making it appear as if something has been glued on top. The other tester agreed that it contributed to breaking the illusion. Upon approaching the benches, the experience occluded them as intended, but with the limited range of the Lidar sensor, this didn't happen until he was about 5 meters away. The issue was also mentioned when we looked at the building from afar; one tester said it would have been cool if the trees in front of the building actually showed up in front of the building. After explaining the range of the Lidar, I wanted to show them how it actually worked, one of the testers uttered this:

Okay, let's see how it feels. Now we're going behind a tree. And then the building elegantly hides behind.

Peter.

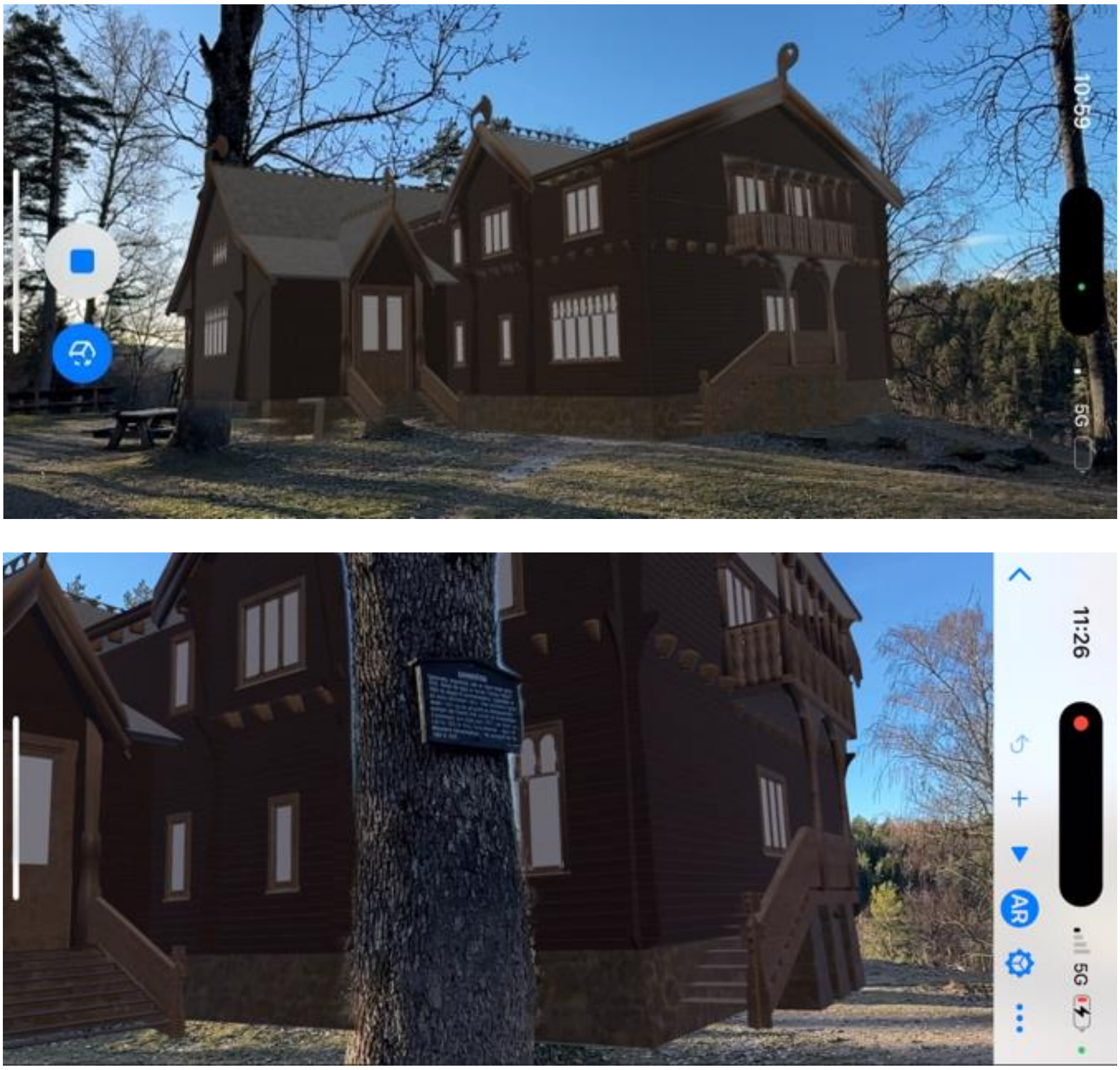

Figure 30: The image on the left shows poor occlusion; the large tree should be occluded, but since the device is too far from the tree, the Lidar scanner cannot contribute to occlusion. The image on the right demonstrates how it works closer to the tree, where the tree is occluded. Since the background is bright, parts of the background still shine through.

Suggestions for improvement and “pro indirect AR”

The recommendations for enhancing the project were primarily focused on technical aspects, such as improving lighting, adding missing details to the foundation such as windows, improving textures etc. However, several suggestions are already addressed in the sitsim framework and could not be implemented using Augmented Reality technology.

