Cartography M.Sc.

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MASTER THESIS

Potential Usage of Mixed Reality Devices in the Field of Cartography

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DECLARATION OF AUTHORSHIP

I hereby declare that this thesis entitled **Potential Usage of Mixed Reality Devices in the Field of Cartography** has been composed by me and is based on my own work, unless stated otherwise. No other person's work has been used without due acknowledgement in this thesis. All references and verbatim extracts have been quoted, and all sources of information, including graphs and data sets, have been specifically acknowledged.

Munich, 28.03.2018 Çağlar Satır

ABSTRACT

Devices that combine real and virtual worlds, namely mixed reality devices, are developing in a similar pace with other types of multimedia technologies. Cartography, being the field that connects spatial information with humans using visualization of data, naturally follows the speed of advancement in multimedia technology. Mixed reality, by its novel nature, promises a significant shift in the way spatial data is presented. In this thesis, potential usage of these devices in the field of cartography is investigated. For this purpose, a recently developed augmented reality device with the name Microsoft HoloLens is utilized with the aim of demonstrating the possibilities available with today's mixed reality technologies. After a therotical background is given, the criteria to assess selected applications are presented. These criteria are then used to evaluate applications that work with HoloLens, from the perspective of technical and human constraints. A detailed assessment of three different applications is done using data obtained from research and surveys conducted. Next, further possible examples of how mixed reality devices can be applied to cartography are examined. Finally, a general discussion of the results is included alongside with what can be done in the future for a better understanding and development of the combination of two fields: mixed reality and cartography.

ABBREVIATIONS

VR – Virtual Reality

AR – Augmented Reality

MR – Mixed Reality

VC – Virtuality Continuum

MDCU – Maximum Duration of Comfortable Usage

MDPU – Maximum Duration of Possible Usage

fps – Frames per second

MB – Megabytes

GB – Gigabytes

Mbps – MBits per second

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1 Introduction

In this chapter, an introduction to the topic of the research will be presented. The aim is to familiarize the reader with general ideas and concepts that led to this research. The motivation of the research and the problem statement will follow, explaining the driving force of this thesis. Later on, research question will be determined and explained in short, whose answers are expected to form the results of the research. Finally, the structure of the thesis will be clarified for the reader, giving information on the contents of the following chapters.

1.1 Overview

Technology of the multimedia devices are developing with an enormous speed. Cartography, with its strong dependence of multimedia technologies, is no exception. It can be argued that the processes of today's cartography are only connected to the work of a, say, 15th century mapmaker on a fundamental level. As in other modern fields of study, change is inevitable in modern cartography. Since cartography relies heavily on the visual stimuli to be able to attract the attention of the map reader, or as a more general term, the user, advances in visualization technologies cannot be separated from cartographic development.

As Stanek and Friedmannova claims (2010): "The role of cartography has changed during times from a recording of topography to imaging of the visual representation of a spatial knowledge". A more recent addition to this argument can be that modern-day cartography is and ought to be more than merely a visual representation of the spatial knowledge, it also needs to capture the attention of humans in ways that were never seen before. This requirement stems from the fact that the visual technologies available in today's world force the creators of cartographic material to adopt new methods and techniques to be able to keep up with the current trends in multimedia content creation.

In an attempt to achieve these goals, late 20th century saw the rise of digital cartography by integration of computers into the field, in addition to further developments such as GPS and location-aware devices. More recently, the field of mobile cartography started to grow with enormous speed. This is clearly due to the major advances in areas such as mobile computing and virtual environments (Feiner, MacIntyre, Höllerer, & Webster, 1997), as well as the successful convergence of two fields; cellular technology and internet (Reichenbacher, 2001).

It is easily arguable that aforementioned technologies eliminated some of the major constraints of cartography such as size and adaptability. As Stanek et al. (2010) mentioned; "Cartography has always fought with space and color, but it was always a trade-off." Nonetheless, the fact that maps are 2D representations of the real world remained more or less the same, with the exception of relief maps, which are labour intensive and time consuming to create and utilise due to their size and weight, compared to modern digital 3D maps.

Despite the developments in creation of 3-dimensional digital maps, until recently, the way the users consumed the 3D cartographic content was still limited to 2 dimensions, as these digital maps were viewed on screens of computer or mobile devices. This meant that the size and dimensionality constraints of maps were not completely overcome.

However, fields of virtual reality (VR) as well as mixed (MR) and augmented reality (AR) technologies, which are newly emerging, promises to change this. It can be argued that widespread usage of these devices will be a huge leap forward in terms of elimination of the constraints on size and dimensionality, since the devices mentioned fundamentally changes the way our world is represented, whose details will be discussed in further chapters of this paper. This translates to a dramatic change in cartography; being the science, art and technology of representing the world.

Mixed reality (MR) devices seek to create three-dimensional virtual worlds that are in interaction with both the user and the environment, which is why cartography can benefit vastly from the technology, being a science that aims to create representations of real world but also can use the adaptability of the mixed reality technology.

On the other hand, Augmented Reality (AR) is a completely new concept of a user interface, in which a user's field of view is amplified by enhancing the real environment with computer generated environments (Schmalstieg & Reitmayr, 2007). Another definition can be that AR "enhances a user's perception of and interaction with the real world" (Azuma, 1997).

It is clear that multimedia cartography is bound to be revolutionized with the addition of aforementioned technologies into the field, seeking the most appealing and in certain cases the truest representation of the world around us.

One of the recent releases of such mixed reality devices, that uses the state-of-the-art computing, displaying and sensor technology to create a AR experience is Microsoft HoloLens. Unlike devices created in most of the early attempts at mixed reality technologies, it can work untethered to a computer, having a standalone operating system and other features.

Figure 1: Early Augmented Reality system developed for military in 1992. Note the tethered nature of the devices that allows no mobility[1].

[1] https://en.wikipedia.org/wiki/Virtual_fixture

Figure 2: : Recent AR and MR technology allows the user the move freely while interacting with both the virtual and real environments. Microsoft HoloLens is one of such devices[2].

In this paper, it is aimed to show the possible applications of mixed reality devices in the field of cartography. Being a device that puts together a compact combination of recent technology, Microsoft HoloLens will be used as the device of choice to demonstrate the potential of MR and AR devices.

1.2 Motivation and Problem Statement

Research in the area of mixed reality devices, especially in the subsection of those that are related to the applications for cartography, is fairly limited. As mentioned in the previous chapter, these devices offer a great deal of potential due to their capabilities, while the power and features of digital technologies are increasing exponentially.

The motivation for writing this thesis is mainly the insufficiency of the research on the issue. It is aimed by this thesis that a contribution to the field of cartography is made, while encouraging other researchers to put more work into the investigation of the potential. Another goal of this paper is to act as a summary of the current situation in cartographic

[2] http://123kinect.com/fortaleza-glasses-revealed-microsoft-hololens/49492/

technology in conjunction with mixed reality technologies, which could demonstrate what is possible in the near future when multimedia cartography starts utilising MR and AR technologies more efficiently and in a more widespread manner.

Mixed reality, or hybrid reality is a newly emerging field in which digital and physical objects exist and interact in the same space (de Souza e Silva & Sutko, 2009).

Therefore, it has a huge potential for media creation and consuming. Cartography, being a field that uses media extensively, can benefit from the mixed reality technologies in a previously unprecedented scale.

Microsoft HoloLens is one of the mixed-reality devices that use a head-mounted display to interact with the user. It uses the state-of-the-art technology to process and display digital content overlaid with the physical environment (McBride, 2016).

This research aims to contribute to the existing theoretical knowledge in the field, by focusing on how mixed reality devices can be utilized when creating and consuming cartographic content.

In short, the main goal of this research is to determine theoretically the potential usage of mixed reality and augmented reality devices such as Microsoft HoloLens in the field of cartography.

What type of questions ought to be answered in order to achieve the goals are given in the following chapter, alongside with the motivations for the questions.

1.3 Research Aim & Objectives

The aim of this research is to come up with the possible applications of mixed reality devices, Microsoft HoloLens in this specific case, that has the potential to work with cartographic content.

The research is projected to supply the field with a general understanding of the state of the art in mixed reality devices, as well as the area of opportunities cartographic visualization can benefit from.

The scope of the research is mainly conceptualized as theoretical, meaning that specific applications will only be used as examples of the possiblities, and HoloLens acting as a way of drawing results from real-life applications. In short, the idea that MR devices can be used in the field of cartography is aimed to be proven by using existing technology and determining what limits it.

1.4 Research Questions

* **What are the characteristics of mixed reality devices?**
  To answer this question, properties and features of mixed reality devices must be thoroughly researched through the practical applications on Microsoft HoloLens and various sources of information.
* **What are the possible cartographic applications that can be integrated with mixed reality devices?**
  Answering this question can be formulated as the core aim of this research. It requires vast amount of time and effort to determine the possible uses.
* **What is the probability of realization (i.e. feasibility) of these applications?**
  This step will come after the identification of the possible uses. Each application will have to be evaluated by certain criteria, in order to determine the feasibility of the corresponding use case.
* **What type of problems are expected during the development and usage of these applications?**
  This question can be evaluated together with the question above. Depending on the difficulties expected, one can identify certain applications as more feasible and others less.
* **How to resolve the problems encountered and which methods can be used to overcome the difficulties?**
  Answering this question, despite not being the main focus of the research, will be useful when evaluating the level of difficulty. E.g. if a problem is solvable without much effort, it can be considered a minor problem and overcoming it would be easier.

1.5 Structure of the Thesis

This thesis is divided mainly into six chapters, according to the different aspects of the subjects. In the first chapter, an introduction, that familiarizes the reader into the subject, is made. Later on, the motivation and the problem statement that led to the creation of this thesis is explained. Rest of the first chapter is focused on the research questions and the objectives of the research.

In the following chapter, a review of the related literature will be included. This chapter will act as a way of seeing the current research as well as obtaining ideas for what type of research is missing from the field. This chapter will be observed in sub chapters mentioning papers from different backgrounds. A thorough exploration of the literature will be made, laying the foundation for the theoretical background, which will form the next chapter of the thesis.

In the third chapter, the theoretical background of the thesis will be given. This will include detailed definitions of some notions that will be discussed in the later sections, such as virtuality continuum, mixed reality etc. This chapter will also contain information on what Microsoft HoloLens is capable of, and in which ways users can interact with the device. Finally, the concept of holographic remoting will be explained.

An overview of the methodology will form the basis of chapter 4. In this part of the paper, a detailed explanation of the workflow will be given. This will include the constraints of the device and the users, as the introduction. Next, the criteria that will be applied in order to measure the feasibility of the applications will be determined. Chapter will end with a chart for easier understanding of the flow of evaluation.

In the fifth chapter, the potential fields of usage will be presented, evaluated and discussed. First of all, features and constraints of each application will be put forward. Next, each potential use case will be evaluated according to the criteria determined in the previous chapter. After a short section mentioning other types of applications that are not selected as main applications due to feasibility reasons, a general discussion of the results will be given.

Finally, the conclusion of the thesis will be included in the last chapter before the references. This part will contain a general overview of the outcome of the research. Apart from that, the future potential of the issues that were mentioned in the thesis will be discussed in a subchapter.

2 Literature Review

In this chapter, research done previously on the topic of multimedia cartography and mixed reality devices will be presented. These papers will be categorized in the subfields in order to create an understanding of the different aspects of the subjects that are relevant to this paper.

A short summary for each paper will be given as well as mentioning the relevance of those research papers to the topic of this thesis. This is crucial in order to be able to create an overview of the current status of the research in the field.

2.1 "Cartographically Augmented Reality"

(Karel Stanek, Lucie Friedmannova; 2010)

In this paper, authors are focused on possibilities to include strictly cartographic methods of visual representation of data into the Digital Earth representation. The main idea is to benefit from thematic cartographic information that have been filtered and made visually significant, while not using maps. For this, use of augmented reality is suggested.

In the end of their introduction, Stanek et al. (2010) give general overview of ideas on how to adapt to the new tools and the new environment, augmented reality in this case. They talk about the fact that the abilities of new mediums encourage the mapmaker to discover new ways of creating maps, rather than advocating a traditional approach. They also make their point that the established rules can be used to some extent, while new ones can and should be added. Finally, they argue that the current AR technology is very limited in the amount of features that can be visualized, but we can confidently say that this has changed since 2010 when this paper was published.

This part of the paper has the potential to provide ideas on how to transfer practices of traditional mapmaking into the mixed reality scheme. It also allows us to see the situation back then and realize the pace of advancement in virtual and augmented reality technology. This is an indicator of what the field can expect from the future in terms of visualization methods as well as other areas of computer technology.

In later parts, they discuss several cases of AR, presenting certain use cases of augmented reality in scope of practical applications. One of them, labelled as 'tagged reality', when used in conjunction with geodata, can act as a new way of embedding augmented reality into cartography. In the final part of the second chapter, authors focus on the visualization problems, especially on label placement problem and provide examples for their solutions in existing AR applications.

In the conclusion, Stanek et al. (2010) explores the similarities and differences between maps and augmented reality. However, due to the time the paper was written, certain characteristics of AR devices are given as drawbacks and alternative solutions were offered. However, in HoloLens, most of the drawbacks mentioned are overcome, encouraging today's cartography to inherit methods from traditional practices more easily.

All in all, the parts of this paper mentioned above can bear some significance for this thesis as it mentions the latest status of the field at the time, which allows an overview of beginnings of the use of AR in cartography, as well as opening into discussion the ways of transferring methods into new type of media.

2.2 "Augmented Reality as a Medium for Cartography"

(Dieter Schmalstieg, Gerhard Reitmayr; 2007)

In this chapter taken from the book "Multimedia Cartography", the potential of augmented reality applications in cartographic perspective is discussed. Furthermore, case studies of stationary and mobile augmented reality applications are discussed that visualizes geoinformation.

In second chapter of the article, the authors mention that Piekarski (2004) has provided a very good overview of issues and features of AR devices from different perspectives. This is also promising for our thesis in order to be able to determine the constraints of the device and finalize the criteria for the evaluation, since it is observed that the general scope of capabilities achieved by mixed reality devices has not been changed fundamentally since then. Despite having been technologically more advanced, MR and AR, as a concept, uses same theoretical background as before.

Later in the article, authors give information on several important properties of hardware to be aware of in AR devices such as, the range of operation, the update rate and whether the device will be tethered on untethered. This gives us the base of what to look for when judging the abilities of AR devices in cartographic setting.

Authors later discusses the visualization part of augmented reality in which a good definition is given as following: “Using head-mounted or projection displays, a system overlays dynamic information on static real world objects such as plain pieces of paper, maps and models of cities and buildings” (Schmalstieg et al. 2007). This definition gives us a perspective on the importance of combining maps with augmented reality concepts, and summarizes the potential of such devices.

Following the information given above, authors talk about case studies related to these theoretical foundations. They mention the fact that paper maps can provide very detailed information densely. However, given the fact that they are static displays unlike computer screens, they do not show some of the benefits of digital maps. At this point, augmented reality is in ideal position, providing the opportunity to project digital information on cartographic material in paper.

After that, the focus shifts to mobile augmented reality, in which the authors give examples of early applications such as Touring Machine (Feiner et al. 1997) as well as some others that followed those examples such as Mobile Augmented Reality System (MARS) (Höllerer T. , Feiner, Terauchi, Rashid, & Hallaway, 1999) and tour guide and navigation applications like Archeoguide (Vlahakis et al., 2001). What make this part of the paper relevant for this thesis is the fact that some challenges are mentioned when designing AR applications for outdoor settings. One of these challenges is the limited field of vision, which forces the designer to come up with new interfaces and brings the need for new methods to be applied. Large number of items to be displayed in an outdoor environment is given as another challenge as filtering this information is a question of its own. Finally, placement of labels is third of main challenges as presented in this section of the article.

In conclusion section, all of the aforementioned issues are somewhat summarized and certain points are presented to the reader. To sum up, authors write about how AR technologies are becoming ubiquitous and more portable, as well as mentioning that information, as a divergence from the past, no longer relies on the abstraction from the original setting. Finally, the article gives an all-around perspective on the potential of augmented reality in cartography and what the future of the focus should be.

2.3 "Desktop Cartographic Augmented Reality: 3D Mapping and Inverse Photogrammetry In Convergence"

(Alexandra Koussoulakou, Petros Patias, Lazaros Sechidis and Efstratios. Stylianidis; 2001)

This article focuses on a certain application of augmented reality on photogrammetry in the city of Thessaloniki. In their introduction, authors mention that the concept of AR is recently being discussed in the context cartographic visualization.

