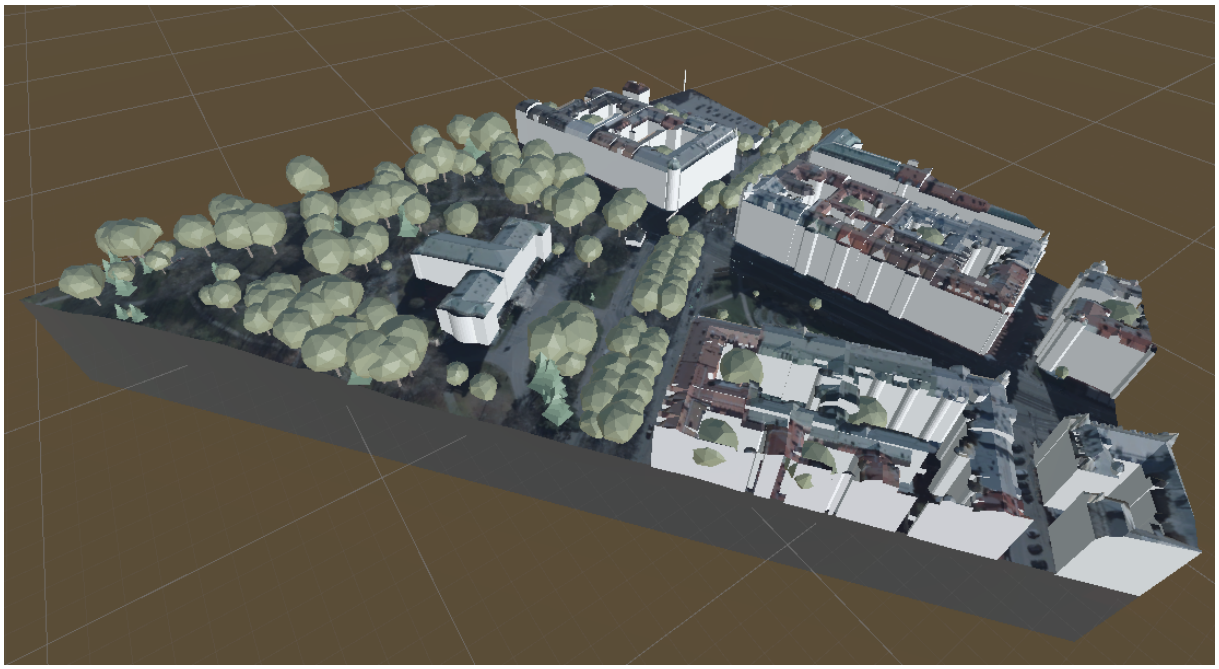

The Gothenburg riots in virtual reality

A reconstruction of a historical event

Master's thesis in Computer science and engineering

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Cover: Excerpt of Vasaplatsen from Gothenburg's digital twin imported to Unity.

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Abstract

The shooting at Vasaplatsen during the Gothenburg riots in 2001 has become known for several reasons, the main one being the misrepresentations in the prosecutor's evidence that was used against the protesters. This master thesis aims to create a proof of concept in the form of a reconstruction of the Vasaplatsen shooting and allow users to experience it in virtual reality (VR). VR today allows us to participate in unique events without physically being there. It also makes it possible to experience what has already happened.

The thesis has included several steps in determining which parts of the shooting can be reconstructed to make it resemble the real event and if this contributes to more knowledge about the shooting. We have also looked at what is important when reconstructing a historical event and if it is possible for these types of reconstructions to be used for crime investigations.

The final VR reconstruction is 2 minutes and 10 seconds, showing the shootings at Vasaplatsen. It is based on an already-made reconstruction by the Swedish director Göran du Rées, who created a documentary using collected images and videos from the event. In our VR reconstruction users can relive the moments before and when Hannes Westberg gets shot by the police as if they were there. The thesis has focused on presence and immersion, and to understand important aspects of when recreating a real event in VR. The report discusses these based on literature and our experiences developing the VR experience. Furthermore, to create a basis for future work, user tests were carried out at the end of the project to gather improvement suggestions.