> *“Ok, what I immediately tried now was to zoom out to see the wide-angle view of everything.”*
>
> *Sindre.*

Figure 31: Screenshot from the device during testing, both testers experienced the model as being "to close".

During the simulation, a 24MM equivalent main camera on the iPhone was used. However, both testers found it to be too much of a tele-field-of-view for this particular experience. The site where the simulation took place has steep hillsides on three of its sides, and in order to get a full view of the building from all angles, the participants requested the ability to "zoom out" and see more of the building from their point of view. Although I could have used the wide-angle lens of the iPhone, which is a 13MM equivalent, it would have added too much distortion and given the experience a "fisheye" lens appearance, destroying the illusion of having a similar field of view as the unmediated reality. In addition to the request to zoom out, the participants also wanted to witness a birds-eye view of the site from a drone's perspective.

As the testers walked further away from the building to view it from a distance, they began to discuss the trees surrounding it. They speculated that the trees may not have been there or looked different during the simulation. Additionally, the testers requested the ability to observe other buildings that were once located at the site.

During a discussion, it was proposed to create an animation of "Sara" the boat arriving with guests. Additionally, there was a suggestion to include a virtual tour with a guide, such as Thomas Heftye. However, one of the testers raised concerns about holding the phone up for a long time while listening to the guide, as it could cause fatigue in their hands.

3: Ease of use in developing no-code prototype

I cannot objectively address whether these development platforms are easy to use; however, I will provide some personal experiences regarding usability. At this stage, I will try to objectively compare the three platforms against each other regarding usability as a prototyping tool and address each platform's strengths and weaknesses. The review is based on the following criteria: possibilities for further development, Easy and quick deployment, ease of sharing and cooperation, ease of calibration, and support/accuracy of occlusion.

Unity with Google Geospatial

Undeniably, Unity is the most comprehensive tool available among the three in terms of further development. Unity is flexible and adaptable to almost any use case. This comes, however, at the cost of a steeper learning curve. Although functional as an NDCP, you will quickly find the need to learn at least basic scripting in the programming language C# to be proficient in Unity, hence, Unity is more of a Low-Code Development Platform (LCDP). The biggest issue a non-programmer will meet with extensive development platforms like Unity is the lack of installed prerequisites. In short, Unity prerequisites various developer-specific software, such as Visual Studio, CocoaPods, Ruby, XCode (for iOS/macOS development), etc. Some of these components are downloadable as executables (I.e., software that installs itself from a package). Others are installed through the terminal/command-line interface, which requires understanding the command line, GitHub, and/or other cloud-based services for software development and version control. This understanding can be obtained from tutorials and documentation. However, Unity may not provide the most straightforward solutions for solving and investigating design problems for basic prototyping in the initial design phases.

To deploy an app built with Unity on iOS devices, you must use XCode and have a registered, paid Apple Developer account. However, the process can be complex and challenging, particularly for beginners. Error messages can be difficult to comprehend when exporting a build from Unity and compiling it in XCode. Therefore, deploying the app requires considerable trial and error. Unity offers several ways to collaborate and share your projects. You can export packages and use unbuilt tools for cloud collaboration. With Unity, you can also deploy your apps to the Apple App Store, subject to approval, and distribute them for beta testing through the Apple TestFlight app.

Being the most comprehensive tool among the three, Unity offers all the features in the other apps combined. At the time of deployment, I used the latest Long-Term support (I.e., thoroughly tested and out of beta) version of Unity available (2022.3.11) This version was still running on ARKit 5, with a few additions from the ARKit 6. Unity prereleases are already available with ARKit 6 support, which will further improve the results I presented. This means that Occlusion (Unity, 2023) and registration/alignment will be enhanced even further in new releases.

Apple Reality Composer

Reality Composer is an iOS app offering limited possibilities for further development and current possibilities compared to similar tools, making it the most straightforward option among the three. However, Reality Composer is an efficient tool for testing 3D models on locations and building quick prototypes. Unfortunately, the version log for the app does not state which ARKit version is currently in use. However, testing of the app indicates that it is currently utilizing ARKit 4 (the first version of the SDK supporting occlusion). When it comes to collaboration and sharing of Reality Composer files, they can be exported to other users as *.reality* files. These files are compatible with the XCode framework, meaning that the progress made with Reality Composer could be further developed into an AR app that can be distributed in the Apple App Store.

Adobe Aero with Google Geospatial

Adobe Aero is the closest to a functional NDCP among the three. This app is a user-friendly experience. When opening the app, you are prompted with a dialogue box helping you to spatially place the AR experience in a physical location using a Google Earth search field, where automatic suggestions appear when starting to type. The Sarabråten case example is a basic app without any interaction or animations. Still, Adobe Aero supports interactivity using either proximity-based triggers or tap gestures. This means it is possible to build interactive spatial storytelling experiences. The AR experiences made in Aero are quick to deploy. However, they cannot run without the Adobe Aero iOS or Android app, meaning they cannot be distributed through the App Store or Google Play store. The app makes calibration to a real-world environment easy, using Google Geospatial Creator. There is no mention of which ARKit version Aero runs on, but since there is no support for occlusion; it is likely based on an older ARKit version.