Main focus of the paper is the concept of inverse photogrammetry, which is believed to be a good solution to the problem of combining the real world with 3-dimensional renderings. They later go into detail of inverse photogrammetry and its applications. After presenting the theory, the authors make their remarks regarding the application of the mentioned concept in the city of Thessaloniki.

What makes this paper significant for our research in mainly the results. Koussoulakou et al. (2001) summarizes the limitations they have come across in three parts. Most significant of them is data capture, where narrow streets posed an obstacle against capturing the 3D images of buildings. Impossibility of elimination of certain objects from captured images are given as another point of issue. Some other minor issues are also mentioned, regarding the equipment and presentation of data.

Al in all, being a cartographic application that is based on augmented reality, the results of this paper has the potential to be useful when evaluating the possible applications of mixed reality devices in cartography, therefore will be considered while assessing the quality of applications presented.

2.4 "Abstract Feature Representation as a Cartographic Device for Mixed Reality Location-Based Games"

(J. J. Huck, P. Coulton, A. Gradinar and D. Whyatt; 2014)

This paper from 2014, presents a number of cartographic design solutions to the creation of a map for the mixed reality location-based game "Pac-Lan: Zombie Apocalypse" (Huck, Coulton, Gradinar, & Whyatt, 2015). Being relatively recent, results obtained in this research can provide this thesis with more up-to-date information regarding the constraints and limitations of mixed reality location based application using cartographic devices.

Main research purpose of this project is to investigate methods to make users depend on screens less and have a more immersive experience within their physical environments. The key point to consider in this paper for our research is the fact that the authors are designing different maps and testing them according to their success in guiding the users away from the map itself and providing them ways to interact with their surroundings more. This is a very important subject to focus on in augmented reality devices due to several concerns, some of them being safety and level of immersion of the user experience.

The first of four map designs presented in the paper is an “anti-glare map”, which is aimed to be more ideal for outdoors (see Figure 3).

Figure 3: The Anti-glare map, aimed to provide easier visibility outdoors. (Huck et al., 2014)

This approach is an innovative way to attack to problem of brightness in outdoor use of augmented reality devices. Indoor applications that are meant to be used in bright surroundings can also benefit from these type of maps specifically designed for such settings. Another such approach is the “Pac-Map”, in which high contrast and thick lines are chosen for similar purposes, in addition to the aesthetic concerns related to gamification of the application (see Figure 4). Features are also simplified for ease of use and with the aim of decreasing the dependence of the user on the map.

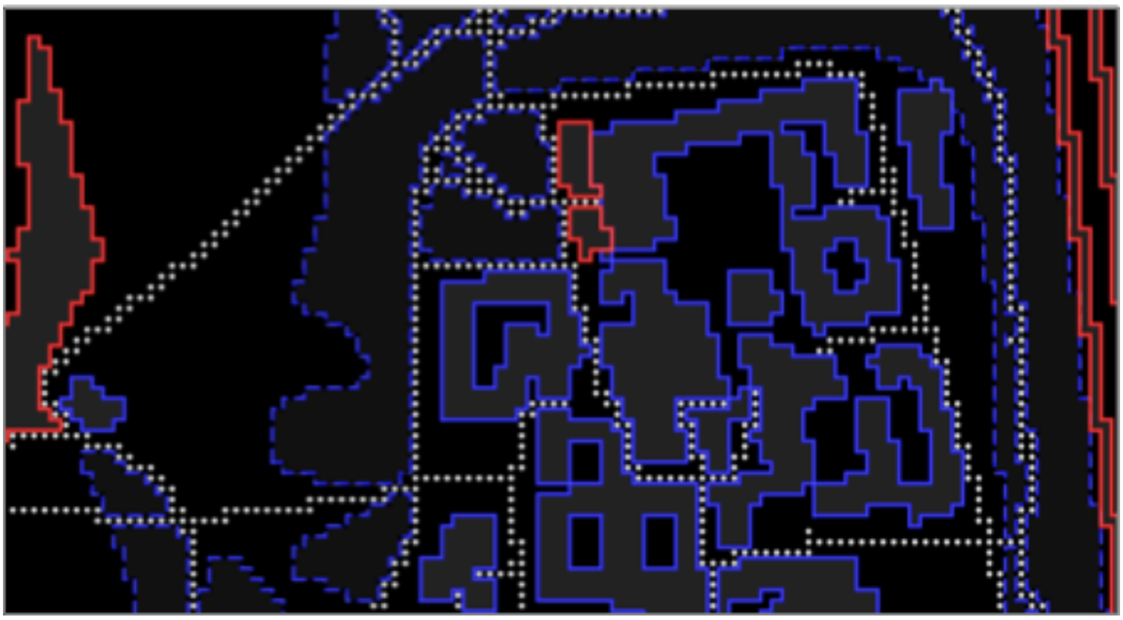

Figure 4: The "Pac-Map" (Huck et al., 2014)

These were two examples of how maps can be specifically designed for augmented reality applications, with various purposes such as thematic concerns, visibility, aesthetics etc. The paper presents two more examples of such maps, making the total number of four that is to be assessed and results to obtained on which map is the best according to the criteria.

In conclusion, it can be claimed that there are infinite possibilities with today's tools and technologies when creating specific solutions to specific problems in cartography. Pac-Map was chosen as the best solution regarding the requirements of this paper. However, cartography that embeds augmented reality, may and is expected to learn from both traditional and newly emerging methods, as seen in the examples above.

2.5 "A Taxonomy of Mixed Reality Visual Displays"

(Paul Milgram, Fumio Kishino; 1994)

This paper, that is heavily cited in research papers on mixed reality, acts as the source for a number of concepts that is used in this thesis, such as the virtuality continuum and mixed reality. The purpose of the paper is to focus on mixed reality virtual displays. The term encompasses a great variety of types of displays, lies along the virtuality continuum. Being published in 1994, when these concepts were only beginning to be used recently, the authors aims to establish the base for terms defining terms mentioned above, hence the name "taxonomy".

In the first chapter the paper discusses the similarities and differences between the concept presented, in an attempt to categorize them into groups at a time when the types of displays were simply referred to as "class 1 display", "class 4 display" etc. Next comes the part where the authors state their motivation for coming up with the research, which is the need for classification.
In the following parts, the paper generally compares and contrasts the terms real and virtual and their extents, whose details will be given in the following chapters.

After defining all the necessary concepts, the definitions regarding the merging of real and virtual worlds are given amongst various other terms. All in all, the aim of the article is to clarify some issues that occurs due to the same concepts being developed by people from different disciplines. From the perspective of this thesis, knowledge gained from this paper (Milgram & Kishino, 1994) is predicted to be very useful in order to create the part of the theoretical background that is related to the basic concepts of the field.

2.6 "A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment"

(Steven Feiner, Blair MacIntyre, Tobias Höllerer, Anthony Webster, 1997)

This paper describes a prototype to combine mobile computing with augmented reality graphics. It also explores the potential of such a combination in supporting the users in their daily lives. Since the prototype promises to allow the users an untethered augmented reality experience, it can provide great potential for the field of cartography. While main idea for the research is to examine the capabilities of the device, cartographic applications can benefit greatly from the lessons learned in this project.

In the prototype they describe, a combination of satellite-based differential GPS tracking system and an orientation tracking system follows the position of the user, while displaying information to the user real-time by using the augmented reality technologies. Since the main focus of the project is to experiment with the software to be used in the user interface, hardware issues are not heavily discussed. Therefore, this paper can be part of the scope of our thesis regarding the experience gained through challenges faced while designing and utilizing a user interface for a device that houses GPS and other tracking technologies and is aimed to be used in an outdoor setting.

Authors mention in the conclusion some of the issues that are needed to be solved if such a system is aimed to be commercialized. One of them is the quality of displays. They argue that the brightness of the head-worn display is not enough when used under sunlight. Issue of display brightness in outdoor settings can greatly affect the feasibility of potential outdoor cartographic applications that will be discussed in our thesis. Another problem with displays that is mentioned is the low resolution and high cost of higher resolution systems. As mentioned earlier, this is only a matter of time for the virtual and augmented reality technologies, as display technology improves in a relatively fast pace and the paper written by Feiner et al. (1997) refers to the technology of late 1990s, therefore, great advancements are expected but still has to be practically tested in order to be able to obtain a convincing result.

Two of other problems they have encountered are the insufficient quality of tracking and loss of tracking. They mention that in certain applications, very precise tracking is required for the application to function properly, and that level of precision is not fully provided by the systems of the day. And for the loss of tracking problem, they have come up with some temporary solutions that directs the user to the last point with a good signal strength. Again, great advancements are achieved in positioning systems since 1990s, therefore, this is another good example that shows the pace and potential of multimedia technologies and what should we expect to see in near future.

2.7 "Augmented Reality as a Digital Teaching Environment to Develop Spatial Thinking"

(Carlos Carbonell Carrera, Luis Alberto Bermejo Asensio; 2017)

This paper (Carrera & Asensio, 2017) analyses the potential of AR as an innovative teaching tool to improve relief interpretation skill based on the results of a workshop with 73 engineering students from La Laguna University, Spain. Authors mention that "in practice within the field of geography, spatial thinking underlies a significant amount of geographic learning such as the use of maps, graphs, images, diagrams, models, and visualizations

(Madsen & Rump, 2012) as an example for difficulties in learning about spatial information. Therefore, they claim to be offering a new way of developing spatial thinking skills for learners, which is augmented reality.

It is mentioned in the following parts that the advancements in augmented reality technologies pave the way for a new type of interaction between the humans and landforms. Later, various definitions for augmented reality and its purpose are presented, citing several authors such as Milgram and Kishino (1994), Azuma (1997), Starner et al. (1997) and others, before explaining the differences between VR and AR, focusing on the varying degrees of realism.

Finally, Carrera et al. (2017) defend their ideas on the potential use of AR in engineering education, by mentioning current fields of use such as architecture and land engineering. Many other use cases are discussed which shows the potential of augmented reality. Finally, they present their methodology and results and suggestions for future work. All in all, our thesis can extract ideas from this paper on how augmented reality can be used as an educational tool, especially when combined with untethered devices such as HoloLens, which provides the learners with more freedom and space to for exploration.

3 Theoretical Background

In this chapter, the underlying theories and ideas, as well as knowledge required to be known in order to be able to fully comprehend the devices and tools used, will be presented. First of all, a short summary of the state of the art in cartography will be included in order to provide an understanding of the latest situation in the relevant technologies. Later on, important concepts that forms the theoretical basis of this thesis will be explained, such as augmented reality, mixed reality and others.

In the following chapters, a detailed overview of the device to be used, namely Microsoft HoloLens, will be presented. Features and properties of the device will be explained in detail in order to create and understanding of what this research is concerned about, practically. This is aimed to complete the theoretical background already given before with practical tools, setting the foundation of the methodology to be used.

Finally, the concept of holographic remoting will be explained since it is a very important concept that is promising to change the capabilities and limitations of the device. Chapter will end with a short conclusion that summarizes the ideas presented throughout this part of the thesis.

3.1 Overview

Field of cartography, especially in today's world, is a multidisciplinary one. Since cartography relies upon visualization as a medium for information exchange, advancement in visualization technology influences the effectiveness and capabilities of techniques used in cartography.

As Cartwright et al. argues (2007): "Multimedia cartography evolved from a need to present geographical information in an intuitive manner". Therefore, any advancement that will carry cartography towards this aim needs to be considered as a potential. Mixed reality, which aims to create an environment that is either realistic or interacts with real environments, is chosen as the medium for this thesis when evaluating the possibilities within multimedia cartography. Höllerer et al. mentions (2004): "Mobile augmented reality systems have a potential to revolutionize the way in which information is provided to users." This can be given as another example to why augmented or mixed reality is worth investigating within the scope of cartography due to its potential. In order to fully comprehend the theory behind these technologies, definitions and explanations are very useful, which will take us to the next part of the chapter.

3.2 Virtuality Continuum

Paul Milgram and Fumio Kishino (1994) defines virtuality continuum as a "mixture of classes of objects presented in any particular display situation, where real environments, are shown at one end of the continuum, and virtual environments, at the opposite extremum" (see Figure 5).

In this definition, a real environment refers to a setting formed completely by real objects, such as a real-time display of the environment or a recording of a real-world scene. Meanwhile, a virtual environment refers to the exact opposite, in which all objects are virtual (i.e. non-real) ones. An example to this type of environment can be a simulation video game or an animation movie made completely of non-real objects.

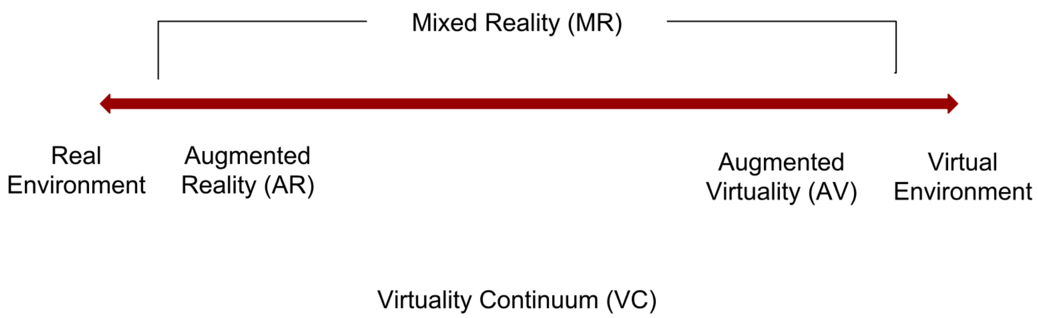

Figure 5: The Virtuality Continuum (VC) (Milgram et al., 1994)

3.3 Mixed Reality

In light of this definition, mixed reality, also called hybrid reality (de Souza e Silva et al., 2009) refers to any concept of environment that consists of both virtual and real objects, to varying degrees, as depicted in figure above (see Figure 5).

Paul Milgram and Fumio Kishino (1994) defined a mixed reality as "...anywhere between the extrema of the virtuality continuum" (VC), where the virtuality continuum extends from the completely real through to the completely virtual environment with augmented reality and augmented virtuality ranging between".

As mentioned before, a mixed reality environment, is one in which real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum.

This definition of mixed reality, which allows the use of the term in a broader perspective, is the reason of the preference of the term over the more widespread Augmented Reality, in the context of this paper, since the aim of this research is to come up with a general idea of the capabilities of such devices, rather than limiting the subject to the abilities of a certain release of a certain device.

3.4 Augmented Reality and Augmented Virtuality

In one of the early definitions by Ivan Sutherland (1968), AR is described as a virtual world supplementing the real world with additional information. It can easily be argued that the difference between AR and AV lies mainly on the purpose of the application, depending on the degree of immersion towards reality or virtuality.

A more general summary of the differences between terms defined above an be seen in the figure below (see Figure 6).

As discussed by Reitmayr et al. (2007), "visualization for augmented reality focuses on two aspects: the realistic merging of artifical objects and effects with reality and appropriate presentation for abstract information". The first aspect focuses on more technical issues such as transparency or correct illumination, while the latter works with abstractions, which is the main playground for cartography.