Keywords: Virtual reality, Reconstruction, Historical event, User experience, Interaction design, Unity, Gothenburg riots

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Kalle Areschoug & Romina Asadi, Gothenburg, May 2023

Glossary

1. Reconstruction - To rebuild an artefact or events.
2. Göran du Rées - Swedish director and lecturer whose video reconstruction we based our work on.
3. Forensic visualisation - Animations and simulations created to answer critical questions, for example in crime investigations.
4. Virtual reality - A computer-generated simulation created to immerse users into a virtual 3D world.
5. Fidelity - How correct the virtual experience is in relation to the original event or object.
6. Immersion - How well reality is shut out with the help of VR software and hardware when being in the experience.
7. Presence - Being in a place that one knows is virtual and fictitious, but reacting to what is seen and heard as if it were real.
8. Locomotion - How to move in VR
9. Marker-based motion tracking - Track human motion through sensors placed on the body
10. Markerless motion tracking - Track human motion with computer vision techniques
11. Cultural heritage preservation - The act of keeping and conserving cultural manifestations
12. Digital twin - 3D model of a physical object, for example a city
13. Mixamo - Online library with premade 3D characters and animations
14. High poly - Refers to the number of polygons in a 3D model. The higher number, the denser mesh.
15. Prefab - Base game object in Unity that one can use instances of.
16. 3D-sound - Sound sources placed out at different locations in the VR world

Contents

1

Introduction

"Gothenburg riots", or in Swedish "Göteborgskravallerna", happened 14-16 June 2001 during an EU summit [1]. The riots were initially peaceful demonstrations in different areas in Gothenburg, but in some cases, for example at Vasaplatsen it escalated to violence between the protesters and the police. This resulted in the police firing against the demonstrators at Vasaplatsen [2, 3, 1, 4]. One person that got injured was Hannes Westberg, who was later convicted of violent rioting [2]. In retrospect, it has been shown that numerous factors resulted in chaos during the event [4]. The demonstrators reacted strongly to the barricading of the Hvitfeldtska gymnasium, which will be discussed further on. It is also revealed, among other things, that the police's internal communication did not work, and they had to rely on the media's reporting [4].

During the many court cases that followed, one of the pieces of evidence that was used was a reconstruction of the riots, created by the prosecutor [2]. It was created with clips filmed during the event by the public and reporters. In this reconstruction, the shooting against Hannes was one of the things that were misrepresented, which received a lot of attention. The prosecutor used the reported media material and created a biased image of the event in favour of the police. Despite this, the reconstruction, together with other material from the police, was used during several trials [2].

Apart from the Vasaplatsen shooting being interesting from a crime perspective, it is also fascinating from a historical and cultural point of view. There are numerous reasons for this, for example, that it is an event still talked about and that it was the first time a sitting American president visited Sweden [5]. In addition, it was also the first time since the shootings in the Ådalen, 1931, that the police fired at demonstrators in Sweden [6].

Du Rées [2] explains that the Gothenburg Riots were one of the most filmed events at the time. Still, due to the lack of long uninterrupted single-take sequences and numerous media sources (video recordings in standard definition (SD) resolution), credible retelling has proved difficult. Both du Rées [7] and Granström [4] agree that these were the main factors that caused misrepresentations in the prosecution's clip. It made it difficult to determine if the sequences were in chronological order and if they were from the same event and time. As a result, questions regarding the credibility of the evidence and how it could have affected the verdicts have

been raised [2]. This is according to Chisum et al. [8], who means that creating reconstructions is a difficult task, where it is easy to place out the different events sequentially but much harder to start reading between the lines and understand the whole picture [8].

As a result, Göran du Rées created a new reconstruction of the event. Du Rées analysed the prosecution's film and created a more authentic version in his documentary "Skotten på Vasaplatsen" [7, 2]. Du Rées uses video clips from six different reliable media sources. These clips were synchronised and documented the event from various locations throughout its course [7, 2]. Among other things, it is noticed that in reality eight shots were heard, but in the prosecutor's clip, it was only six. It was also noticed that the sound of specific media sequences in the prosecutor's clip had been manipulated and used to make the event seem more dramatic [7].