Discussion

This thesis aimed to explore the advancements in AR technology and its potential to be used in disseminating cultural heritage. Specifically, the thesis aimed to evaluate whether the Lidar sensor has advanced AR technology sufficiently to address three main issues with AR in cultural heritage dissemination, namely alignment, occlusion, and calibration. The thesis also aimed to explore how no-code approaches and low-fidelity prototypes could be used to get answers to problem statements at earlier stages of sitsim development. I find that the Lidar sensor, in some situations, like indoors contributes to improvements in alignment, where virtual content now registers better against the real world. I furthermore find an improvement in calibrating AR experiences with real-world elements at locations with strong GPS signals, made possible by Google's Geospatial framework. Nevertheless, the shortcomings of AR regarding alignment in outdoor peripheral locations and occlusion still partly remain. For the time being, these limitations are seemingly caused by technical limitations in the range and resolution of the Lidar sensor. Hence, AR has not surpassed the previous limitations in cultural heritage dissemination.

When sitsim was in the early phases of development, it was decided to make the experiences available on consumer-grade devices without needing specialized hardware. However, the best consumer-grade mobile devices struggle to achieve accurate occlusion culling. A recent master's thesis has delved into AR occlusion on more specialized hardware than mobile devices and has come to similar conclusions (Kuzma, 2022). Since 2018, the Apple ARKit SDK has continuously progressed and undergone significant yearly upgrades. The depth frameworks available on iOS devices can read camera data and generate accurate depth maps that can be verified using the Lidar sensor (Apple, 2020). Therefore, a possible solution could be combining multiple sensory inputs with machine learning techniques to enhance the system's accuracy and effectiveness.

It can be challenging to analyze and understand AR content due to this fast pace of development, especially when there is usually no documentation available about the SDK version used by various composing tools and applications. Therefore, it is necessary to be aware of the significant releases of ARKit to accurately evaluate and comprehend mixed reality content. This was one of the reasons I wanted to compare multiple AR composing tools. I aimed to gain comprehensive knowledge to analyze AR in mobile Augmented Reality.

It is important to note that my thesis does not provide a complete review of all the technology available for AR dissemination of cultural heritage. Instead, I focused on a no-code approach, which has limitations compared to what a skilled development team could achieve.

The invested resources in developing the other sitsim experiences referenced in my thesis make them an unfair comparison from the simple prototypes I have developed to answer my research question. But that is also an important argument that I want to make. No-code tools and low-fidelity prototypes make it easier to get answers to problem statements at earlier stages of the process. Hence, it is a more cost-efficient way to discern good ideas from bad ones. This is useful to avoid full-fledged research designs where you have erroneous presuppositions about the user or, for that matter, technical aspects. There is, unfortunately, no way of knowing if a prototype of a new media form will work before you have tried it (Nyre, 2020). When it comes to sitsim design processes, it's crucial to test early with low-fidelity prototypes, in order to provide good user experiences. Participatory design methods like future workshops based on ideas or sketches can be incorporated in the early stages of sitsim design. Moreover, low-fidelity prototypes allow for on-location testing using humanistic evaluation methods such as think-aloud, surveys, and focus groups. These methods can provide valuable insights to improve in initial design stages. My two research questions have been intertwined and worked in conjunction to provide me with valuable insights made possible only because of my choices of method. This has given me valuable insights that have enabled me to analyze and understand mobile augmented reality and the sitsim in new ways. In the following, I will use these insights to explore whether the sitsim platform should adopt AR in the future once the technology has advanced sufficiently. First, through a discussion of whether true visual realism is needed to disseminate cultural heritage.

The notion of true AR against the location’s added benefit of Aura.

Bolter and colleagues argue that achieving perfect realism in any medium is impossible, as all forms of media fall short of duplicating reality (2021). An opposing understanding is found in Sandor and colleagues’ definition of *true AR* as a “modification of the user's perception of their surroundings that cannot be detected by the user” (Sandor et al., 2015). This means that augmented reality is so well integrated with the real world that the user cannot differentiate between the two. Albeit a normative definition, some AR studies aspire towards true AR (Geronikolakis et al., 2020). However, Sandor and his colleagues argue that achieving true AR requires advancements in modalities beyond the visual channel. This means that to achieve true AR, the sensory stimulations that reach our other senses, such as smell, hearing, and tactility, must match realistic visual stimuli. However, the idea of true AR, which aims for photorealism in the virtual elements and coherent stimuli for the other senses, is not the only way to provide valuable experiences for users of a mixed reality experience on a heritage site.

The sitsim platform has demonstrated that achieving perfect realism or true AR is unnecessary to create all-encompassing user experiences. Bolter and colleagues argue that In the context of media theory, the term aura, often ascribed to Walter Benjamin, is often associated with the authenticity of an experience and “the ability of a media form to represent the authentic” (2006). They claim that mixed reality applications, situated in a location and blending physical and virtual reality for a unique experience might revive the possibility of evoking aura (Bolter et al., 2006). Hence, in AR representations of cultural heritage sites, the experience of realism and authenticity is heightened by the *in-situ* presence on location.