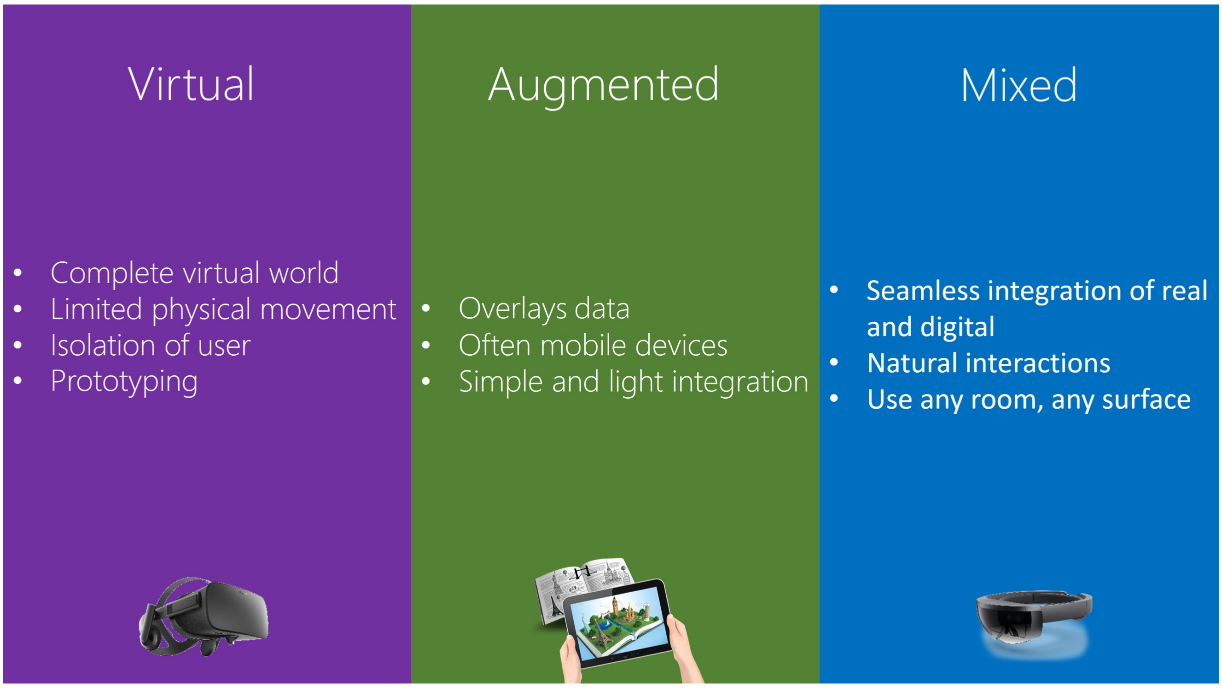

Figure 6: A summary of general properties of different terms that lies within the virtuality continuum.[3]

3.5 Microsoft HoloLens

Microsoft HoloLens is the name given to the smart mixed reality glasses developed by Microsoft, first released in March 2016 (Development Edition) (McBride, 2016).

Untethered fashion of Microsoft HoloLens opens to door to a whole new set of applications within cartography. The constraint of cables and limited spaces has become a thing of the past and that will allow the field of cartography to change the paradigm radically.

HoloLens has four microphones built-in, two specialized for ambient noise detection and reduction, two of them recording the users's voice. HoloLens scans the room the user is in and creates a 3D mesh of polygons in order to be able to determine the shape and size of the room. Therefore, an outdoor usage would be expected to be highly limited. Outdoor elements such as brightness from the sun, rain etc. also has the possibility of hindering the usability of HoloLens in an outdoor setting.

[3] https://www.pluralsight.com/content/dam/pluralsight/blog/2016/05/holographic/holographic_comparison.jpg

Microsoft HoloLens uses three different methods as its ways of acquiring input: Gaze, Gestures and Voice, the details of which will be explained in the following sections.

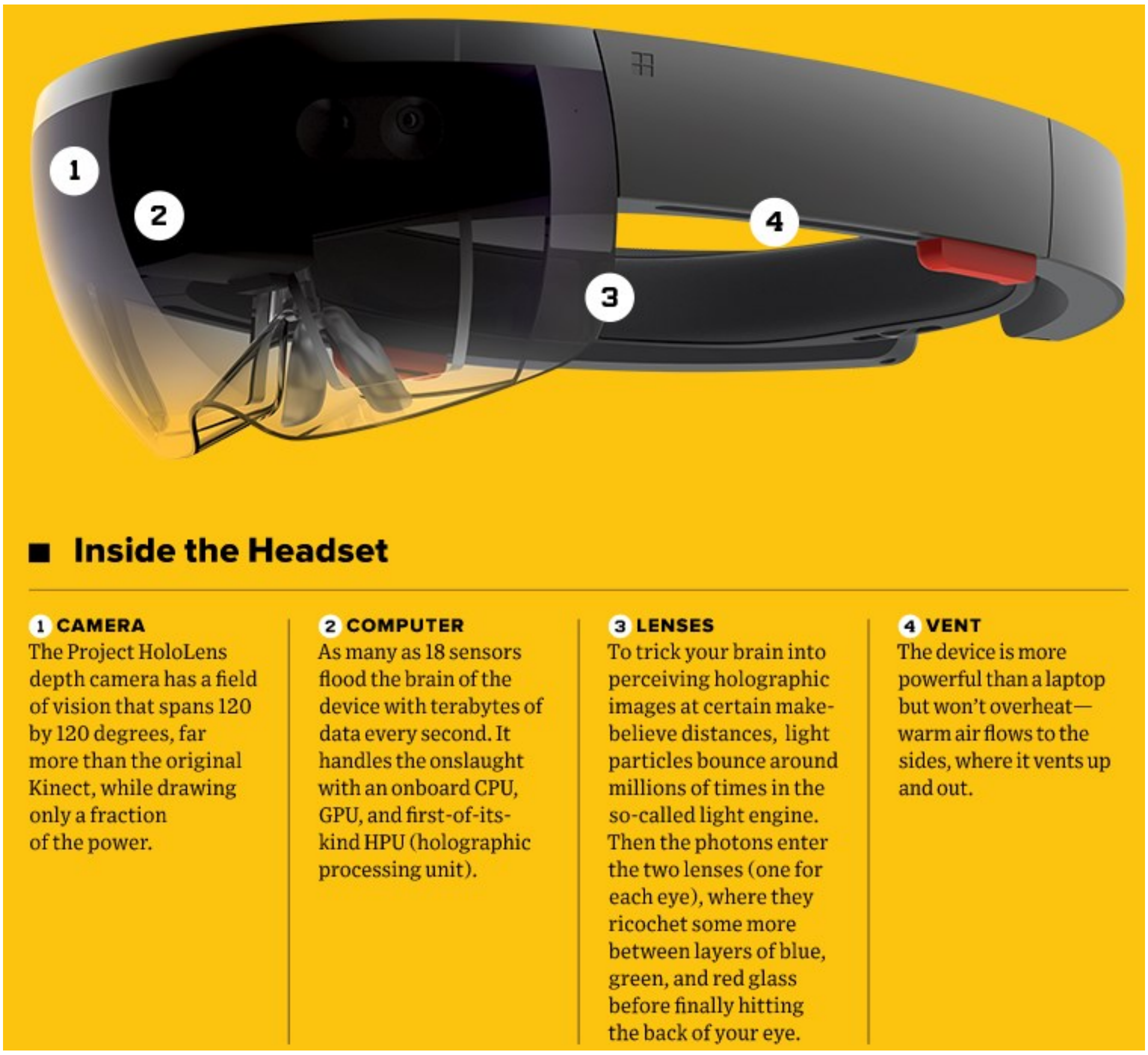

Figure 7: A brief summary of the features of Microsoft HoloLens[4]

3.5.1 Gaze

The first input method that will be discussed is the gaze[5]. When the user looks towards to HoloLens, the center point of their perspective is the intended point. In many applications, this point is depicted as a small circle in the center (see Figure 8). This center point can be personalized according to the needs and design choices of the developer, so that the user can

[4] http://chrisphilpot.com/hololens
[5] https://developer.microsoft.com/en-us/windows/mixed-reality/gaze

experience different types of cursor designs, but the location of the point remains the same. It can be considered as a similar input device to a mouse, this one being in the 3D space.

One crucial point to remember when using the HoloLens is that the device gets the orientation of the user's head as the input for the direction of the Gaze functionality (Klint, 2016). It does not use the point the user's eye is focused on, unlike an eye-tracking device. Therefore, the user has to move their head to be able to determine which function to choose, which button to click etc.[6]

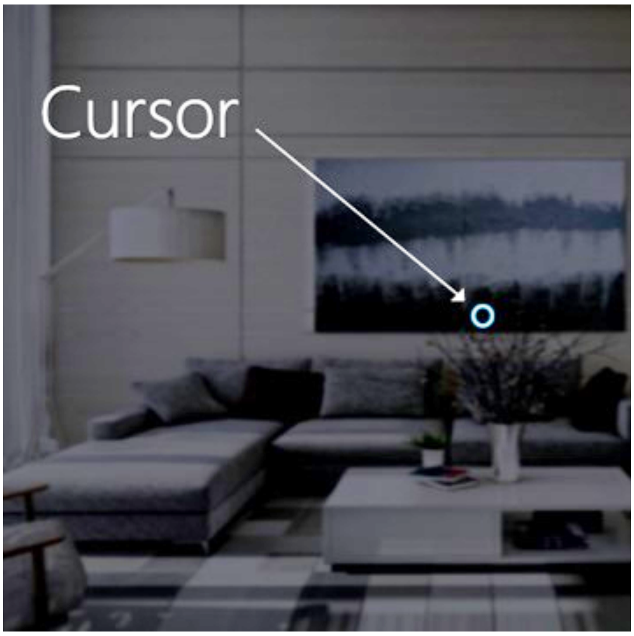

Figure 8: An illustration of the cursor, which acts as the reference point for "Gaze"[7]

3.5.2 Gestures

After the user aimed at the intended point on the screen, wall etc. next step in the interaction, similar to a tap or a click in conventional devices. One of the easiest to use gestures is the 'air tap' where the user puts the index finger in the ready position and then presses it down to make an interaction (see Figure 9). For this gesture to work, the hand should be within the field of view of the HoloLens.

[6] https://docs.microsoft.com/en-us/windows/mixed-reality/gaze
[7] https://docs.microsoft.com/en-us/windows/mixed-reality/images/cursor.jpg

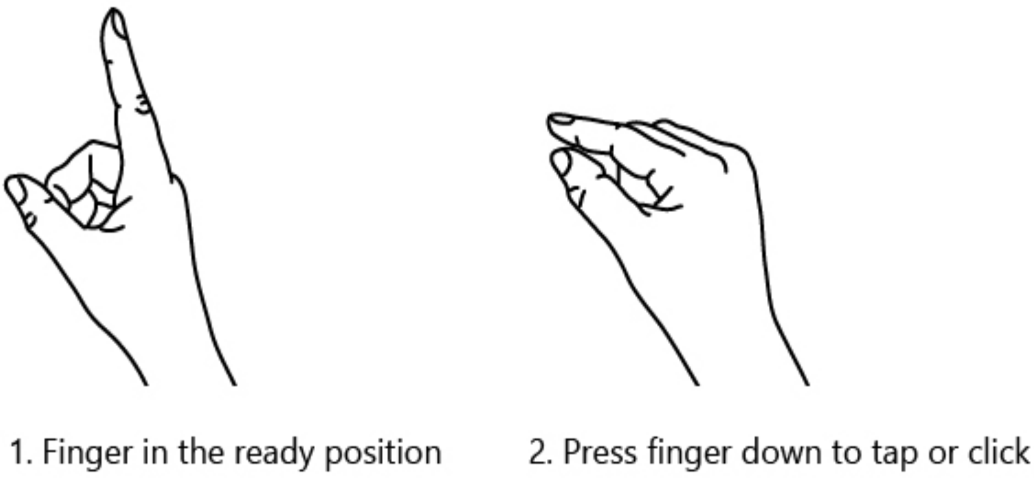

Figure 9: Demonstration of the air tap gesture[8]

The combination of a gaze and the air tap gesture creates an interaction Microsoft calls a 'gaze-and-commit'. (Microsoft Corporation, 2018) This is similar to a move and click in a conventional computer. It is discrete as the action is either completed or not completed, there is no middle point.

Another gesture that is widely used is called 'Bloom' (Microsoft Corporation, 2018). This gesture is reserved for the purpose of going 'back' or 'home'. To do this gesture on HoloLens, the user should hold out their hand, palm up, with the fingertips connected, before opening their hand, seen in the figure below (see Figure 10).

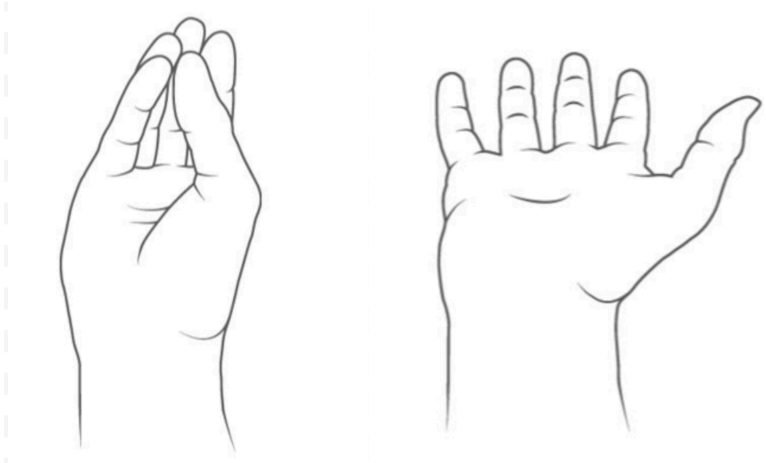

Figure 10: Bloom gesture; fingertips connected (left), hand is in opened position (right)[9]

[8] https://docs.microsoft.com/en-us/windows/mixed-reality/gestures
[9] https://developer.microsoft.com/en-us/windows/mixed-reality/gestures

3.5.3 Voice

The last of the three main forms of input is voice[10]. It allows the users to directly use their voices to interact with the holographic space without the need for gestures. The user simply gazes at a point they intend to interact with and speak. Personalized voice commands can also be created by developers. Vocal commands can be considered as shortcuts in which the user can basically say "select" instead of making the gestures required, which sometimes can be more difficult to achieve. The HoloLens uses the same speech recognition engine that Microsoft uses in all other Windows applications.

Voice can also be used to dictate words into the system instead of the screen keyboard of the HoloLens. Spelling words by using gaze and gestures on a keyboard is usually slow and requires effort. Therefore, vocal dictation is an alternative way to shorten the time for text input greatly.

Finally, the user can interact with the Microsoft assistant Cortana via voice commands in order to fulfill certain tasks such as "Go home", "Start recording", "Take a picture" etc. It should be noted that by 2018, HoloLens only supports the English language[11].

3.5.4 Spatial sound

Sound is very useful for the user to perceive their environment, especially when objects are outside their field of vision. HoloLens is utilizing a 3D simulation method that uses a Head Related Transfer Function (Microsoft Corporation, 2018), in which, the way sound reaches the human ears is analyzed and simulated realistically.

As the HoloLens field of view is limited by one general direction, sound can improve the immersive experience by alerting the user of objects that out of sight, thanks to the 3D sound technology. The users can also perceive the location of the objects since the volume will increase as the user gets closer and decrease as they get further away.

10 https://docs.microsoft.com/en-us/windows/mixed-reality/voice-input
11 https://www.microsoft.com/en-us/hololens/faq

3.5.5 Clicker and Xbox Controller

Another input method that is worth mentioning is the included clicker (see Figure 11). Its main purpose Is to be an alternative input method to the gestures. Since gesture control is a method that takes users some time to get familiar with, the clicker can be used for certain functionalities e.g. when the application requires a large number of clicks, the gesture method can be strenous since it forces the user to keep a hand up for most of the time. Another concern is the speed with which the buttons can be clicked. The clicker provides a reasonable alternative since it does not rely on the position and the shape of the hand, therefore ensuring an easier use.

Figure 11: A sketch of the clicker in use[12]

The Microsoft Xbox controller (see Figure 12) is another device that is compatible with the HoloLens. Having more buttons allows the controller to be a potential input method especially in a situation where the application has a variety of clickable areas. Specialized shortcut buttons can also be embedded to the system in order to create a more fluid experience for the user, similar to the shortcut buttons used in computer keyboards.

[12] https://support.microsoft.com/en-us/help/12646/hololens-use-the-hololens-clicker

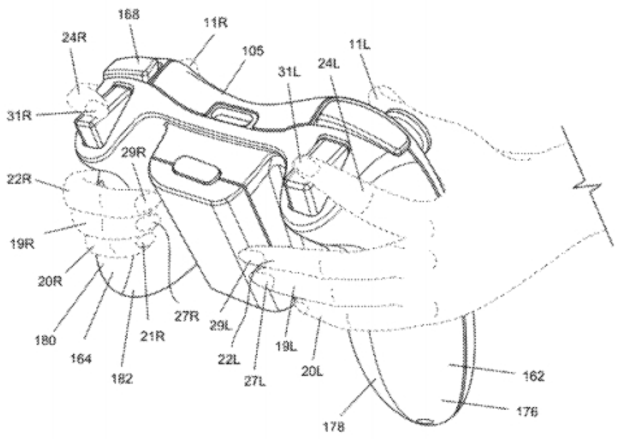

Figure 12: A sketch of the Xbox controller with buttons marked[13]

3.6 Inside-out tracking

Inside-out tracking is a method of positional tracking, that is used to track the position of head-mounted displays[14]. As opposed to outside-in tracking, the sensors are fixed onto the device being tracked and they determine the position in relation to the external environment, instead of sensors placed in an independent position[15]. Microsoft HoloLens uses inside-out tracking as it houses two visible-light low resolution cameras to keep track of objects in the environment. Advantage of this is that this method allows more freedom since the mobility of the user is not limited by a fixed space, therefore allowing for a higher level of realism compared to other methods.