Reconstruction is one of the steps in crime investigation [9, 8, 10]. It is a common practice of gaining knowledge and evidence about what happened during a crime, how and when it happened and who was involved [9, 8, 10]. In the examples above, film clips have been used, but according to Flor et al. and Ma et al. [10, 11], it can also be done in other ways. For example, one can create a 3D model of the crime scene in modelling software and then make it possible to experience it in virtual reality (VR) [10, 11]. By making the crime scene in VR, the user can navigate the virtual world and observe the crime scene from different viewpoints and perspectives [11].

1.1 Purpose and research questions

Du Rées [2] mentions that uncertainties remain surrounding the incident and the legal processes afterwards. Therefore, to contribute to a more objective and immersive representation of the event, this thesis aims to implement interaction design by creating a new reconstruction of the event and combining it with VR technology. This will let the users explore the events themselves and will help them create their understanding of what happened that day, which in turn goes hand in hand with the historical and cultural perspective. To accomplish this, the following research questions will be aimed to answer:

1. RQ1: Which aspects of the Vasaplatsen shootings in 2001 can be reconstructed using VR technology?
    (a) Sub RQ1: What is the most efficient and reliable way of implementing motion tracking of people in VR from a real-life event?
    (b) Sub RQ2: Which factors are relevant to consider when reconstructing a real event in VR?
    (c) Sub RQ3: What aspects are important to create a high immersion and presence in virtual reality?
2. RQ2: Can a VR reconstruction of a crime scene contribute to an increased

understanding of the event?

1.2 Delimitations

The project has the following delimitations:

- The Gothenburg riots consisted of several events, but this report will only focus on the shooting at Vasaplatsen.
- The final product will be based on the documentary by du Rées and no further search will be made for other video material from the event.
- Our focus will be to create a proof concept that can act as a basis for further work.

1.3 Related work

When creating reconstructions, it is essential to have the correct data, especially if the reconstruction is used in crime investigations [12]. In addition, there are two important factors to consider, the first being the accuracy level. Many parameters must be considered when creating a reconstruction to make it realistic. Not only does the event itself need to be created precisely but details before the event needs to be investigated [12]. The second factor is that the reconstruction cannot stand independently in a forensic investigation. There must be complementary evidence, especially since pictures and videos are more likely to impact a jury [12].

Reconstructions can be done in different ways, not only in crime investigations but also for educational and cultural purposes. Below variants will be presented, these are only some of many.

1.3.1 Dramatisation

On July 22, 2011, Norway was hit by two terrorist attacks by the right-wing terrorist Anders Behring Breivik [13, 14]. The first attack occurred in the Oslo government district, where a bomb was detonated. The second act occurred in Utøya, where the assailant ruthlessly murdered 69 people, mainly young adults and children [13, 14]. In total, 77 individuals were killed during both attacks, and 319 were injured [14]. Six years after the attacks, the creation of the documentary "Reconstructing Utøya" begins. The documentary is based on reconstructing and dramatising four survivors' memories of the attack [14].

In the documentary, scenes shown describe the course of events until friends and family of the survivors are shot and how they themselves escaped. It is worth mentioning that the documentary contains modifications, for example, towards the end where a school disco takes place to give a positive twist to the documentary. However, this disco never occurred in reality because of the attacks [14].

1.3.2 3D-modelling and animation

3D animations have been discussed and used in crime investigations to understand cases better. Reconstructions of car and motorcycle accidents have been created to give a picture of the accidents for juries in court cases [12]. One terrorist attack partially reconstructed by 3D modelling and animation is the truck attack by IS terrorist Rakhmat Akilov on April 7, 2017, on Drottninggatan in Stockholm [15, 16].

The animated 3D reconstruction showing the truck's 1,063-meter-long path was made by the Swedish National Forensic Center (NFC) and is the first of its kind to be used in a Swedish legal process [17, 16]. In the reconstruction only objects, vehicles and buildings are visible, and the truck is driving the same route and speed as the police described in their preliminary investigation [17, 18].

The animation film aims to create an overview of the course of events, facilitate the legal processes and create educational material [17, 16]. By creating a 3D model, investigators can return to the digital version of the crime scene for further investigations. The model can also, together with materials such as images and videos, create a credible basis in legal proceedings. It also provides the opportunity to experience the event by entering the virtual environment [16].