Bolter and colleagues refer to reality media “as those media forms that explicitly interpose themselves between us and our visual, auditory, or tactile perception of the everyday world and in this sense seek to redefine reality itself” (Bolter et al., 2021; Engberg & Bolter, 2020). Bolter and colleagues identify two central terms from the literature on the experienced realism of reality media: immersion and presence. Immersion refers to the extent to which virtual environments can provide a realistic and all-encompassing sensory experience to the user. It involves creating a virtual world that is visually and audibly realistic, making the user feel as if they are physically present within that environment. (Engberg & Bolter, 2020).

On the other hand, presence is a psychological state that refers to the feeling of "being there" in a virtual environment. It is the subjective experience of existing within and feeling connected to the virtual world. Presence depends on the individual's perception and psychological engagement with the virtual environment. Immersion focuses on the technology's capabilities to deliver a realistic sensory experience; presence emphasizes the psychological state of feeling present and connected within the virtual world.

This experience of presence was observed in my tests and has been confirmed repeatedly through sitsim development. As an example, after looking up from the phone, one of my testers said this, referring to the dragon-style villa:

"Now I'm almost surprised that it wasn't there when I brought the phone down."

Sindre – Sarabråten user test.

Mixed reality combines the unmediated presence on location with the accompanying virtual experience. Double description is a theory that involves analyzing a phenomenon using two levels of description: the intrinsic level refers to specific details, and the extrinsic level to a broader context (Hui et al., 2008). Sitsim experiences provide such a double description, where details are delivered on the screen, providing the intrinsic level, and the surrounding heritage site provides the extrinsic level, i.e., context. This creates a double description effect that heightens the user's experience. User experience from the fort of Paimogo survey also reports on the value of this double description:

"The sensory from the real world is important to make the simulation more credible."

Female, 36 feedback from fort of Paimogo survey.

I argue that immersing oneself in a heightened experience where you start imagining what once was causes users to consider sitsim and AR experiences at cultural heritage sites authentic. My earlier findings indicate that this can happen despite obvious fallacies in the visual representation (Bøe, 2021). Maybe this is what constitutes aura?

"It´s interesting because we know it's not a real environment, but we feel like if it was."

Female, 51 – feedback from fort of Paimogo survey.

Walter Benjamin's concept of aura refers to the unique presence and physicality of a work of art. According to Benjamin, aura is the quality that makes a work of art unique, authentic, and filled with historical and cultural significance (Benjamin, 1935). By offering an experience of presence, AR can provide a sense of authenticity akin to experiencing the aura of an artwork in person. Through sitsim, users can explore virtual reconstructions like in my case study, interact with virtual characters like in my Lofoten experience, or virtually visit inaccessible cultural sites like the shipwreck of the Greek isles of Alonnisos and Peristera, all of which could contribute to a sense of presence that might evoke a sense of aura for users.

Mixed reality has not reached a level of true AR, nor will it ever, because it is impossible to achieve perfect realism since all media fall short of duplicating reality. Still, mixed reality and sitsim have immense potential to invoke a sense or aura for visitors to a cultural heritage site rendering the notion of true AR less important in this context.

AR or indirect AR to disseminate cultural heritage?

My goal is to spark the imagination of visitors to cultural heritage sites and encourage them to learn more about our collective cultural heritage. Even though AR is advancing, many scenarios still exist where indirect AR can and should be applied. In the following paragraphs, I will show some viable scenarios based on the case studies I have worked on.

Heritage sites deteriorate over time, and historic sites often inadequately represent their original appearance. Moreover, the environment surrounding a cultural heritage site may have its own stories to tell. The site’s landscape can drastically change over a century, which sometimes needs to be presented to accurately depict the history of a heritage location. For example, the military Fort of Paimogo was constructed in 1674; since then, coastal erosion has caused substantial parts between the fort and shoreline to deteriorate.

Figure 32: The appearance of the fort surroundings differs from the period the simulation was representing. Today, concrete has been used to avoid further erosion. On the left, some rock formations have been restored for the simulation (3D render from before adding vegetation and water in the game engine.)

This meant that to accurately represent the fort in a different time period, we added some of the deteriorated rock back to the simulation shown in Figure 32, trying to preserve the geological layering (Mateus et al., 2017). During my case study at Sarabråten, I was given suggestions for enhancing the surroundings that included making similar changes. For instance, the trees in the area look different now than they did in the late 1800s, and this could have been addressed by using indirect AR to bring back historical layers.

"But those trees were actually... They probably weren't there. You can look at the pictures on...[inaudible]"

Peter – Sarabråten user test.

At Sarabråten, it was suggested that the experience could have been improved by modeling the inside of the building. This was done at fort of Paimogo, which was an indoor/outdoor experience. The fort's interior is almost pitch-black, which would have caused poor image quality with an AR simulation. With indirect AR, the interior was modeled. Hence, we had more artistic freedom regarding lighting (e.g., adding fire in the fireplace, lighting the room with candles. etc.). These added elements are, of course, also used for narrative storytelling purposes; for example, one of the soldiers we animated in the fort was meant to provide a jump-scare when walking out of a dark room and abruptly starting to talk.