According to Microsoft, HoloLens lets users enjoy the concept of a world-scale experience. This refers to the fact that the user is not limited to a radius of 5 meters and they can wander to more than this distance[16]. Surely, this can only be provided by programming that takes into account the requirements for developing such applications. As can be seen in the figure (see Figure 13), world-scale experience allows for the highest scale of realism and freedom of movement, which brings an important advantage to Microsoft HoloLens than other devices that does not feature such an experience for users.

[13] https://www.polygon.com/gaming/2012/5/9/3009467/xbox-360-controller-patent-reads-biometrics-of-your-hands
[14] https://xinreality.com/wiki/Inside-out_tracking
[15] https://www.wareable.com/vr/inside-out-vs-outside-in-vr-tracking-343
[16] https://docs.microsoft.com/en-us/windows/mixed-reality/coordinate-systems

Experience Scale	Requirements	Example experience
Orientation-only	Headset orientation (gravity-aligned)	360° video viewer
Seated-scale	Above, plus headset position relative to zero position	Racing game or spaces simulator
Standing-scale	Above, plus stage floor origin	Action gamewhere you duck and dodge in place
Room-scale	Above, plus stage bounds polygon	Puzzle game
World-scale	Spatial anchors (and typically spatial mapping)	Game with enemies coming form your real walls, such as Roboraid

Figure 13: Scales of mixed reality experience[17]

3.7 Holographic Remoting

The problems caused by certain GPU, memory and storage constraints of the HoloLens can be overcome by a concept called holographic remoting, which can be utilised by an application called Holographic Remoting Player, announced by Microsoft in 2016[18].

Holographic remoting allows the usage of the capabilities of the main computer on which the holographic application is being developed. It is achieved by a Wi-Fi connection between the HoloLens and the computer on which the development environment and tools are installed. By its nature, the performance of applications created using this method will also depend on factors (Corrado, 2017) such as:

- The performance of the main computer that is running the application
- The internet connection speed of the main computer, in case the application requires it.
- The speed of wireless connection between the HoloLens and the main computer.

[17] https://docs.microsoft.com/en-us/windows/mixed-reality/coordinate-systems
[18] https://developer.microsoft.com/en-us/windows/mixed-reality/holographic_remoting_player

It is recommended by Microsoft that a GeForce GTX 970 or AMD Radeon R9 290 or a better graphics is used, to ensure maximum frame rate and lower latency, as well as optimal graphics quality[19].

Since Microsoft HoloLens is a device that currently is under development, external applications such as the Holographic Remoting Player is known to have issues such as:

- Freezing of the scene in HoloLens, in which case a restart or a disconnect-connect cycle is reported to solve the problems.
- Crashing of the development applciation running on the main computer such as Unity 3D.
- Connection problems due to Wi-Fi interference or distance between the device and the computer.

Problems mentioned above should be expected to be solved, or at least the situation to be improved as mixed reality devices develop. Nonetheless, the method of holographic remoting can easily be taken into account while evaluating the feasibility of potential applications.

3.7 Conclusion

In this chapter, the theoretical infrastructure of the research area is given by introduction of certain concepts such as virtuality continuum and mixed reality. Features and constraints of The HoloLens are discussed, as well as the ways of interaction with the device are explained thoroughly. In light of the theoretical knowledge obtained, the methodology of how the potential applications can be evaluated will be presented. The main target of the next chapter will be the constaints of the devices and the applications as well as the technical and human criteria.

[19] https://docs.microsoft.com/en-us/windows/mixed-reality/holographic-remoting-player

4 Methodology

This chapter will mainly consist of the methodology of the research, that is, the workflow applied in order to obtain the desired results. First, a summary of constraints will be presented, both from the perspective of the device and the user. Next, the criteria chosen to be able to evaluate the application will be explained with the reasoning behind. A summary of the chapter will be given in the end by using a chart created to visualize the process of the workflow.

As can be seen in the graph below (see Figure 14), the research will be conducted in a workflow. From a variety of applications that have been investigated, certain candidates are selected for evaluation. This selection is done mainly in two steps, whose details will be given below.

First of all, the following is determined as minimum criteria:

- Does the application have a cartographic focus? This can be explained as having an aspect related to cartography such as; navigation, location based services, thematic maps, aerial photography, remote sensing etc.
- Does the application use methods of mixed reality? As mentioned before, this thesis uses HoloLens as device of choice, which narrows down this criterion into the concept of augmented reality. Therefore, virtual reality applications are not included.

These two criteria are created to determine if an application is worth mentioning in this thesis. Various augmented reality applications exist, serving different purposes. Hence, a filtering of such applications is crucial. Filtered and discarded applications will not be mentioned here, since it is not the concern of this research.

Next two criteria are named as fundamental criteria:

- Does the application have a working example that is shown to work on HoloLens? This is crucial since the application has to be tested by users and results will be obtained by surveys. Furthermore, this will act as a proof of potential.
- Is there data available regarding our technical criteria? Since it will be difficult to objectively assess the potential of an application without its technical properties, availability of data is essential.

These two criteria are designed to divide the applications between ones that are actively used and can be investigated, due to the information and tools available, and those that are more theoretical ones. Applications that fail to pass these criteria will still be mentioned. However, due to the difficulties expected in testing these applications, and impossibility of assessing the feasibility with the tools available, they will be kept shorter and as general overviews.

Finally, applications that pass both of the filters mentioned will be carried into the last step, where they are evaluated against certain technical and human criteria, whose details will be presented in the following sections of this chapter. A discussion of results will be included in the end of every evaluation.

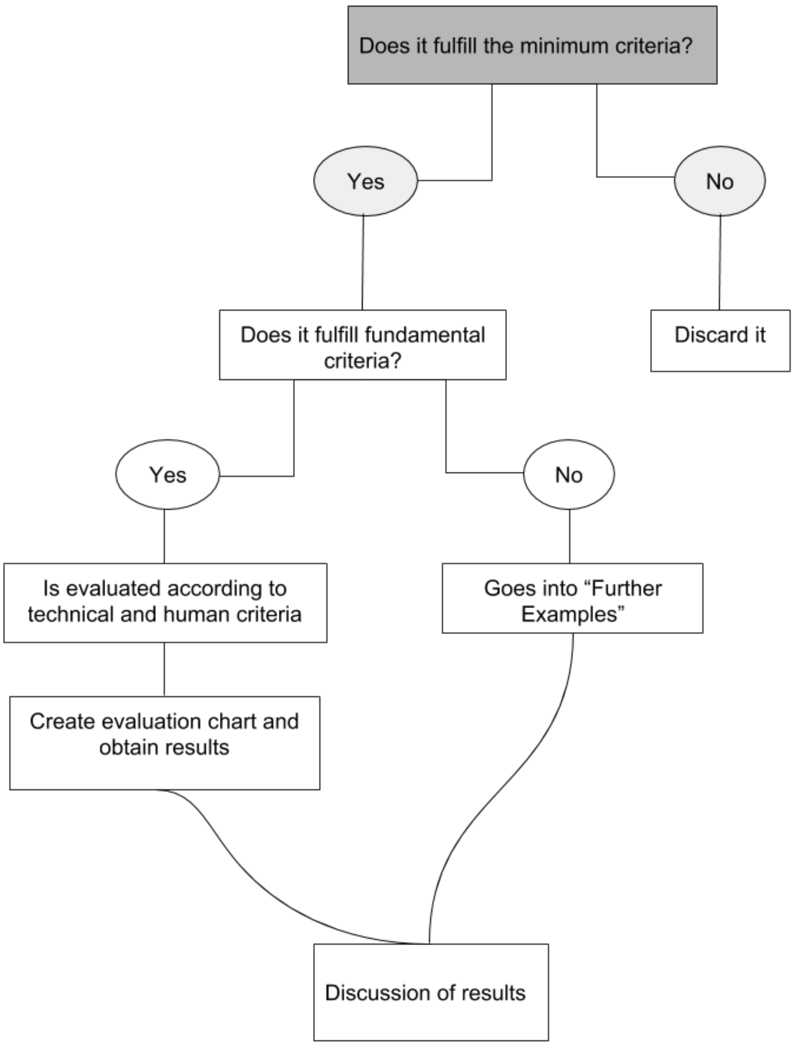

Figure 14: A representation of the workflow of the thesis

4.1 Technical Constraints

Due to several factors, such as the technology available, aim when a device is designed or merely the nature of the device/application itself, some technical constraints may occur. In our case, the following list can give a comprehensive overview of the constraints that might be useful to know when determining the criteria to judge potential mixed reality applications[20]. These factors will form the basis for the technical criteria, as they will be created by using the limitations that the following constraints induce:

- Limits of the battery for untethered work: How many hours for which type of application?
- Limits of resolution of the image that is projected into the user's point of view
- Limited field of vision (how many degrees? How useful is it going to be when using a real application?)
- Limits of internet connection speeds and types (mobile internet or wireless communication?)
- Other types of connectivity possible (Bluetooth, near-field etc.)
- Amount of built-in storage space in the device (How large are typical applications? How many applications can fit into the device, with or without an internet connection?)
- How useful is the device when the environment is bright? Can the user see the images outdoors?
- Limits of the sensors (Can the sensors acquire information outdoors? How many sensors are there and how accurate are they?)
- Which file formats does the device support? (Can any 3D data be uploaded or generated/projected on the device window?)
- How sufficient is the memory and processing power of the device for certain applications?
- Number of polygons that can be displayed on the device
- Texture size limitations
- It is aimed that the frame rate is around 60 fps for a fluid experience. Can the device process the data fast enough for this? (The application developer must ensure the 60 fps for the best experience)[21]

[20] https://developer.microsoft.com/en-us/windows/mixed-reality/performance_recommendations_for_hololens_apps
[21] https://developer.microsoft.com/en-us/windows/mixed-reality/hologram_stability

4.2 Human Constraints

Another aspect of mixed reality devices, as with many other products that are designed for human consumption, is the human constraints. In the context of the thesis, human constraints can be defined as; limiting factors of a device or an application, that is not caused by technicalities of the mentioned product, but those that occurs due to the nature of humans.

In other words, technical constraints do not draw the whole picture for an understanding of the level of possibilities of a product. Humans have different needs than machines. Therefore,for instance, an application may have all the technical capabilities for a specific task but might still fail to be usable by human consumers. To extend our investigation into a different perspective than merely technical details, certain human constraints will also be taken into account. Some examples can be claimed as the following:

- Weight of the device, especially for long term usage
- Motion sickness
- How accurate is the gesture – voice control?
- Dangers of using the device for long term, both indoors and outdoors
- How realistic/enjoyable/useful is the experience for the users?

In light of these constraints, human criteria will be determined, which will form the other half of the evaluation of applications for cartography in mixed reality devices. Due to its nature, these constraints are more subjective than objective, therefore, a different approach will be needed when dealing with human constraints.

4.3 Evaluation Tables

As this paper aims to evaluate several ways of integrating cartography into mixed reality devices, certain criteria has to be used to test against the features of the corresponding application.

For each potential application, relevant criteria for the specific application will be selected from the list above. After a thorough analysis of the capabilities and constraints of the device, as well as the technical or user demands for the application, two evaluations will be conducted:

- Evaluation by technical criteria
- Evaluation by human criteria

During the evaluation by technical criteria, data obtained from different sources regarding numbers such as; optimal connection speed, required storage space, memory demands, processor power needed etc. will be used to compare and evaluate the feasbility of such applications.

On the other hand, an evaluation for the human aspects of the application will be taken into account. Those criteria will be the aspects of the application such as those that affect the comfort of the users, their willingness to use the application, as well as the quality of the user experience. For this evaluation, human tests are planned to be conducted.

In order to create an easy to grasp evaluation process, tables for each group of criteria will be created, containing the criteria determined to be the most relevant for obtaining the best results.

4.3.1 Technical Criteria

Technical criteria are criteria that are interested in technical constraints. They depend on the ability of the device and the applications due to certain features. Technical constraints determine the technical limits of an application or a device which is a very beneficial tool in order to evaluate the non-human aspects of the research. As mentioned before, technical criteria are chosen amongst the limitations caused by technical constraints. For the sake of practicality, certain aspects will be put forward in order to evaluate the applications in the best possible way.

The technical criteria table will be created using the following criteria:

- Internet connection speed:

This is the first criteria in our Technical Criteria table (see Table 1). Most applications nowadays require an internet connection, wireless or mobile, to be able to function properly. This is mainly due to two reasons: Large size of certain types of data making the storage of the data for entire application on the device either difficult or redundant. In this case application developers generally rely on internet based systems similar to the web applications used on today's computers.

Another reason for the usage of internet services in applications is the aim of providing the user with the most up-to-date data, especially in areas where the concent and type of data changes in a rapid rate. Offline systems, due to their nature, mostly fail to provide the user or the application with the latest data, therefore more and more applications become online ones as network speeds are increasing and always connected devices are becoming ubiquitous.

While evaluating the sufficiency of internet connection speeds for each application, average connection speeds in Germany will be taken into account, to be able to determine the possiblity and ease of use for mentioned application in an average setting that had internet connection. Data will be taken from reports of internet speeds in Germany created by Speedtest[22].

- Storage space:

Second criteria in our table will be storage space. Each application occupies a certain amount of storage space on Microsoft HoloLens, since they are direclty installed onto the device from the internet from Windows Store. However, not being a full sized computer, HoloLens provides a limited amount of storage space available for applications.

Depending on the ratio of the space already filled by other applications on the device, as well as the space required for the application that is to be downloaded, this may create problems regarding the amount of space available for downloading and installing applications. Hence, storage space is the second technical criteria to be used when evaluating a potential application. The larger of a space an application take sup on the

[22] http://www.speedtest.net/reports/germany

device, the lower of a score it will receive, considering the already occupied space, as mentioned above.

Data for each application will be obtained either from the website of the application developer or from the relevant page of the application on the Windows Store[23].

- Frame rate:

Another critical data to look for in a mixed reality application is the maximum frame rate that can be provided by the device and the application. This is cruical for the concept of hologram stability. According to Windows Dev Center: "Frame rate is the first pillar of hologram stability."[24]

Since displays on HoloLens refreshes 240 times a second with four different images every second, it creates a experience of 60 fps for the user[24].

Since this frame rate is constant for the device, in order to be able to keep up with this rate, applications must aim for 60 fps. This helps with 3 things and ensure the best experience:

- Creates a minimum amount of latency due to certain technicalities of the system.
- Provides a consistent latency for the user, which in other frame rate are not fulfilled and can cause errors that affect the quality of the image.
- Reduces the amount of a judder, which is basically errors in the holographic image such as uneven movements and duplications.

- Battery life:

Fourth important criteriton when evaluation mized reality cartography applications is battery life. This refers to two things: Estimated duration of usage for the HoloLens application and the effect of the application on the device's battery life. These two factors will be compared for the sake of this criterion, measuring the ability of the given application to provide the user with a fully uninterrupted experience within the time frame determined as a standard usage.

[23] https://www.windowscentral.com/microsoft-hololens-processor-storage-and-ram
[24] https://developer.microsoft.com/en-us/windows/mixed-reality/hologram_stability

It is claimed that HoloLens has a battery life of 2 to 3 hours (Callaham, 2016). Therefore, unless otherwise stated, this value will be used as the standard duration of an uninterrupted use.

- File formats:

This criteria is especially important in applications that the users share files between each other such as Skype, but also effective in other applications, since all applications uses files one way or another. Therefore, when an application supports only a limited plethora of file formats, compatibiliy of the application decreases and problems may occur. This issue can significantly jeopardize the application's ability to work in different settings, which, for the mentioned application, will result in a low score in our evaluation table.