1.3.3 Virtual reality reconstructions

There have been many reconstructions of historical buildings in VR [19]; some examples will be presented in this section.

1.3.3.1 Nefertari: Journey to Eternity

One of the more successful reconstructions is "Nefertari: Journey to Eternity" [20]. The VR experience was developed by Experius VR and was released in 2018. "Nefertari: Journey to Eternity" is a reconstruction of the tombs of Queen Nefertari, where the user can explore the tombs in VR and see how they looked 3000 years ago. The user can interact with different hieroglyphs and get audio historical accurate facts about the hieroglyphs, Queen Nefertari, and the ancient Egyptian gods and goddesses [20].

The VR experience was created by digitally reconstructing the tomb with the help of 360 cameras and scanning [20]. One of the most substantial advantages of this VR experience is the detailed and meticulous recreating of the tomb and the hieroglyphs. Since the VR experience is based on a small room, the developers had to be creative when filling the room with intractable artefacts and objects.

1.3.3.2 The Night Cafe: A VR Tribute to Vincent van Gogh

The Night Cafe: A VR Tribute to Vincent van Gogh which explores virtual reality and culture creatively [19]. It was developed by Borrowed Light Studios [21] and was released in 2016. The VR experience allows the user to explore Vincent van Gogh's painting "The Night Cafe". Unlike other cultural VR experiences, The Night

Cafe lets the user enter the painting and explore the picture from within. This is an interesting way of exploring VR as a medium. The opportunity to not only observe the painting and see it in 2D, but users can also now travel into the colourful world of the painting.

There are some problems with this kind of VR recreation, however. One of them is the creative freedom the developers take when creating an experience similar to this one. The developers studied the painting and other impressionist paintings [21], but they still had to add new material to the painting and world. This dilemma opens the door to the question we struggle with and discuss in this thesis; how far from the objective truth can a developer stray when recreating an object that exists in real life?

1.3.3.3 Anne Frank House VR

On Steam, there are many art museums and recreation applications allowing the user to explore different cultures [19]. One example is "Anne Frank House VR", where the user can walk through the house Anne Frank lived in, interact with items, and be told about the life of Anne Frank. They utilise virtual reality to conserve the life of Anne Frank while making sure it is available for everyone [22].

2

Background

Even though the shooting at Vasaplatsen is perhaps the most infamous event from the Gothenburg riots, it was not the only event during the demonstrations [23, 24].

The Gothenburg riots were one of many large demonstrations in the EU during the early 2000s. There were already riots associated with demonstrations in Nice, Seattle, and Prague in protest against the European Union (EU) [25]. The Swedish government and the city of Gothenburg wanted to avoid the conflict and escalation that had happened in the other cities. Due to this, they started to have a dialogue with the organisers of the different demonstration factions one year before the EU summit. Up until the EU summit in Gothenburg, many believed that all the demonstrations would be peaceful [25]. However, the outcome of the demonstrations were mixed, where some demonstrations were successful while others, like the one at Vasaplatsen, escalated to violence.

The reason for the demonstration was mainly due to two factors. The primary reason was the dissatisfaction against the EU that was wildly spread at the time. People feared losing their voice and influence over the decisions and politics if the EU took too many decisions. The secondary reason was the then-sitting president of America, George W. Bush, visiting the summit. This was the first time a sitting president was visiting Sweden. There was also a widespread discontempt against the USA generally, and the president specifically in Sweden [25, 23, 24]. These factors lead to many thousand people gathering in Gothenburg during the days of 14-16 of June 2001.

2.1 Events during the riots

Our thesis focuses on the shooting at Vasaplatsen, but five more noteworthy events took part during the Gothenburg riots that influenced the outcome and are relevant to be familiar with. These are:

1. The barricading of the Hvitfeldska gymnasium.
2. The demonstrations at Götaplatsen.
3. The march towards The Swedish Exhibition & Congress Center.