Narrative storytelling is an aspect that is made much easier with indirect AR. As an example, the experience of the sinking ship off the islands of Alonnisos and Peristera was built using conventions from movies and narrative storytelling. For instance, we used jump-cuts through different weather scenarios to depict the passing of time (see Figure 33)(Bordwell et al., 2019). Also, a scene from a video clip with fierce weather inspired the lightning strike (Figure 33). The story of the ship sinking due to heavy weather and a lightning storm would have been challenging to disseminate with AR on-location if the weather had been nice.

Figure 33: Albeit grey weather on the day of testing, the waves and weather shown through indirect AR intensify the experience. (Liestøl, 2022 - Screenshot from Youtube)

The third example, showcasing the possibilities of indirect AR, is connected to the notion of views. In an indirect AR experience, a virtual camera tracks the mobile device to determine which parts of a 3D environment should be rendered and displayed on the screen. This is great if the viewer is happy seeing the experience from the point of view from which he is standing. However, again exemplified by the descending ship. AR gives you a poor vantage point if you stand on the shore. With indirect AR, you can send the camera to the action while panning/tilting the phone to adjust your view. The Alonnisos Peristera experience also enabled a "dry dive" to the wreckage, expanding the viewing modes beyond what is possible in AR (Figure 34).

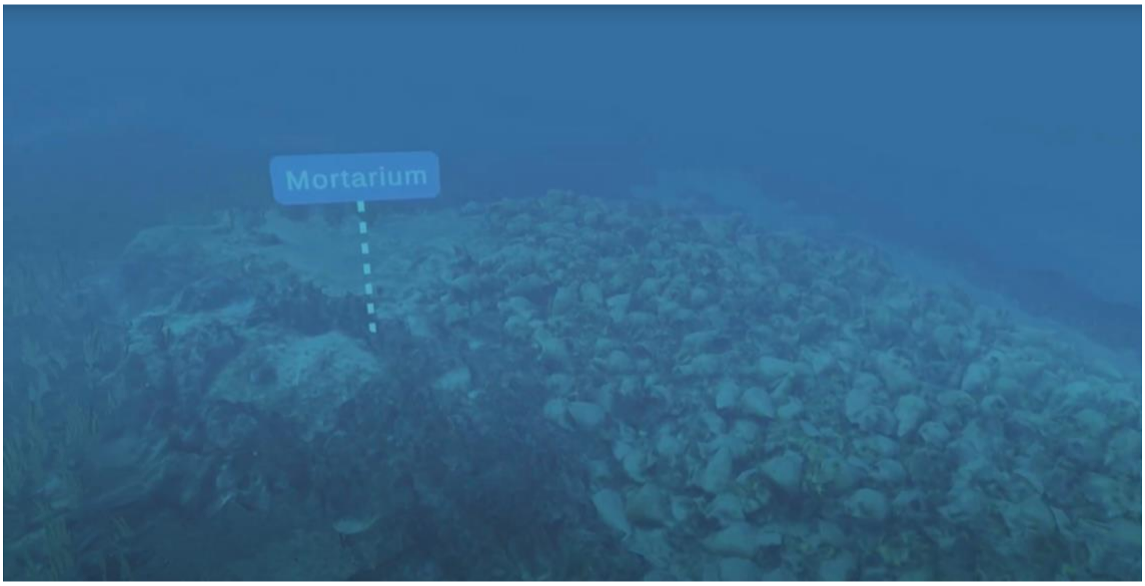

Figure 34:Example of how a “dry-dive” to the ancient wreckage appear in the sitsim; this would not be possible in AR. (Liestøl, 2022)

Feedback from test users at Sarabråten also supported the argument of different views. Test users requested the ability to zoom out, which isn’t possible using AR if the virtual elements shall remain connected and aligned to the camera image. Test users also requested a “drone view” of the entire scene and stated that they would truly be impressed if they could see the other buildings throughout the area. These features are already built into the sitsim platform, enabled by indirect AR as a mode of representation.

Although indirect AR has advantages, the most significant benefit of AR is cost. Developing 3D models is costly because it requires immense amounts of human labor. Modeling a heritage site’s entire surroundings takes much more work than just modeling the artifacts that must be displayed. Hence, the proposed tools and methods can make AR experiences showcasing cultural heritage sites more widely available. Using Adobe Aero, the experience can just as easily be shared with a QR code on location, making the exciting genre of AR spatial storytelling available to an even broader audience.

AR could also be valuable for disseminating historical artifacts, especially those removed from peripheral locations, into central museums. Photogrammetry models of historical artifacts displayed where they were found is an exciting application of AR. This also eliminates the issue of alignment, at least in cases where there is no physical element on location to align the model against. Bringing artifacts back from the center to the periphery has been performed through a recent advancement in the sitsim platform (Liestøl et al., 2021). Sitsim now can show 3D models from various collections, such as the BiTFROST collection, an extensive collection of digitized 3D artifacts from the Museum of Cultural History at the University of Oslo (KHM, 2021).