- File size limit:

Similar to file formats, file size limit is another criteria regarding files that are used and interacted with on HoloLens. Certain applications have limits of allowed file sizes to be sent between users. This situation also has the potential to affect the performance and usability of an application.
For instance, if a cartographic image has a size of 1 GB and the application that utilizes these images only allow 500 MB as a maximum file size, it will render itself merely useless since dividing images, especially in cartography, diminishes the power of the image, even when dividing is an option.

- Polygon count:

Polygon count is another important aspect when evaluating the performance of mixed reality application since it is the 3-dimensional twin of resolution which applies for 2-dimensional images. The higher the polygon count, the more detailed a 3D image appears. However, due to the fact that reliable and consistent information on the limits of HoloLens and applications is very difficult to come by, this criterion will not be included in our table,, but it is still worth mentioning for future research on the subject.

By using the human and technical criteria mentioned above, in order to create a better visualization and understanding of the evaluation, the table below is created. (see Table 1) Potential applications will be ultimately evaluated by help of this table. In the following chapter, this table will appear at the end of each application in order to achieve a concrete result.

	Minimum value	Optimal value	Real average value	Feasibility
Internet connection speed (Mbps)				
Storage space (GB)				
Frame rate (fps)				
Battery life (hours)				
File formats				
File size limit (MB)				

Table 1: Template table for technical criteria

4.3.2 Human Criteria

Human criteria rely upon human constraints mentioned previously. Due to its nature, these criteria have more subjectivity than technical ones. However, they are still expected to provide with valuable information on the potential of applications, since the end user is what these applications are created for, in other words, the target audience.

The data for human criteria tables are acquired using surveys conducted by 11 participants, that will provide the insight into the significance of each application regarding criteria that is affected by human factors that will be explained in this chapter (see Appendix).

Human criteria that will be used for the table are the following:

- Maximum duration of comfortable usage (MDCU):

This criterion is created since HoloLens is a head mounted device, and has to be carried on the user's head as long as it is in use. It is obvious that this issue might lead to problems, especially in long term usage, since humans are not naturally habitated to use devices mounted on their heads. To measure the amount of time a user can comfortably use the device when mounted onto their head, this criterion is created. Results gained from this criterion is expected to provide insight into the usability of HoloLens for extended durations. It shall be noted that, this criterion takes into account the amount of time during which the user does not feel the need to remove the device from their heads. This is important since the next criterion (MDPU) is about the total possible time a user is willing to wear the device, including small breaks. The evaluation will be done as number of people out of 11 since 11 people were surveyed (see Appendix).

- Maximum duration of possible usage (MDPU):

In contrast to MDCU, MDPU defines the maximum duration of usage a user reports to be able to bear with, meaning that after this duration, the user is not willing to continue wearing the device on their heads, even when small breaks are offered.
This criterion is important to determine the maximum amount of time an application is likely to be used. Therefore, typical durations of applications will be compared with MDPU to obtain information about how usable they are. As before, evaluation will be done as number of people out of 11 (see Appendix).

- Motion sickness:

Another issue that occurs when users are exposed to 3D screens such as 3D glasses, virtual reality goggles or augmented reality devices is motion sickness. Motion sickness is defined as "… a condition in which a disagreement exists between visually perceived movement and vestibular system's sense of movement"[25].

Therefore, considering that mixed reality systems basically rely upon the creation of a world that is not real but simulated, and movement is also a part of this simulated reality, motion sickness is expected to occur in users due to their bodies being stationary but their visual fields are exposed to information that is sometimes moving.

[25] https://en.wikipedia.org/wiki/Motion_sickness

While certain applications utilize methods that does not include movement but only still images, other use motion as part of the experience. In light of this information, the issue of motion sickness is worth mentioning and investigating in mixed reality devices, hence, included as a criterion in human part of the evaluation. An average of ratings given out of 10 will be evaluated (see Appendix).

- Quality of user experience:

Finally, the last point of human criteria is the quality of user experience. This concept is different from previous ones since quality is a very subjective concept and is difficult to measure. However, user experience is a very important part of the perception of a product. It is basically what makes people want to use a product more or less. Therefore, a measure of the quality of user experience will be included, while having less of a significance for our research, compared to first three criteria.

Below can be seen the table for human criteria (see Table 2). A more detailed explanation of how the values are measured and evaluated will be given in the end of each evaluation table in Chapter 5, using the data relevant for each application, therefore here is only an overview is given. As done previously, average of rating will be taken into account (see Appendix).

	Acceptable value	Surveyed Value	Feasibility
Maximum duration of comfortable usage (MDCU)			
Maximum duration of possible usage (MDPU)			
Motion sickness			
Quality of user experience			

Table 2: Template table for human criteria

4.4 Conclusion

Throughout the methodology chapter, a general understanding of the workflow of the research is given. First, the steps that leads to the final research are given. Next, concepts such as technical and human constraints are explained with examples. After that, the criteria for evaluation are determined and each criterion is explained in detail including the motivation for including each one of them and what they mean for our research as well as answering the question why this criterion is significant for the sake of this thesis.

Finally, the evaluation tables are presented in order to provide a general overview of the evaluation process. In the next chapter, the potential fields of usage will be presented alongside with detailed explanations of their concepts, features, limitations. Finally, criteria determined in this chapter will be used to evaluate each application and results will be obtained and discussed.

5 Potential Fields of Usage

This chapter will consist of what can be argued as the main body of the thesis. Several applications of mixed reality devices in the field of cartography will be presented.

First, a concept of each application will be explained, as their backgrounds and what each application is useful for, as well as a general summary.
Next, features of the application will be discussed in detail. This is crucial since the available features will determine the limits of the concept and also will give a general overview of the type of application to use within the cartographic concept.

In the third chapter, each application will be put in focus regarding their constraints, both the technical and conceptual ones. Constraints will be key when evaluating the application, especially from the point of view of the technical criteria.

Next, and maybe the most important chapter will be the evaluation of the application according to the criteria. These criteria were already determined in the methodology chapter. Therefore, this part will mainly consist of the comparison of the features and constraints of the application against the criteria. Evaluation tables will be included in order to be able to give a general overview of this comparison. Finally, a discussion of the evaluation results will be contained in the end of the chapter.

5.1 Video chatting application (Skype) enhanced with cartography

Videochatting applications that connect two or more people over large distances via internet connection by voice, image, video or a combination of those is a well-known concept. Skype by Microsoft is one of such applications[26]. What makes Skype relevant for this paper is that it has a version available for Microsoft HoloLens.
In this chapter, certain features of Skype for HoloLens as well as its potential as a cartographic tool will be discussed.

[26] https://www.microsoft.com/en-us/store/p/skype/9wzdncrfj364

5.1.1 Concept

This version of Skype allows a HoloLens user to connect with a traditional Skype user, as well as a connection between two HoloLens users, in which case a HoloLens to HoloLens connection is created. Both types of connection has the potential to be helpful in cartographic context, while the latter allowing a more immersive experience for both ends of the connection[27].

Considering the capabilities of the device, an application that involves the transfer of the images of 2D maps, relief maps and 3D globes via Skype is a candidate for a potential use case.

5.1.2 Features

Spatial Mapping

HoloLens constantly maps the environment with its built-in sensors, which provides a dynamic live feed of the surroundings of the other user(s). This is crucial since share of information has to be real-time to ensure the currency of the video feed. An example of this can be seen in the image below (see Figure 15).

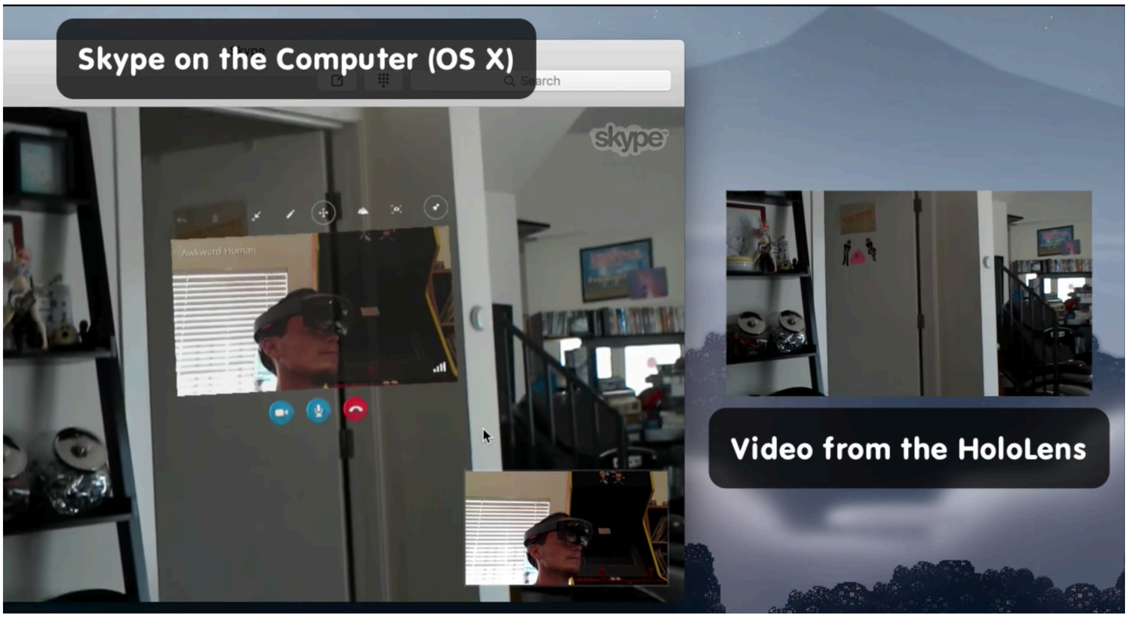

Figure 15: A screenshot of a connection in Skype for HoloLens[28]

[27] https://support.skype.com/en/faq/FA34641/frequently-asked-questions-about-using-skype-for-hololens
[28] https://hololens.reality.news/news/skype-video-chatting-works-hololens-0171644/

Hand Tracking

One of the most innovative features of the Skype for HoloLens application is that the hand movements of the user are tracked and copied to the other user's virtual space. This feature is what creates the potential for the cartographic applications such as discussing over a real or holographic map over long distances, as well as modifying them.

As seen in the image (see Figure 16), any modification made by the HoloLens user is immediately transferred to the other end of the connection. Any size of an image can be easily opened during such a connection and modifications as well as discussions over the image can be made by both parties.

Figure 16: An example of a connection between a regular Skype user and a Skype for HoloLens user. Any modifications done by either party is reflected in other's field of view.

The capabilities are not limited by 2-dimensional traditional maps, though. Any type of 3D objects are also allowed in these video calls. For instance, two users can be in the same virtual space accompanied by a 3D holographic relief map.In this case, both users are required to have the headsets. A concept of such an application is shown below (see Figure 17).

A combination of 3D holograms with Skype for HoloLens technology provides the means and capability to create a virtual space to create, share, discuss and modify cartographic material. Constraints of the technology are mostly caused by the fact that the HoloLens is still under development. A major part of these constraints, details of which will be discussed in detail, can be expected to be overcome by the developments in computer technology and especially by spreading of the mixed reality devices, which will bring the new technologies along with it.

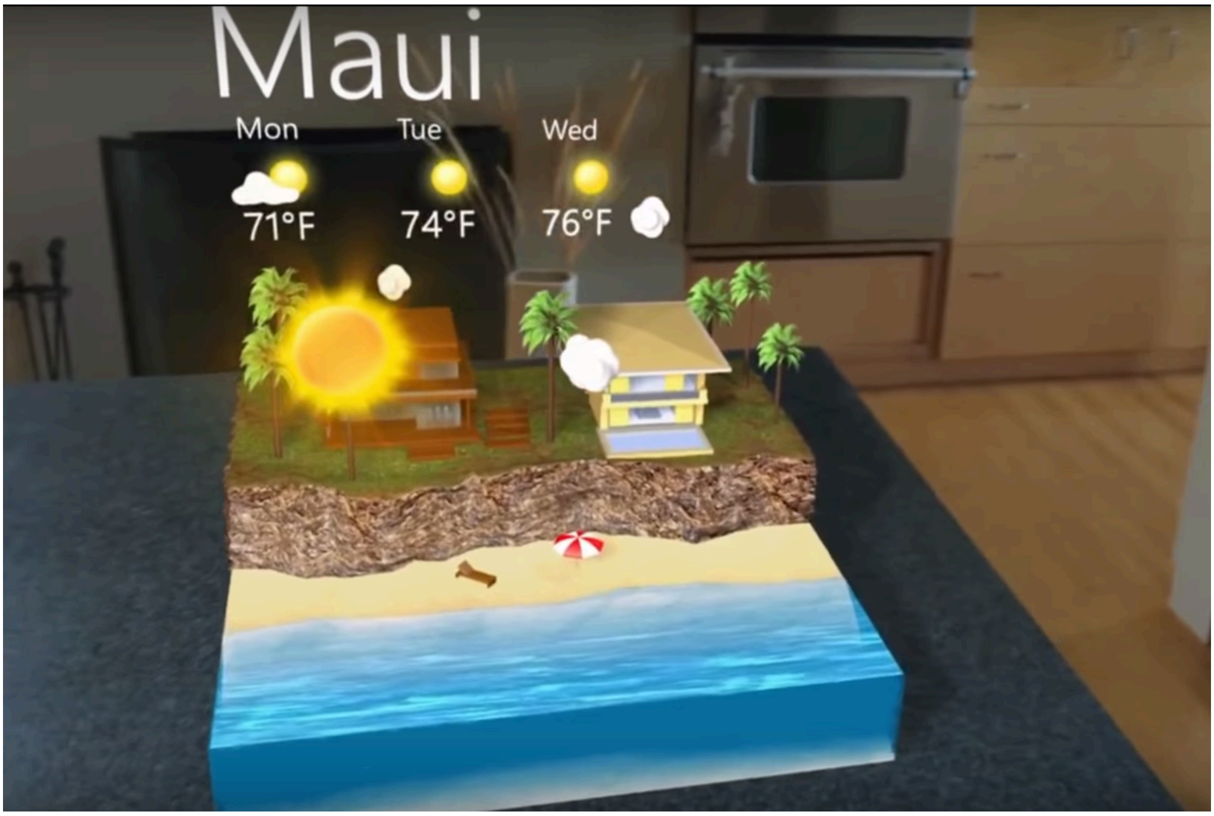

Figure 17: An example of a representation of a part of the world using a 3D hologram. These holograms can be still 3D images or dynamic, fluid ones[29]

5.1.3 Limitations

Bandwidth needed for Skype on HoloLens:
HoloLens video calling - 600kbps/700kbps
HoloLens HD video calling - 1.8Mbps/2.1Mbps[30]
An internet connection fulfilling the requirements mentioned above is essential for a fluid user experience, otherwise interruptions are expected. Therefore, these values will be accepted as minimum and optimal values.

Too many Holograms:
This is a warning that can occur when one of the connected users have added too many holograms to the space. To ensure the high call quality, there is a limit to the number of holograms that can be added to the space. Microsoft claims that this limit is hard to reach and suggests closing some photos or erasing some features to allow more 3D objects to appear within the space.

[29] https://www.youtube.com/watch?v=MVXH5V8MVQo
[30] https://support.skype.com/en/faq/FA34641/frequently-asked-questions-about-using-skype-for-hololens

File format constraints:

Currently only the following formats are accepted to be used in Skype: .jpeg, .jpg, .png, .bmp, .dib, .gif, .tif, .tiff [31]

Trying to upload a file in formats other than the ones counted above will result in an error that warns the user about the format of the file.

Another constraint regarding the file format is the video support of Skype. Skype for HoloLens currently does not support the share of video files, which diminishes the number of potential cartographic applications. However, future updates may change this situation by allowing video sharing.

5.1.4 Evaluation

TECHNICAL CRITERIA

	Minimum	Optimal	Real average value	Feasibility
Internet connection speed	0.7 kbps	2.1	41.18 / 8.43 Mbps	High
Storage space	60 GB (maximum)	Up to 12 GB	223.84 MB	High
Frame rate	30	60	Up to 60	High
Battery life	1 hours	2 hours	2-3 hours	High
File formats	.jpeg, .jpg, .png	.tiff, .shp, .slddrw	.jpeg, .jpg, .tif, .tiff, .dib, .bmp	Medium
File size limit	100 MB	2 GB	300 MB	Medium

Table 3: Technical criteria table for Skype for HoloLens

Potential of Skype for HoloLens for cartographic applications is already discussed in previous chapters. However, it comes with certain limitations as can be seen from the table.