4. The demonstrations at Järntorget.

5. The storming of Schillerska gymnasium

2.1.1 The barricading of the Hvitfeldska gymnasium

The first event speculated to have raised tension between the demonstrators and police, happened at the Hvitfeldtska gymnasium [26]. The school was one of sixteen that accommodated demonstrators who did not live in Gothenburg and needed a place to stay. Around 500 people stayed at Hvitfeldtska, mainly young adults. On the morning of the 14th of June, the police barricade the school with containers prohibiting anyone from leaving the area. Despite this, some demonstrators tried to leave, and in return, they had to turn over their belongings to the police and got were searched. The demonstrators that decided to stay at the school were kept there for roughly 24 hours. The police later stormed the school, arrested everyone still left, and kept them overnight [26, 23, 24].

2.1.2 The demonstrations at Götaplatsen

At the same time as the demonstrators were kept under lockdown at Hvitfeldtska, a demonstration against President Bush was happening at Götaplatsen [23]. Around 12 000 people joined the demonstrations in protest against USA and President Bush. During this demonstration, there was no altercation between the protesters and the police, and everything went as planned and peacefully [24, 23]. Two more demonstrations similar to this one took place, each including over 10 000 people, they were also successful and peaceful. [26].

2.1.3 The march towards The Swedish Exhibition & Congress Center

The third major event happened on the morning of the 15th. Unauthorised demonstrations were held at Götaplatsen and had plans to march toward The Swedish Exhibition & Congress Center, where the EU summit was happening [26]. The demonstrators moved close to Exhibition & Congress Center, where the police had created a defensive line. When the demonstrators got close to the police line, violence arose and the two parts clashed. The police pushed the demonstrators back towards Götaplatsen, where a group of protesters broke free from the rest of the demonstration. The group contained individuals from the faction "Svarta Blocket", known by the police for using violence [26, 25]. The faction moved down on Avenyn and caused havoc on stores, outdoor seating, and shop windows, of a value of several million Swedish kronor [23].

2.1.4 The demonstrations at Järntorget

The fourth event that got attention afterwards was the demonstrations at Järntorget. On the evening of the 16th of June, a couple of hundred people gathered for a peaceful unauthorised demonstration against the police brutality that had occurred

the previous days [23, 25, 24]. The demonstrators stayed at Järntorget to show solidarity against the people taken into custody. The police were quickly there and established a ring around the demonstration. After a while, the protesters were allowed to leave on the condition that they should be searched and checked for Swedish citizenship [23]. Roughly half of the protesters did, while the other half stayed. The demonstrators remained peaceful and made no aggression. After another couple of hours, the executive police on site got tired of keeping the peaceful demonstrators on lockdown. Without authorisation from his bosses, he released the rest of the demonstrators without repercussions [25].

2.1.5 The storming of Schillerska gymnasium

As Hvitfeldtska, Schillerska was a school where demonstrates lived and slept during the event. During the evening of the 16th of June, the police and the national task force stormed the school Schillerska gymnasium [23, 26]. The police had heard rumours about a German terrorist staying at Schillerska [26]. The task force and the police took around 80 people who were forced down onto the ground. The people had to stay on the ground with little clothes for 45-90 minutes [23]. There are accounts of the police saying racist and degrading terms to the demonstrators. Just as they did at Hvitfeldtska, the police left Schillerska empty-handed, as they did not find any German terrorist [26, 23]. Many demonstrators reported being shocked and traumatised during and after the event [23].

3

Theory

This chapter will explain the applicable theory for this master's thesis. It will begin by exploring factors to consider when using images as evidence, followed by an explanation of virtual reality and how one can create an immersive and rich experience for the user.

3.1 Virtual reality

According to Kardong-Edgren et al. [27], there is no unifying definition of virtual reality for academic and educational purposes. However, Merriam-Webster [28] proposes the following general definition: *"an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment"*. Something certain, however, is that virtual reality is continuing to develop and is now in its second wave of innovation where new technologies and methods are being developed [27]. Examples are updated hardware such as new headsets or so-called head-mounted displays (HMD) [29], which will be used in this thesis.

Several factors make a successful VR experience; fidelity, immersion and presence [27]. Examples of situations where these factors are included when using VR are in therapy and training [30]. Patients can be exposed to their fear or phobia, and the military can train in urban areas without physically being there. Each factor will be discussed more thoroughly below.