Since the two modes of representation AR and indirect AR both have interesting advantages, future research should explore how the two modes could be combined in the sitsim platform. I imagine a sitsim experience with transitions from AR to indirect AR in certain scenarios to clarify then and now. For example, when displaying where a historical artifact was found.

Sitsim - progress from its mode of representation

Design thinking and synthetic-analytic methodology share a common belief that design is an iterative process that involves a constant search for progress. While I have commenced additional loops of investigation in the already circular synthetic-analytic process, these small design circles are not entirely new; they are already present in the design process of a sitsim. They are addressed as borrowing conventions; these conventions are essentially genre-specific traits borrowed from other fields within the humanities, such as rhetoric, narratology, and film studies, but also Freud's theories of humor, Roland Barthes's theories of photography, Walter Benjamin's theories about art in the mechanical age of reproduction, etc. (Fagerjord, 2012).

Sitsim has always aimed at designing a new media form. During the initial stages of development, indirect AR was chosen mainly for technical reasons. Moving forward, the choice of indirect AR should be made because of other reasons. As the sitsim platform progressed and user testing was conducted, sitsim evolved into something greater than just its mode of representation. Conventions have been borrowed, gathered, tested, and eventually accepted into what has developed into a distinct form of representation of its own. Even if it were technically possible, transitioning the sitsim platform into a new mode of representation would not be advantageous. Such a transition would result in the loss of too many conventions that have been meticulously adapted to the platform.

Because even though I had a firm belief that AR would benefit the sitsim platform as a mode of representation, my tests and experiences have proved me wrong. I still believe in disseminating cultural heritage with AR. I believe that presenting digitally reconstructed or 3D scanned artifacts at their original location using AR can enhance the sitsim platform. Also, I think AR has the potential to render spatial storytelling at Cultural heritage sites available to more people. The sitsim platform stands well-founded on its own, and whenever there are resources available, I would recommend the sitsim approach using indirect AR. But with limited resources and exciting stories to tell, I hope this thesis can contribute to an understanding that the engaging art of spatial storytelling with AR is an accessible tool to convey cultural heritage.

Media design – as a way to analyze media innovation.

The advancement of Augmented Reality (AR) solely depends on the development of both sophisticated hardware and accompanying software that can fully exploit its potential. Consequently, these are exhilarating times for the research field as Apple's extended reality headset is set to launch in early 2024, featuring innovative ways of sensor fusion that will enable new methods of registering AR content against the real world.

Lars Nyre and Anders Fagerjord argue that media design is crucial for researchers to comprehend new media. In line with their argument, I believe that understanding Extended Reality (XR) has become increasingly important with the launch of Apple Vision Pro.

To fully leverage the potential of technologies like this, it's essential to comprehend the technical implications and limitations of extended reality and spatial computing. Doing so not only opens up a new world of opportunities for invention and development.

Understanding the core principles of developing extended reality experiences could provide the understanding needed to analyze these new media forms.

Reality Composer Pro was released with XCode 15 beta 3. This is an AR experience compilation tool developed for Vision Pro. This application is similar in functionality to the other development platforms I have presented. However, its main purpose is to create Mixed Reality experiences where the level of immersion, i.e., how much of the surrounding area the user can see, is adjustable by the user and the app developer. This paves the way for new experiences that combine AR with VR in a novel way. Still, the theories presented in this thesis on AR, VR, MR, and XR still apply and can be used to understand how users will interact with this new medium.

As of November 2023, we know little about GPS availability in the Vision Pro; however, the documentation states that VisionOS 1.0 Beta can fetch Core Location data (Apple, 2023b). This might imply that Vision Pro can be used for immersive sitsim experiences *in situ*. Such experiences will imply designing a new user interface that enables the users to remain aware of their surroundings to apprehend the increased experience of aura that presence on location provide. The suggested methods in this thesis also apply to such developments, and I assert that extensive use of user testing at earlier stages will be essential to create human-centered experiences in this new medium.

Evaluation of the media design approach

My first experience with sitsim development in Lofoten in 2020 showed me how problematic it is to presume user feedback. The survey results did not meet my expectations.

Performing extensive studies, like in Lofoten, is costly. Hence, I wanted to develop a design that prohibited me from asking the wrong research questions in a full-fledged investigation. This experience led me to inquire about different ways to get feedback from users at earlier stages of development.

The design of my case study is based on building low-fidelity prototypes. I have presented different means to produce prototypes that could serve different purposes in a design process. The different platforms can be utilized for different things and at different stages throughout a design process. Together, these three platforms comprise a toolkit for quicker results than conventional ways of sitsim development. However, it is essential to note that these tools are not suggested as substitutes for the sitsim framework, which already provides many of the same tools (like off-location testing). The end results provided by skilled developers building on the sitsim framework will provide much better user experiences, with fewer bugs and a well-thought-out user interface.

However, the tools I present can get quicker results by doing many small tests along the way. During my investigation, I primarily focused on technical issues and utilized prototypes to address a specific technical question. The goal of this inquiry has been to determine whether sitsim could benefit from a new mode of representation. I need to address that I could have used the same method to investigate various aspects, including content queries, UI advancements, etc.