[31] https://support.skype.com/en/faq/FA34641/frequently-asked-questions-about-using-skype-for-hololens#Addin

First of all, internet connection speed is evaluated. According to Microsoft[32], a minimum of 700 Kbps is recommended, while the optimal number is 2.1 Mbps. These values were compared to the average internet speeds in Germany, taken from Speedtest[33]. Two different numbers indicate download (41.18 Mbps) and upload (8.43 Mbps) speeds. Both numbers are relevant for Skype application since it is a peer-to-peer application, meaning both upload and download speeds determine the practical speed of the connection. It can clearly be seen that these internet speeds are more than enough for a reliable connection. Therefore, it can be concluded that from this aspect, Skype for HoloLens is a highly feasible one.

Another criterion is the storage space. Due to the fact that HoloLens is a standalone device that requires no computer to work, applications has to be installed onto the device via the application store. When we look at the storage space of HoloLens[34], we can see that the flash memory is 64 GB with 60 GB usable. The optimal value of 12 GB is selected as an arbitrary value, assuming 5 different applications are installed onto the device, therefore making the optimal size for an application 12GB. Since Skype for HoloLens has a download size of 223 MB[35], no major issues with storage space is expected.

Third of important aspects when judging HoloLens applications is the frame rate. For stable holograms, 60 fps is recommended by Microsoft[36] as the optimal value, and 30 fps as minimum. Skype for HoloLens has no trouble fulfilling this requirement, being an application developed by Microsoft itself.

Battery life of the device, given as 2 to 3 hours (Callaham, 2016), is relatively long for this application. A minimum of 1 hour and an optimal value of 2 hours is chosen, as a value for a typical Skype session, reflecting the values from Statista[37], for years 2008 to 2010. Therefore, it can be argued that the typical battery life of Microsoft HoloLens allows a resonable duration for Skype for HoloLens, which results in a "High" rating for this aspect.

32 https://support.skype.com/en/faq/FA34641/frequently-asked-questions-about-using-skype-for-hololens
33 http://www.speedtest.net/reports/germany/
34 https://docs.microsoft.com/en-us/windows/mixed-reality/hololens-hardware-details
35 https://www.microsoft.com/en-us/store/p/skype/9wzdncrfj364
36 https://developer.microsoft.com/en-us/windows/mixed-reality/hologram_stability
37 https://www.statista.com/statistics/273081/average-voice-and-video-minutes-of-skype-users/

The issue of file formats is the fifth criterion in our table. As before, Microsoft claims the allowed file formats as .jpeg, .jpg and .png, which are mostly used on internet. As the application is assessed from a cartographic perspective, shapefiles and other file types used in mapmaking are expected to work for a better cartographic application. The minimum is determined as .jpeg, .jpg and .png as these formats allow the exchange of image files, which might include maps as well. Hence, the rating of medium is determined to be a fair evaluation for Skype for this aspect.

Finally, file size limit is another important constraint since Skype for HoloLens allows sharing of files between peers and this has been presented previously as a very important feature for exchange of cartographic information such as shapefiles and maps. Since a maximum size of a .dbf file, which is the DBASE table storing the attribute information for a typical shapefile[38] is 2 GB, maximum file size is determined as such. A lower value of 100 MB is determined as minimum file size, since typical image files have sizes lower than this value. Therefore, the limit of 300 MB makes Skype for HoloLens moderately feasible from the aspect of file size.

All in all, getting a score of High from 4 of the technical criteria and Medium from the other 2, it can easily be argued that Skype for HoloLens is a highly feasible application, from the perspective of our technical criteria.

[38] https://support.esri.com/en/technical-article/000010813

HUMAN CRITERIA

	Acceptable value	Surveyed Value	Feasibility
Maximum duration of comfortable usage (MDCU)	7/11	7/11	Medium
Maximum duration of possible usage (MDPU)	7/11	8/11	High
Motion sickness	<3/10	1.8/10	High
Quality of user experience	7.5/10	6.7/10	Medium

Table 4: Human criteria table for Skype for HoloLens

When it comes to human criteria, four different aspects have been presented. First of them is the maximum duration of comfortable usage (MDCU). This value defines the duration which the users are comfortable wearing the HoloLens before they start to feel discomfort. According to the survey conducted, 7 people out of 11 reported their MDCU as more than 15 minutes. This number is on the lower limit of the acceptable value defined. Therefore, a rating of "medium" is given according to the scale introduced. This result would mean users would not like to use this application more than 30 minutes. This case is not so desirable as the application would probably require more than 30 minutes of active use time.

The second criterion is maximum duration of possible usage (MDPU). It is expected to reflect the maximum amount of time the user reports to be able to use the device, including short breaks. Out of 11 users, 8 of them claimed that they are likely to be able to withstand wearing the device more than one hour in Skype for HoloLens application. This clearly shows that MDPU is not a significant concern for most users. Therefore, no major drawbacks are expected regarding the length of usage.

Next, the issue of motion sickness is evaluated. According to the scale given to the participants, where 0 means no discomfort at all, the average of 1.8 is obtained. This clearly shows that due to its static nature Skype for HoloLens does not cause a major discomfort for the users in terms of motion sickness. From a cartographic perspective since Skype allows sharing of static images, it can be argued that the scope of possibilities is limited compared to an application that is based on dynamic content.

Finally, participants were asked to rate the quality of the experience while using the application. This criterion is highly subjective, therefore, the results must be approached with caution. As before, the average of scores given by users are compared against the value of 75 % which will show if 3 out of 4 participants have a positive opinion on the quality of user experience. The score of 6.7/10 can be considered as a medium score, being within the premises of the acceptable value.

To sum up all the evaluation made in this chapter, Skype for HoloLens as a cartographic application gained a high score from 6 of 10 criteria and a medium score from 4 of them. This can be interpreted as Skype being a feasible, reliable and beneficial application for potential of HoloLens. Engineers, cartographers, architectures and designers can benefit from the technology which is promising to bring people together from all around the world in a digital setting where they can share their ideas, creations and experiences.

5.2 3D Holographic Map Viewing (Holo Terrain)

Another type of a potential application, that has a major focus on cartography is 3D holographic map viewing, through mixed reality glasses. In this chapter, potential of these applications with current examples will be discussed and evaluated.

5.2.1 Concept

Another type of a potential application, that has a major focus on cartography is 3D holographic map viewing, through mixed reality glasses. These methods will be discussed with a focus on two examples of such applications:

First example is called HoloTerrain, developed by Dangling Concepts. HoloTerrain is a 3D terrain and map visualization tool for HoloLens[39]. It allows the users to see a bird-eye view of the Earth, holographically, rendered as a three-dimensional relief map. An example of such a

[39] http://danglingconcepts.com/holo-terrain/

relief map, where the holographic square shows an area of 48.83 km x 48.83 km. (See Figure 18)

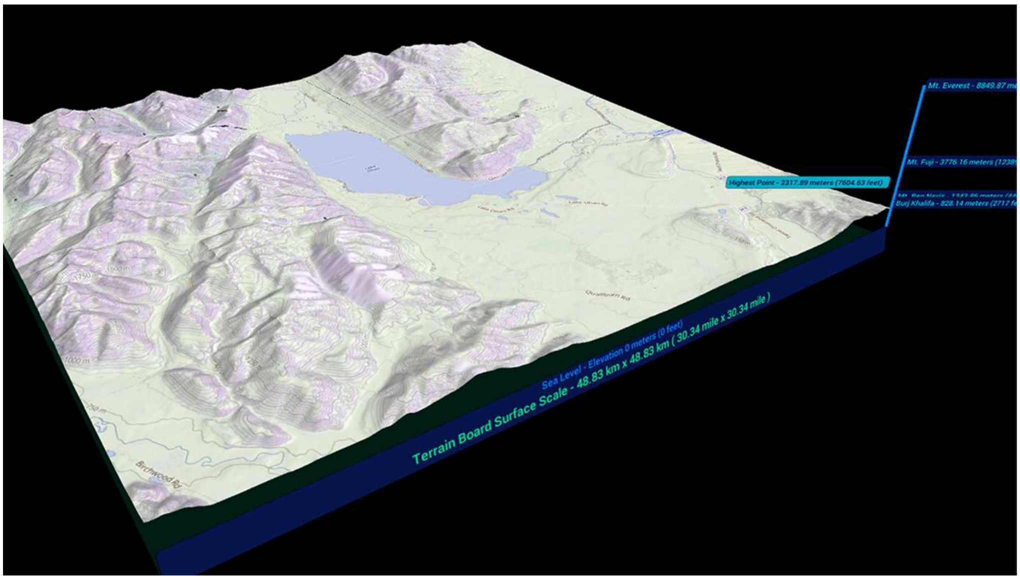

Figure 18: A view of HoloTerrain application, showing 3-dimensional features of the Earth[40]

Another prototype of an application is the HoloLens Terrain Viewer developed and published by ESRI[41]. Conceptually, this prototype is very similar to HoloTerrain. However, due to the fact that data is less available and realization of the project is less likely than HoloTerrain, HoloLens Terrain Viewer will not be evaluated or discussed in detail. It is mentioned here to demonstrate the potential of terrain viewers and to show that 3D terrain viewers are becoming commonplace as applications for Microsoft HoloLens.

[40] https://www.microsoft.com/en-us/store/p/holoterrain/9mwkd575dqq3
[41] https://github.com/Esri/hololens-terrain-viewer

5.2.2 Features

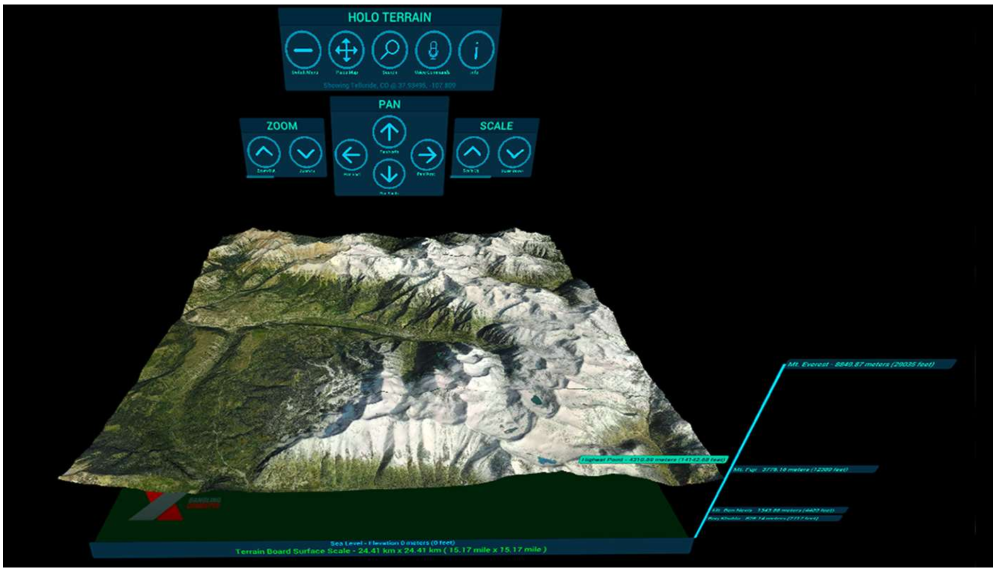

Figure 19: 3D holographic interface of HoloTerrain[42]

As demonstrated in the figure above (Figure 19), the interface can be considered straightforward. There are three main components of the view: the 3D map, information bar, and the controls.

To the very left of controls, there is the zoom function. 4 zoom levels are available ranging from 3.8 sq miles all the way up to 40 sq miles. User can choose between these zoom levels by using a combination of functionalities: Gaze + Gestures, or Gaze + Clicker (Controller).

Second control is called Pan. Here the user has the choice of clicking to one of four buttons, in order to navigate to north, south, west or east. These directions refer to the real world directions, meaning, a pan to the north will bring up the adjacent part of the world to the north, within the same zoom level. Again the controls has to be clicked using a combination of input methods Gaze and Gesture or Clicker, as the case in Zoom control.

Third control on the bottom of the controls screen is Scale. This is different from Zoom, since it resizes the apparent area the map displaces, while not changing the zoom level or any other variable. This function uses the same input methods needed for previous two controls.

To the top of the controls screen, there is the rectangular area titled "HoloTerrain". This

[42]https://www.microsoft.com/en-us/store/p/holoterrain/9mwkd575dqq3

area is home to buttons such as “Place Map”, “Search”, “Voice Commands”. When the user clicks “Search”, another window comes up with search details (see Figure 20).

Here the user can choose between the type of the thematic layer and more importantly, can do a search for any area of the Earth surface.

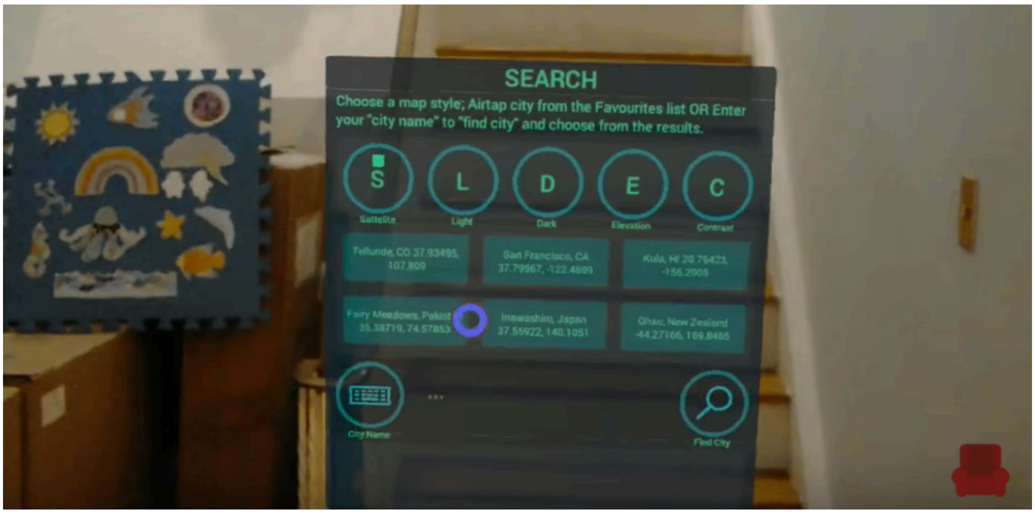

Figure 20: Search functionality of HoloTerrain[43]

Voice commands are also embedded in as a method of giving input to the system. Users can use their voice to give commands such as “Pan south” or “Zoom in” using the built-in microphone of the HoloLens. When working as expected, this function is obviously a great addition in order to be able to shorten the time spent on using the controls since they require at least two input methods in combination such as Gaze + Gesture.

However, in the tests done, it is seen that reliability of voice commands is lower than that of the clicking method. Accents and mispronunciations can affect the function of voice commands, in varying degrees.

Another feature is the information bar, having the elevation data for the highest point on the currently displayed area, as well as some other examples of elevation, to act as comparison with current area (see Figure 21).

[43] https://www.youtube.com/watch?v=1MIOii_TRLY

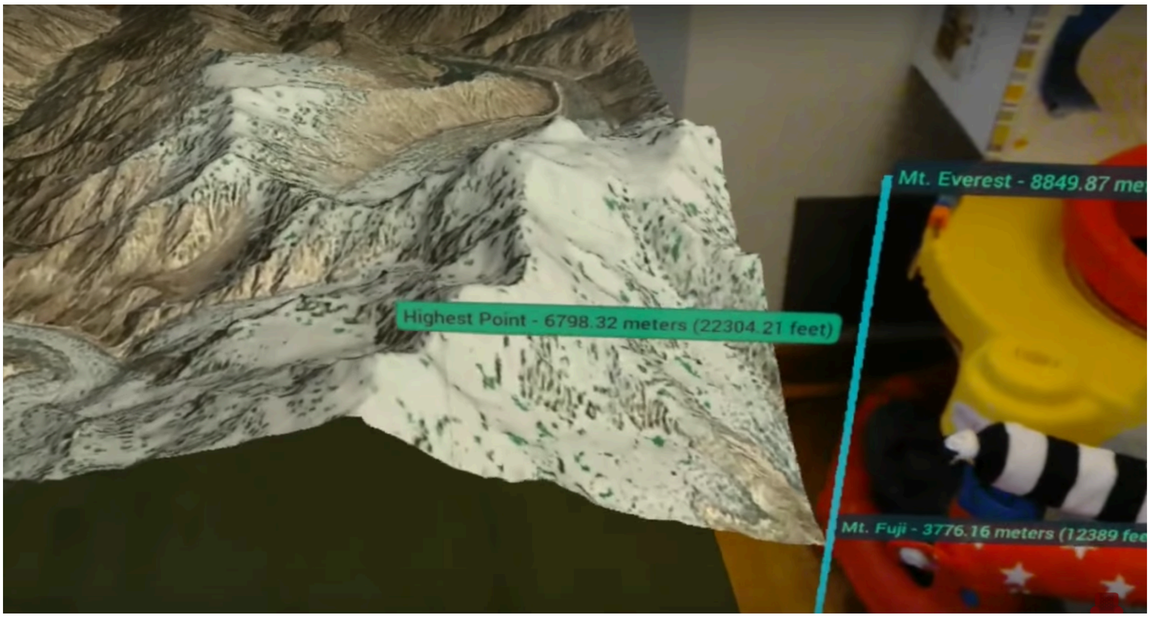

Figure 21: Detail from the HoloTerrain application, showing examples of elevation[44]

A recent update to Holo Terrain has the potential to be very useful in cartographic studies and education, which is the availability of a shared holographic session of up to four devices.