3.1.1 Fidelity

Fidelity in the context of virtual reality can be explained as how correct the virtual experience is in relation to the original event or object [31, 32]. It can be split into multiple categories, such as display, physical and psychological fidelity [32, 33]. Display fidelity refers to the computational optimisation of the experience, display size and resolution [33]. Physical fidelity refers to how well the objects replicate the real object [32]. Psychological fidelity is how well the experience creates psychological effects in the user, such as stress and fear.

3.1.2 Immersion

Immersion in virtual reality is about the level of sensory fidelity that a VR system provides, or in simpler words; how well reality is shut out when being in the experience, how many of the human senses are involved and with what quality [30, 32, 34]. Immersion is objective and measurable, where two systems can have different levels of immersion [30, 32, 35]. It is a VR system's hardware and software that determines the level of immersion, such as display size, display resolution and field of view (FOV) [30, 32, 34]. Immersion in virtual reality consists of different parts that must co-exist to optimise the result [32].

3.1.3 Presence

The third building block in virtual reality, presence is about being in a place that one knows is virtual and fictitious, but reacting to what one sees, hears and does as if it were real [36, 30, 35, 34]. In contrast to immersion, presence is subjective and therefore hard to measure [37, 34]. Factors affecting presence include graphics, level of realism, sound, and range of movement [36, 34]. As a result, one can conclude that increased psychological fidelity and immersion can lead to increased presence [27, 34]. An example of when the user experiences presence is by having an avatar or seeing one's hands in the virtual world and being able to interact in the virtual world with them [34].

3.1.4 Movement in virtual reality

When designing for VR, one important aspect is how to move in the experience, the so-called locomotion [38, 39]. There are many ways to implement locomotion in a VR experience. A recent comparative study found at least 22 established methods of locomotion in VR [39]. Some of the more common ones are using a joystick, pointing and teleporting, moving in place, and flying. The decision of which method to use affects the user experience and can be difficult when designing a new VR experience. Locomotion can help make the experience more fun, easier to understand, and prolong the time the user can stay in the experience without feeling motion sickness [40].

A common side effect of using VR is motion sickness [41]. Users experience motion sickness because the brain cannot comprehend that their body is still in the room while in the headset, they are moving. This results in the brain receiving conflicting signals, which in turn is what causes nausea [42, 41]. Some methods of locomotion have been shown to decrease or delay the feeling of motion sickness [43]. One of these methods is pointing and teleporting, which is a target-based motion where the user decides on the destination, and the system handles the movement [43, 38]. In addition, the feeling of teleporting is reported as futuristic and resembles science fiction, which is appreciated by the users [43].

Pointing and teleporting is best used when the VR experience has a vast area to explore, and the user does not need to manoeuvre around any obstacles [40]. Using

a joystick as locomotion is better suited in a more high-paced VR experience where decisions must be made quickly.

3.1.5 Selection in virtual reality

Being able to interact with objects is an important part of VR and has a significant effect on the result [38]. According to Bowman et al. [38], the most common way is to have virtual hands that move with the hand trackers one holds. The difficulty, however, is that objects far away cannot be reached. For this reason, ray interactors have been developed to act as an extension of the user's hand [38, 44]. In combination with scripting, in other words, short pieces of code, rays and hands can be used to interact with the virtual world [45], see Figure 3.1.

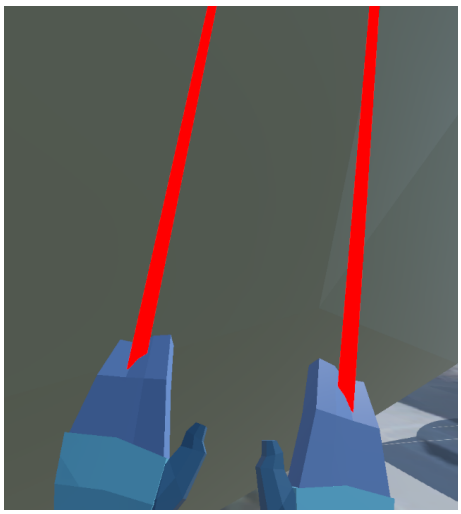

Figure 3.1: Hands and rays in Unity

3.1.6 User interface in virtual reality

Designing a user interface (UI) for 3D such as VR differs from a UI on 2D platforms such as desktops and mobile phones [46]. UIs for 2D platforms have gone through many iterations, and paradigms have been established. This is not the case for UI in VR. However, some recommendations and principles from classical UI design apply to VR, but there are big differences when designing in 3D compared to 2D [46].