Active participation in the development processes is of great value when researching media innovations. I agree with Lars Nyre that researchers must actively engage with digital media to effectively analyze it in today's fast-paced media landscape (Nyre, 2014). The field of media studies can contribute to progress not only by analyzing new media but also by synthesizing it. Delving into user manuals and documentation and actively developing solutions has been essential for me to grasp technical possibilities. This approach provides immense insights when analyzing new media forms.

The contribution of this approach

When this thesis was submitted (November 2023), I could not find any scientific mentions of “Google Geospatial” in JSTOR, ORIA, or Google Scholar. Media design as an academic discipline is still a small branch within the conventionally more analytic discipline of media studies (Nyre, 2020). Regardless, an extensive research community works with digital cultural heritage from disciplines such as Museology, Archaeology, Cultural heritage studies etc. The Google Geospatial Creator holds immense value to researchers within such fields to disseminate their findings.

This thesis contributes a method to use no-code approaches and low-fidelity prototypes to get answers to problem statements at earlier stages AR design processes. For anyone interested in pursuing spatial storytelling using AR. Unity is the best platform of the three; it supports all the features in the other platforms combined, providing the best registration and occlusion capabilities and all the stylistic and functional features needed to make comprehensive experiences. However, if you want to create spatially located AR experiences more easily, I suggest trying Adobe Aero with Google Geospatial, as it is a quick way to deploy and share AR experiences. However, as Apple Vision Pro is near its release Reality Composer and the accompanying XCode framework provide exciting possibilities. Reality Composer is also the easiest tool to calibrate on-site.

My approach is closely connected to my experiences as a student and teaching assistant in the course media students as researchers. As part of their coursework, students must create their own problem statements for a research project related to sitsim development. By utilizing the tools and methods proposed in this thesis, they can gain a better visual and conceptual understanding of their experiments before deploying them into the final sitsim on location. This approach can also benefit the development process by distinguishing good ideas from bad ones more easily.

The limitations of my approach

Based on my work with no-code approaches, it is important to note that my findings are limited to the existing technical solutions available. This means that my approach does not involve a new technical invention. However, I have focused on addressing a problem not discussed in the literature related to AR in cultural heritage applications. Specifically, my approach highlights the advantages of using Lidar sensors to address the shortcomings of previous AR dissemination solutions. Having limited myself to no-code approaches might seem like a big limitation in this sense, but my findings show that the issues aren't currently related to software but the hardware side, specifically related to the range and resolution of the Lidar sensor. This means the issues I report on would have been present despite a larger development team.

No-code approach to AR spatial storytelling in educational context

While completing my case study, I intentionally avoided seeking assistance from experienced developers. I intended to make the method easily applicable to students who follow the course I have been teaching as a teaching assistant for the past three years. The course adheres to the pedagogical approach Computer-Supported Collaborative Learning (CSCL). CSCL emphasizes the importance of involving both students and teachers in collaborative efforts to create new knowledge and solve problems together (Leinonen & Durall, 2014).

This pedagogical approach aligns with a shift in design science from user-centered design to co-creation, which involves users from the initial stages of research. By including students as design partners and leveraging the concept of a beginner's mind, fresh perspectives can be brought to the research process. Involving students in Vertically Integrated Projects designed to answer significant issues, such as sustainability, is motivating and relevant to their professional lives (Carlson et al., 2022). Liestøl has included students as researchers in his research for many years at the BA level, and some students have been able to publish their research papers in peer-reviewed journals as a result. Liestøls approach is valuable not only for students' research comprehension but also as an approach to teaching digital competencies.

A recent whitepaper from the Norwegian government recommends implementing digital competencies into disciplines other than where it has conventionally been taught (Kunnskapsdepartementet, 2023 - Utsynsmeldingen). This report has made it highly relevant to involve students in research within their fields of interest while providing them with digital competencies. At the Faculty of Humanities, where I work and study, many subjects could benefit from innovative methods of disseminating their fields. I hope the methods presented in this thesis can provide students with digital competencies while engaging them in research within their fields of interest.

An AI no-code revolution?

Digital competencies are in high demand, and developers are a limited resource. Therefore, no-code approaches to software development have numerous advantages. Currently, there is a shift happening from code-centric software development to a larger availability and use of low-code development platforms (Sahay et al., 2020). Low and no-code approaches to software development typically involve graphical user interfaces, which can increasingly be facilitated by artificial intelligence (AI) writing necessary code based on natural language.

In the past, we have seen similar shifts. During the early days of websites, proficiency in HTML was required to develop a webpage. Then came What You See Is What You Get (WYSIWYG) editors, Content Management Systems (CMS), and blog platforms like WordPress, making this new media democratized and accessible to everyone.

The no-code developer platforms (NCDPs) I have presented, especially Adobe Aero, are practical tools for creating and deploying Augmented Reality (AR) experiences for spatial storytelling on cultural heritage sites. However, as demonstrated in my methods chapter, the current process still relies excessively on human labor, even for prototyping. I firmly believe that AI will not replace human jobs, but those who master AI will have a competitive advantage. Therefore, I will likely employ AI tools extensively in future sitsim development.