For this functionality to work, an internet connection is required. Up to four devices has to be connected to the same Wi-Fi network. In this setup, one device acts as a host for the session and other three are clients. For the current version (version 2.1), the clients can only see what the host is displaying. However, future updates can offer additional modes of communication between the connected devices, in which multiple devices can act as hosts or a remote connection can be possible.

Apart from HoloTerrain, another application called "Hololens Terrain Viewer" has been released as a package by ESRI. It has features similar to HoloTerrain[45]. This application is not yet published to the official Windows Store for HoloLens applications therefore the details will not be discussed. However, it is worth mentioning as an alternative to Holo Terrain as it is developed by ESRI, a significant name in cartographic applications.

[44] https://www.youtube.com/watch?v=1MIOii_TRLY
[45] https://github.com/Esri/hololens-terrain-viewer

5.2.3 Limitations

Limitations caused by connection speeds

As most applications on HoloLens, feasbility of using Holo Terrain depends on a reliable internet connection. Due to the large amount of 3-dimensional map data used int eh application, connection speeds in places with limited Wi-Fi signal or low bandwidth can be an issue when the application tries to download the data required to display.

Limitations of zoom levels and scaling

As mentioned in the previous chapter, there are four zoom levels available in Holo Terrain. This is one of the main constraints of the application. Unlike 2D maps applications like Google Maps, the user does not have the freedom of viewing the whole globe, or going into very detailed sections of the earth surface.

Another limiting factor is the small number of scaling options. There are two sides to this issue. First of all, steps of scaling is adjusted in very small increments, therefore the user generally has to press the button more than once to significantly change the scale of the hologram. Second issue is mainly caused by the limits of how large the square can be resized to. Considering the content of the hologram that is projected onto the user's eyes, more freedom on the option of adjusting the map would be beneficial.

5.2.4 Evaluation

TECHNICAL CRITERIA

	Minimum	Optimal	Real average value	Feasibility
Internet connection speed	700 kbps	2.1 Mbps	41.18 / 8.43 Mbps	High
Storage space	60 GB (maximum)	Up to 12 GB	16.6 MB	High
Frame rate	30	60	Up to 60	High
Battery life	2 hours	5 hours	2-3 hours	Medium
File formats	.obj	.3ds, .blen, .fbx, obj	.fbx, .obj	High
File size limit (MB)	-----	-----	N/A	High

Table 5: Technical criteria table for HoloTerrain

As before, the first criterion to be checked is the internet connection speed. As no specification has been found in developer's website, values are given according to the numbers given in the previous application: Skype for HoloLens. First of all, at all time during active use of HoloTerrain, the user sees a square that is downloaded and static until the user decides to move the map for which they have to click on one of the buttons to move, rescale or zoom the map. Since Skype handles live video feed from two different users in real time, it can easily be expected that the minimum and optimal internet connection speeds required for Skype will be more than enough for HoloTerrain application. Real average value is calculated from Speedtest as before. Therefore, a rating of "high" is awarded.

For storage space, the same method as before is applied, same numbers for minimum and optimal apply. Download size for HoloTerrain is obtained from the website of the application.[46] Being considerably low compared to minimum and optimal values, feasibility regarding storage space is filled in as "high".

[46] https://www.microsoft.com/en-us/store/p/holoterrain/9mwkd575dqq3?activetab=pivot%3aoverviewtab

Frame rate is not that essential of a concept for this specific application since it deals only with static images as mentioned in internet connection section above. Therefore, expected values for HoloLens itself will be sufficient to see if this application is going to work as expected regarding the frame rate. As long as HoloLens works correctly, HoloTerrain is expected to work as planned, when it comes to how many frames per second it can produce.

Issue of battery life is arguably the only weak point of this application. Due to the static nature, longer durations of use can be expected. A maximum of 5 hours is determined as a limit to how long users can wander around in the 3D map before they are finished with their work on HoloTerrain. This number can be changed according to the research done on typical usage durations, which we lack at the moment, since the application is recently published and this criterion for this application cannot be determined for certain. However, difficulties are expected as typical battery life of HoloLens is 2 to 3 hours and the device have to be charged before continuation of the use.

Selected examples from 3D file formats that is used in most common 3D object creating software (such as 3D Studio, Blender, Unity3D)[47] is used. Since HoloTerrain uses Unity3D libraries, the file types it uses is limited to .fbx and .obj. Therefore, this poses a limitation for the software to be used when creating visual material for this application. Since HoloTerrain supports at least one of these software, Unity3D, which is selected as the minimum criteria, a feasbility rating of 'Medium' is applied.

File size limit is not applicable to HoloTerrain since the files presented in this application is downloaded in real time from the internet, therefore no limit on file size is applied. 3D images are generated according to the capabilities of the device, hence, no problems are expected. As an indication of no constraints, feasbility is considered as "high".

[47] http://edutechwiki.unige.ch/en/3D_file_format

HUMAN CRITERIA

	Acceptable value	Surveyed Value	Feasibility
Maximum duration of comfortable usage (MDCU)	7/11	7/11	Medium
Maximum duration of possible usage (MDPU)	7/11	7/11	Medium
Motion sickness	<3/10	2.27/10	High
Quality of user experience	7.5/10	7.8/10	High

Table 6: Human criteria table for HoloTerrain

As in previous application, human criteria is assessed using four different aspects. First of them is the maximum duration of comfortable usage (MDCU). According to the survey conducted, 7 people out of 11 reported their MDCU as more than 15 minutes. Acceptable values are kept as standard per each application. Therefore, a rating of "medium" is given according to the scale introduced. None of the participants reported they are willing to use the application for more than 30 minutes in one go,

The second criterion is maximum duration of possible usage (MDPU). Out of 11 users, 7 of them claimed that they are likely to be able to use the HoloLens while being on HoloTerrain application. Same rating as previous criterion is applied. Therefore, a moderate level of difficulty is expected.

Users rated the experience from motion sickness perspective with an average of 2.27/10. Since lower values in this criteria means a more desirable experience, the results that can be extracted from the survey is that HoloTerrain and similar applications does not pose a major discomfort for the users in terms of motion sickness. This is mainly due to HoloTerrain relying on static 3D images that only changes at the will of the user, rather than a constantly changing dynamic visual field.

The score of 7.8/10 is obtained from the answers given to the user experience question. As mentioned before, it is a more subjective measure than others but still useful for a general understanding of the current status of mixed reality applications. Being higher than the standard that is defined before as 7.5, HoloTerrain is evaluated as having a score of "high" in quality of user experience.

Finally, the following can be said as a general overview after the application is thoroughly evaluated according to 10 criteria. Results show that HoloTerrain obtained a high feasibility rating from 7 of the criteria and medium from others. Therefore, already being an application with a heavy cartographic focus, HoloTerrain shows great promise due to its feasibility and ease of use. Advancement of mixed reality technologies can only be expected to bring forward more of such applications to the world of cartography, given its innovative and revolutionary approach to cartographic visualization.

5.3 HoloTour

HoloTour is an application developed for HoloLens by Microsoft. In the following sections, concept, features and limitations of the application will be further explained. Evaluation of the application will follow before ending the chapter with the discussion of results.

5.3.1 Concept

HoloTour allows the users to explore historical sites such as Ancient Rome and Machu Picchu in Peru. The main idea behind the application is to allow users to feel like they are present in the ancient sites. This effect is created by using images produced using 360 degrees of field of vision.

Figure 22: Augmented text showing the translation of Latin original.[48]

5.3.2 Features

Apart from the full field of vision, the application also uses the augmented reality features as seen in the figure above (see Figure 22). This feature also acts as an example to how text and other augmented features can be utilized in cartographic contexts.

Another feature of the application is the use of spatial sound. Using the built-in speakers of the Holo Lens, information is passed onto the user in a specially designed way, in which the user can sense the direction of the sound. While acting as an audio guide, the sound is also used to direct the user in certain directions, which aims to provide easier and a more paced usage. This feature is also key for the aspect of realism within the mixed reality environment[49].

Cartography, especially in small scales, can potentially use methods featured above, in ways that were not previously possible at this level. An example of such usage can be seen below,

[48] https://compass-ssl.surface.com/assets/f4/fe/f4fe1720-1ee9-4622-adf0-d6b13b7ca297.jpg?n=HoloTour_Feature3_img_1920.jpg
[49] https://www.microsoft.com/en-us/hololens/apps/holotour

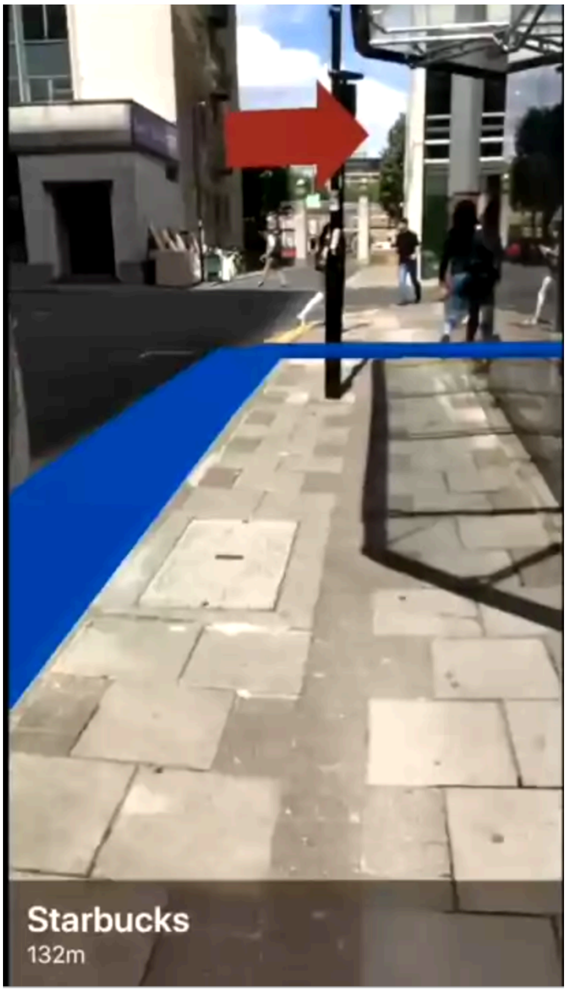

Figure 23: A conception of augmented reality used for navigation.

where augmentations to the real world objects are used for navigation in real streets. (Figure 23)[50]

Due to the constraints of outdoors use, which will be discussed in later chapters, indoor usage of MR devices in a similar fashion can also be conceptualized (Feiner et al., 1997).

5.3.3 Limitations

Limited number of locations

One of the most significant limitations of the application is the fact that it only contains two ancient sites, Rome and Machu Picchu. This limits the opportunity to utilize the full capabilities of the HoloLens in such an interesting and creative way. There is no question that inclusion of a larger number of ancient sites, as well as other locations, such as museums, venues etc. would render the application a more extensive one as well as opening more doors for the field of cartography. Examples may include an application of indoor cartography or the mapping of an ancient site by use of mixed reality technologies.

Limited resolution

According to Microsoft, the maximum supported resolution is 1280x720 pixels. Compared to modern display devices, this resolution is quite low. Most devices with a screen nowadays use a resoultion of 1080x1920 pixels as minimum. Being accustomed to these everyday devices, users may encounter less of an immersive experience due to low resolution.

Especially in this specific application, where the visual content is aimed to be realistic rather than schematic, this effect is even more pronounced. Form a user experience point of view, a higher

[50] http://i.gzn.jp/img/2017/07/24/apple-ios11-arkit-demo/cap00004_m.jpg

resolution can be argued to create a mixed reality environment that resembles the real-life locations more closely[51].

5.3.4 Evaluation

TECHNICAL CRITERIA

	Minimum	Optimal	Real average value	Feasibility
Internet connection speed (Mbps)	Not required	Not required	41.18 / 8.43 Mbps	High
Storage space (GB)	60 GB (maximum)	Up to 12 GB	5.52GB	High
Frame rate (fps)	30	60	Up to 60	High
Battery life (hrs)	1 hours	2 hours	30-60 minutes	High
File formats	.jpeg, .jpg, .png	----	.jpeg, .jpg, .png	High
File size limit (MB)	No limit	-----	Various	High

Table 7: Technical criteria table for HoloTour

Unlike previous two applications, HoloTour does not rely upon an internet connection. All images and sounds are downloaded during the installation of application. Therefore, a slow internet connection, or even lack of it, does not influence the functionality of the application. Therefore, feasibility is "high", meaning that no problems regarding internet connection is expected.

The minimum and optimal values for storage space are described in previous applications. The difference here is the fact that HoloTour uses no internet connection, resulting in a much larger download size. All kinds of data that the application used in included within the application package, making the storage space needed more than 10 times of other applications. Still, due to available space in HoloLens, no storage space issued are likely to occur[52].

51 https://developer.microsoft.com/en-us/windows/mixed-reality/rendering
52 https://www.microsoft.com/en-us/store/p/holotour/9nblggh5pj87

Battery life is not as big of an issue as other applications since the application is limited by two ancient sites, which takes less time than an application like Skype. Frame rate, file formats and file size limit are also not expected to cause problems. Further research in these issues is likely to produce more results, since the application has the potential to be enlarged and these constraints are prone to changes as the amount of locations increase and requirements of HoloTour evolve.

HUMAN CRITERIA

	Acceptable value	Surveyed Value	Feasibility
Maximum duration of comfortable usage (MDCU)	7/11	7/11	Medium
Maximum duration of possible usage (MDPU)	7/11	4/11	Low
Motion sickness	<3/10	5/10	Medium
Quality of user experience	7.5/10	6.09/10	Medium

Table 8: Human criteria table for HoloTour

Human constraints will be handled by the same measures applied for Skype and HoloTerrain applications. It is clearly seen that more users reported feeling motion sickness than in other applications, due to the dynamic nature of the application. An average of 5 out of 10 is obtained, meaning more users reported motion sickness than our acceptable value.

The issue of motion sickness also affected the amount of time users are willing to use the device continuously. Results of 4/11 and 7/11 are obtained as MDPU and MDCU values, respectively. This causes the rating to fall into an area between low and medium. Therefore, it can be argued that HoloTour does not fully pass the criteria, especially ones related to human consumption, but future developments can help solve the issues mentioned. Finally, from the user experience criterion, a rating of 6.09/10 is obtained. This is likely due to the fact that some users felt discomfort and this caused the effects of motion sickness to deteriorate the general impression for the application on the users.

All in all, HoloTour is a good example of the capabilities of HoloLens and augmented reality in general, due to its clever use of the features. As an educational tool and for entertainment purposes, HoloTour carries great potential. Nonetheless, it comes with its limitations such as the narrow scope of locations and ancient sites. Issues regarding the user experience are the arguably the weak points of the application and need more attention in order to create a fuller experience with less problems in the future.

5.4 Further examples

In this chapter, several other applications of mixed reality devices will be discussed. These examples are separated from the ones mentioned before. This is due to the lack of sufficient research on the subject or less feasibility. Therefore, these examples can be classified as "honorable mentions" since they have some potential to be useful in the future, but do not fulfill completely the criteria to be a potential cartographic application of mixed reality devices.