Depending on what type of VR experience is being developed, the UI has to be customised for the experience. Doerner et al. [46] propose two types of UIs; natural UI and magical UI. Natural UI is more suited for realistic VR experiences, where the developers aim to resemble the real world as much as possible. The natural UI means that the user can only interact with objects close to the user, just like in the real world. Magical UI, in turn, means that all limits are off, where the users can, for instance, extend their arms beyond realistic proportions to interact with an object.

3.1.6.1 Placement

There are two ways of displaying the UI: screen space and world space [47]. In the first case, interface elements are placed directly on the user's field of vision, while in the second case, interface elements are placed in the 3D world. World space UI is preferred since the elements do not block the user's field of vision [47].

Furthermore, according to Bowman et al. [38], one of the main problems in the 3D world is that actions become more difficult as one gets more degrees of freedom. Selecting something in a menu that floats in the 3D world is more challenging than having a menu on a surface.

3.2 Motion tracking

Motion tracking of humans involves capturing and digitising real people's bodies and facial movements. These digitised versions can then be used within, for example, the film and gaming industries [48]. There are many different ways to motion track, but they are often divided into two main groups; marker-based and markerless [49].

3.2.1 Marker-based tracking

Marker-based means that sensors are attached to the human body, and with the help of advanced cameras and software, the movements are documented [49, 48]. This type of tracking gives a reliable and detailed result, but the equipment makes it complex and expensive [48].

3.2.2 Markerless tracking

Markerless tracking does not depend on sensors but instead uses computer vision techniques, namely depth cameras and computer algorithms, to document movements [49, 50, 48, 51]. The depth cameras combine colour and depth to perceive movement in a 3D environment, while the algorithms use deep learning and cameras to identify key parts of the human body, such as joints, to document the movements [48, 51].

Markerless tracking is more accessible to people because there is no need for expensive equipment [48]. However, it is less reliable as one cannot reach the same level of detail as marker-based [50, 48].

3.3 Managing uncertainties

During this thesis, there will be cases in the reconstruction where we need to deal with uncertainties. This may apply to uncertainties regarding the characters' positioning, appearance and actions. For this reason, it is relevant for us to look more closely at how these uncertainties can be communicated to the user.

A recommended way is to work with so-called visual cues such as markings in the image to communicate metadata [52, 53]. Metadata, in this case, refers to the level of uncertainty. Some examples are flickering, grayscaling, colours, sizing and blurring, which can be applied to one object, several or the whole scene [52, 54, 53]. A higher degree of uncertainty can be visualised with faster flickering, more gray- or colour scale, more significant size change, or more blurring [52, 54].

However, there are disadvantages to the methods, where, for example, flickering can result in visual fatigue and be difficult to interpret [55, 52]. Colour and grayscale, in turn, can also be challenging to interpret, and they also depend on the starting phase of the object [52]. For example, it is difficult to desaturate an object already in grayscale from the start. It is also complicated to understand how users will experience an applied colour filter [52].

Furthermore, two general difficulties when visualising uncertainties are distraction and precision [52]. Distraction is a matter of whether one wants the uncertainty to attract the users' attention or not. Is the aim to make the user focus and notice the uncertainty or to look past it? Precision, in turn, is about what parts of the object are uncertain and how many parts. An example brought up by Westin and Eriksson [52] is a railing they have to reconstruct in their project aimed at creating a visualisation of the Sanctuary of Hercules Victor in Tivoli. The position of the railing was certain, but not the material. In that case, by marking the object as uncertain, there was no way to communicate to the viewer which part of it was uncertain.

3.4 Cultural heritage preservation

One area of VR that has exploded in terms of applications since the hardware became more accessible is cultural heritage preservation [19]. Cultural heritage preservation is the act of keeping and conserving cultural manifestations. The aim is to preserve the object's physical and cultural characteristics to ensure that it will outlive us and that its value does not dwindle [56]. VR offers new opportunities to preserve historical events and cultural traditions by reconstructing them digitally. This opens up the possibility of preserving and exploring the culture that otherwise would be sealed off due to distance and price.