In sitsim development, AI is already used to generate voiceovers based on speech synthesis. AI-powered tools like Sourcegraph, IntelliCode, DeepCode, and others are available to assist coders in generating and troubleshooting code. Similarly, my effort to gather and code qualitative data in NVivo can be made more efficient through AI tools like MAXQDA, QualCoder, and others. AI tools such as 3DFY, Meshy, Alpha3D, etc. can convert text to 3D. To stay ahead in media innovation and media design, it is necessary to keep up with the latest AI-powered tools and techniques.

Significant progress will be made in all areas of research presented in this thesis before it is published. However, addressing the potential issues arising from all this progress is also necessary.

Progress/Obsolescence – sustainability issues

I analyzed a rapidly changing moment and medium during my thesis work. This makes it challenging to stay up-to-date and not become outdated immediately. Jason Farman argues that the dichotomy of progress is obsolescence because while technology progresses, the old becomes obsolete (Farman, 2021).

This is an important notion when contributing to media development. Media studies are well-equipped to understand the adverse effects of progress. My research question emerged with the release of the iPhone 12. When I wrote this chapter, the latest version was the iPhone 15. With progress comes a downside - a considerable number of obsolete devices.

Figure 35: Depicts 426,000 cell phones, equal to the number of cell phones retired in the US every day (Jordan, 2007).

In a series of photographic artworks called: “Running the Numbers: An American Self-Portrait”, Chris Jordan exemplifies obsolescence issues. Figure 35 depicts screenshots from an animation that slowly zooms in from an extreme total of the 426,000 phones discarded in the US daily only to be revealed as phones when the images have been zoomed into a closeup (Farman, 2021; Jordan, 2007 Example is mentioned in Farmans book.).

“This storm is what we call progress.”

Walter Benjamin.

Canonical texts and writers within media studies raise awareness about technology's flip side and sustainability concerns. Hence, media studies are responsible for taking a step back from their contributions to progress and analyze it critically. For the scope of this thesis, I delimit myself to mentioning the issues, however, these issues will need to be continually addressed further because:

Design never ends; there is a constant need to redefine the problem.

Several illustrations depict the design thinking framework; some are linear, and some are presented as a circle (Brattli et al., 2023). The illustration earlier in this thesis (see Figure 8) provides an insight into how messy a design process can be, but the illustration still leads back to the starting position. The issue of considering the design process as a circle is that, metaphorically, you are brought back to where you started; however, you have gained much insight along the way. Hence, I think of the design process as a concentric spiral, where your understanding is improved each time, you complete the process.

Conclusion

This study aimed to evaluate whether AR is the preferred mode of representation over indirect AR in sitsim experiences when the necessary technology is available. Although sitsim initially used indirect AR because of technical limitations this does not necessarily mean that sitsim will be a better platform with AR moving forward.

This study demonstrates that current mobile devices' alignment and registration capabilities could be suited for disseminating cultural heritage in areas with good GPS and cellular coverage or indoors with short distances between walls; in optimal conditions, discrepancies are barely noticeable. However, in real-world conditions, for instance, in areas with weak GPS signals, such as my example at Sarabråten, relying solely on other sensors such as Lidar, accelerometer, and gyroscope won't provide sufficient alignment. This is because Lidar sensors have a limited range; in addition, there are real-world challenges with point-cloud world maps, because of changing vegetation on a location, etc. Furthermore, this study found that current mobile devices work decently for both human and object occlusion. However, Unity, the solution that gave me the best results, had a shortcoming. It required me to choose either human or environmental priority, and selecting one substantially negatively impacted the other. In addition, the resolution and range of the Lidar sensor meant it worked well only within five meters of the device. The last and final concern was calibration, this study finds a considerable improvement regarding calibration, at least in terms of usability. Provided good cellular and GPS service, calibration will be a much easier task to accomplish.

These results have been gathered through low-fidelity prototypes, showing that the tools and methods I have used provide a good toolkit to get answers in preliminary design decisions in sitsim development. While exploring user experiences with AR prototypes, usability issues with AR arose, besides the three main challenges I have addressed. Test users provided feedback on the AR system's limited field of view, lack of different perspectives to witness the experience, and historical inaccuracy caused by the camera view of the environment. These limitations with AR come in addition to the three primary concerns that initiated my investigation. Therefore, my findings suggest that indirect AR is a beneficial mode of representation for sitsim and cultural heritage applications.

The design process never ends, and my methods often lead to new questions and inquiries. Sitsim is a platform that enables the dissemination of a location's past, present, and future. Although AR technology still has some inaccuracies, user experiences were encouraging; future research on the sitsim platform should explore how transitioning between indirect AR and AR could differentiate movement in time. For example, from the past in indirect AR to the present, showing AR representations of cultural artifacts at the site where they were discovered. This could provide another engaging way of storytelling leading to an enhanced understanding of our shared cultural heritage.

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