5.4.1 Pokémon GO style augmented reality game

Pokémon GO, is a location based augmented reality game developed by Niantic for mobile devices[53].

This game relies on a system where it uses the location sensor of the mobile phone and maps application to locate certain creatures called Pokémon and other rewards which requires the user to physically travel to the desired location[54]. This feature is what connects the game to cartography, as users have to search through the map, which reflects the real world, to gain points and advance through the game.

Unlike traditional examples of mixed reality applications, this game uses the mobile phone directly as an augmented reality screen. Therefore, no headset is required. This allows an

[53] https://en.wikipedia.org/wiki/Pok%C3%A9mon_Go
[54] https://www.cnet.com/news/for-better-or-worse-pokemon-go-is-ars-signature-killer-app/

augmented reality experience with no extra hardware other than mobile phones.

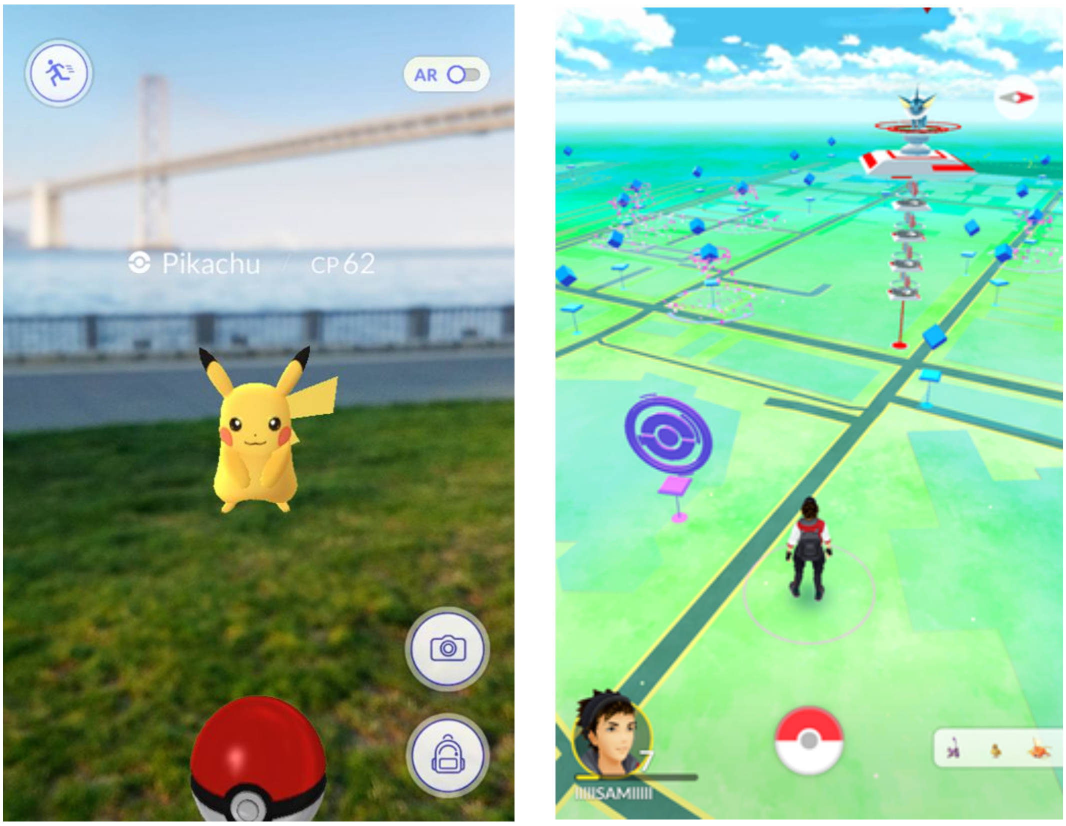

Figure 24: Augmented images onto real image from camera (left), example of thematic map layer (right)

Since the focus of this thesis is to evaluate possibilities of Microsoft HoloLens as a mixed reality platform, a detailed investigation will not be given. Another reason is that Pokémon Go does not claim to be a cartographic application since it is designed as a game. However, it is a good example of the state of the art in mobile cartography and location based services. Thematic map layer used in the game is another design element that uses cartographic methods to visualize the gaming universe, that utilizes the maps application installed on the phone (see Figure 24)[55] . A version of such an application that uses AR or VR headsets as display devices can bring more immersion and realism to the scene while retaining the mobility.

[55] https://upload.wikimedia.org/wikipedia/en/c/c2/Pok%C3%A9mon_Go_-_screenshot_of_map.png

5.4.2 Integration with Google Street View

Google StreetView is a feature of Google Maps, which provides panoramic views from street level of various location around the world[56]. Originally being a desktop feature, Google announced in 2015 that Google Cardboard, which is Google's virtual reality glass[57], will support Street View (Lopez, 2015).

Figure 25: A screenshot from Google's Street View (Google Maps)[58].

As seen in the figure above (see Figure 25), Street View is an application where 360 degree-photos are taken from adjacent positions and merged to create a panoramic image. In desktop application, users have to use an input device such as a computer mouse to navigate through the map. However, in virtual reality version, the direction user gazes at is tracked and the map rotates accordingly. This creates a whole new level of experience in which users can feel the sensation of presence in locations far away from them.

An idea to adapt Google Street View to augmented reality can improve the functionalities greatly. For instance, an indoor location featured in Google Street View[59] can be projected onto augmented reality glasses such as Microsoft HoloLens to create the realistic effect, which can be used for entertainment, education and other purposes such as a digital tour

[56] https://www.google.com/maps
[57] https://vr.google.com/cardboard/
[58] https://www.google.de/maps/
[59] http://indoorstreetview.com/

of museum etc. Potential advancement in display resolution of mixed reality devices can also increase the degree of immersion that maybe reached by a Street View integration.

5.4.3 Usage with unmanned aerial vehicles / Drones

Unmanned aerial vehicles or drones, are aircraft that is operated without a human on board[60]. When attached cameras, these vehicles automatically gain the function of recording image and video from air. This is very useful for places that are hard to reach or too dangerous for humans, or simply to obtain aerial images of earth. Before augmented reality, drone imaging were solely used for video recording or transmission, while with AR, digital image and data can be used to augmented the video (Levski, 2018).

One possible application of drones combined with AR is during natural disasters and emergencies. An example has already been developed by Boeing, where a drone streams live footage of the area of wildfire (Darack, 2017). This imagery is then merged with high resolution DTM and projected onto the augmented reality headset of the user (see Figure 26).

Figure 26: HoloLens used for a firefighting application (Boeing)[61].

With the help of this technology, possibility of reacting faster and assessing the scale of the danger increases. This method can also help with disaster relief efforts. For instance, an

[60] https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle
[61] https://www.youtube.com/watch?v=omGoz66xHU8

area affected by an earthquake, hurricane or flood can be scanned with a drone and damaged roads, buildings as well as flooded areas can be determined by augmented reality integration. An example of such a use can be seen in system used by Rapid Imaging (see Figure 27).

Figure 27: Disaster response can benefit from AR-Drone integration[62]

Another use case of drones with AR technology is by the police. FBI has a report on investigating the possibilities of the field[63], which shows the potential of such applications. Cartographic visualizations are surely promising to be useful when police officers have to reach a certain location with speed and accuracy, as well as for directing the traffic, to see congestions etc.

As mentioned before, unmanned aerial vehicles can be used to obtain data from a large area, which would then send data or imagery to the headset of an officer, or to the police station, helping to locate crime and manage other issues in cities and rural areas.

Many other fields of use can be found considering the potential of augmented reality, such as architecture, education, entertainment, military etc. The ones presented here are applications that have been shown to carry potential to be used in the future.

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[62] https://www.youtube.com/watch?v=uimSnxUPbIE
[63] https://www.fbi.gov/file-repository/stats-services-publications-police-augmented-reality-technology-pdf/view

5.5 Future Work

In this research, applications of mixed reality that benefits the field of cartography have been discussed. For this purpose, applications were assessed according to the research and surveys conducted. Also, some further examples were given to demonstrate the potential of mixed reality. To build onto the work done, these examples can be increased in number, in future research. More applications that uses the potential of HoloLens more fully, can be tested. Being a recently released device, Microsoft HoloLens is used to demonstrate the potential of augmented reality headsets. However, better devices with more capabilities and better outdoor usage possibility will surely be developed and inverstigation of better devices can naturally be expected to help more potential to appear.

When it comes to evaluating the applications, technical criteria can be extended. More assessment can be done to evaluate the long term efficiency of the devices and application and some other crtieria can be introduced that measure the difficulties in development phases of augmented reality applications. This would help create a more comprehensive understanding of the potential of such methods and tools.

Regarding the human criteria, surveys that are conducted with more people can be done, in order to obtain a larger sample size. This would ensure a more confident and reliable information about the factors that affect user's perception of the applications. Number of criteria can also be increased with some additions that measure different aspects of practical use of the system.

To sum up, there is a very important potential for what can be done with VR, AR and MR; as the know-how and technology will only advance from current status, as well as mutlimedia cartography. Therefore, the combination of two fields can be expected to bring along new applications, which opens new possibilities for research in the area.

6 Conclusion

In this chapter, a summary of the thesis will be presented as well as a discussion of results. Research questions stated in the first chapter will be reviewed and the degree with which these questions werw answered successfully will be stated. Next, comments will be made on the difficulties encountered during the research and what can be extracted from this research for the field of cartography and future researchers.

The first research question asked about the characteristics of mixed reality devices. First of all, research done in the field was presented using concepts known as virtual reality, augmented reality and mixed reality. As a result, different time periods and different aims made way for devices with different capabilities and technologies. To narrow down the research area, Microsoft HoloLens is selected as the device of choice. Therefore, this question was answered within the scope of capabilities of HoloLens. After a general overview, the properties of the device was given. Next, input methods such as gaze, gestures voice etc. were explained. Concept of holographic remoting is also discussed. As a result, first question of the research is answered to a large extent.

Second question referred to the main body of the thesis. The main motivation of the research, which is to find possible cartographic applications that can be integrated with mixed reality devices, is mainly answered by applications that are already developed either fully or as prototypes. In order to be able to answer this question, a methodology is created. This methodology used criteria that aims to first classify applications into two groups. First group, what can be called the main group of applications, are ones that are discussed in detail in fifth chapter. Members of the second group are explained as further examples. For assessment of the first group, two classes of criteria are created, being technical and human ones. By using these criteria, three different applications, Skype for HoloLens, HoloTerrain and HoloTour were evaluated. Two tables were created for each applications, referring to two groups of criteria. As a result, all three applications obtained a score of "High" from most of the criteria, and "Medium" from the others. Therefore, it is deduced from these assessments that these three applications are good potential applications of mixed reality in the field of cartography. Another section containing three different applications which are not fully assessed are included as extra knowledge. Those examples were explained more simply, rather than being put into a detailed evaluation. All in all, the main research question of this thesis was answered to a certain degree by using research done in the area and human surveys conducted.

Last two research questions refer to the problems encountered during the development and usage of the application as well as methods to overcome those problems mentioned. In order to answer this question, the parts of the process that was not included in this research should be observed. One of the difficulties encountered is the amount of research regarding the topic of this thesis. Being a newly advancing field, there is not a large collection of research readiliy avilable to use. Therefore, practical examples were mostly considered as means of obtaining data related to cartographic mixed reality applications. Another limitation was the lack of three-dimensional geodata that is ready to use with the HoloLens. Some attempts to use the data in hand failed, therefore, no new applications could be developed, which resulted in a more intensive focus on the existing applications.

Finally, the ultimate result that be extracted from the entirety of this master's thesis can be argued to be that mixed reality devices carry a great potential when it comes to developing methods that can be within the context of cartography, specifically cartographic visualization and navigation. Mixed reality can be helpful for various different disciplines and fields such as education, architecture, security, military, entertainment, disaster protection and relief, city planning etc. Most of these areas can benefit to a great extent from cartography when used in cooperation with such devices in order to create a more immersive, effective, intuitive experience, as discussed and evaluated to a certain level by this master's thesis.

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APPENDIX

Below is the survey conducted with 11 participants, 7 males and 4 females, all between 20-30 years old, from various backgrounds. No other questions have been asked other than 4 questions shown below.

SURVEY QUESTIONS

Thank you for participating in this user test that I conduct for my thesis project. Here, I will introduce you to Microsoft HoloLens and show you some applications on it. At the end of each application I will ask couple of questions. Do you have any questions?
If everything is alright, then let's start!

- Please describe your thoughts out loud throughout the whole experience.

<u>After the application had been tested:</u>

Did you feel motion sickness? How would you rate the level of discomfort regarding motion sickness?

- *Please write a value between 0 (no discomfort at all) and 10 (highly disturbing)*

How long do you feel you can work with this device using this application before needing a break?

- Up to 15 mins
- 15-30 mins
- More than 30 mins

How long, in total, do you feel you can work with this device using this application?

- Up to 1 hour
- 1-3 hours
- More than 3 hours

How would you rate the quality of user experience?

- *Please write a value between 0 (totally unusable) and 10 (no issues at all with user experience)*

SURVEY RESULTS

Skype for HoloLens

Did you feel motion sickness? How would you rate the level of discomfort regarding motion sickness?
Please write a value between 0 (no discomfort at all) and 10 (highly disturbing)

- 5 participants answered “0”
- 1 participant answered “1”
- 3 participants answered “3”
- 1 participant answered “2”
- 1 participant answered “8”
- **Average value: 1.8 points out of 10**

How long do you feel you can work with this device using this application before needing a break?

- Up to 15 mins (4 participants)
- 15-30 mins (7 participants)
- More than 30 mins (0 participants)
- **Participants answered “15-30 mins” or “More than 30 mins: 7 out of 11**

How long, in total, do you feel you can work with this device using this application?

- Up to 1 hour (3 participants)
- 1-3 hours (6 participants)
- More than 3 hours (2 participants)
- **Participants answered “1-3 hours” or “More than 3 hours”: 8 out of 11**

How would you rate the quality of user experience?
Please write a value between 0 (totally unusable) and 10 (no issues at all with user experience)

- 3 participants answered “5”
- 4 participants answered “6”
- 1 participant answered “8”
- 3 participants answered “9”
- **Average value: 6.7 points out of 10**

HoloTerrain

Did you feel motion sickness? How would you rate the level of discomfort regarding motion sickness?
Please write a value between 0 (no discomfort at all) and 10 (highly disturbing)

- 4 participant answered "0"
- 1 participant answered "1"
- 3 participants answered "3"
- 3 participants answered "5"
- **Average value: 2.27 points out of 10**

How long do you feel you can work with this device using this application before needing a break?

- Up to 15 mins (4 participants)
- 15-30 mins (7 participants)
- More than 30 mins (0 participants)
- **Participants answered "15-30 mins" or "More than 30 mins: 7 out of 11**

How long, in total, do you feel you can work with this device using this application?

- Up to 1 hour (4 participants)
- 1-3 hours (6 participants)
- More than 3 hours (1 participants)
- **Participants answered "1-3 hours" or "More than 3 hours": 7 out of 11**

How would you rate the quality of user experience?
Please write a value between 0 (totally unusable) and 10 (no issues at all with user experience)

- 5 participants answered "6"
- 4 participants answered "9"
- 2 participants answered "10"
- **Average value: 7.8 points out of 10**

HoloTour

Did you feel motion sickness? How would you rate the level of discomfort regarding motion sickness?
Please write a value between 0 (no discomfort at all) and 10 (highly disturbing)

- 4 participants answered “8”
- 4 participants answered “5”
- 3 participants answered “1”
- **Average value: 5.00 points out of 10**

How long do you feel you can work with this device using this application before needing a break?

- Up to 15 mins (4 participants)
- 15-30 mins (6 participants)
- More than 30 mins (1 participant)
- **Participants answered “15-30 mins” or “More than 30 mins: 7 out of 11**

How long, in total, do you feel you can work with this device using this application?

- Up to 1 hour (7 participants)
- 1-3 hours (3 participants)
- More than 3 hours (1 participant)
- **Participants answered “1-3 hours” or “More than 3 hours”: 4 out of 11**

How would you rate the quality of user experience?
Please write a value between 0 (totally unusable) and 10 (no issues at all with user experience)

- 3 participants answered “4”
- 2 participants answered “5”
- 3 participants answered “6”
- 3 participants answered “9”
- **Average value: 6.09 points out of 10**