3.5 Copyright

The proof of concept created in this thesis will be based on material from other people's work, namely video sequences from the documentary by du Rées [2] based on clips from various media sources. The resources that will be used are from either documentaries or private persons, and thus it is essential to consider copyright and intellectual property.

Two laws that may be relevant are the right of use (nyttjanderätten) and the right of citation (citationsrätten). The former means the law protects original creations,

and the creator is the owner (SFS 1960:729) [57]. The latter means that everyone is allowed to cite from the creations as long as that is done in good faith and that it is done to the extent that it motivates the purpose (SFS 1960:729, cha 2. 22 §). There is also a need for good practice (in Swedish "*med god sed*") when working with copyright. This means the creator and source should be referenced in context with the creation. Further, the reference must be done in a way that does not change the meaning of the creation (SFS 1960:729, cha 2. 22 §).

During this thesis, we will recreate a new and unique variant of a historical event where parts are built on another person's "creation". Our guess is that it should be within the framework of the right of citation, the right of use and good faith. However, there are still uncertainties, which is why this needs to be investigated further. According to Journalistförbundet [58], joint copyright can be created if permission is obtained from the original creator, where the material may be used and modified. In short, a solution could be contacting Göran du Rées or Uppdrag Granskning for permission to use their clips.

3.6 Images as credible evidence

It has become increasingly more common for images and video to be used in forensic investigations [59]. Images and videos are data-rich sources for understanding our world [60]. When used as evidence, it is important that they are of good quality and demonstrates their purpose to feel truthful.

To avoid bias when interpreting images and videos, it is, among other things, important that the clips are presented with context so that we can be sure they have not been misused [60, 61]. Context can be conveyed through, for example, supplementary text, narrative or with the help of other images. However, according to Granot [61], the viewer's subjective opinion can still create a conscious or unconscious bias when video or images are presented as evidence during trials. This is because they provoke more feelings than other pieces of evidence. For this, there is still no good solution today.

In his documentary, du Rées based the creation of his reconstruction on six different steps [7, 2]. These are presented below, followed by a brief description together with reinforcement from other sources:

1. **Original materials and equipment must be verified** - When film and sound sequences are edited and combined, it must be possible to return to the original material and source.

2. **The creators' intentions must be clearly stated** - When we watch a clip, it is important to understand the sender's goal and purpose. What are they trying to accomplish with the photo and video they took? This is reinforced by Granot et al. and Mathison [60, 61], who also believes it is easy to modify and manipulate images to achieve a specific feeling or redirect attention.

3. **Space and location must be clearly described** - To enable us to locate ourselves when we watch a clip, camera angles and location must be clearly described. Mathison [60] mentions that this is also important, again for context, as the camera angle shows what the sender felt was worth documenting at the time.

4. **Time must be objectified** - The easiest way to manipulate time in videos is to make the clip longer or shorter. In this way, the time is manipulated without the user noticing. To counteract this, du Rées believes that to the extent that it is possible to have single-sequence shots from the event to objectify time.

5. **Use black boxes at each clip** - In cases where it is not possible to use single-sequence clips, black boxes should be used to indicate clip changes.

6. **Call in experts when the image is to be used as evidence** - People in the legal process often have no knowledge of film and images. Due to this, it is vital to call in experts to confirm the film's credibility. Granot et al. believes it may also be relevant to train jurors and lawyers in this area.

3.7 Theoretical framework

The following part will discuss the theoretical framework and start by explaining the basics between the user and a product, then delve deeper into rich experiences and how to achieve them.

3.7.1 Content-Oriented Model of User Experience

The content-oriented model of user experience breaks design into three steps; how, what and why [62]. The three steps are all needed to create an enjoyable user experience. Everything in design starts with the "why"; the needs and envisioned experience of the design. The "what" is the decision of instrumentality and function. The "how" is how the interactions should look and feel [62]. According to Hassenzahl [62], these points must be included in the design to achieve enjoyable products with a good user experience. During the project, we will use the content-oriented model of user experience to the best of our ability to create an enjoyable VR experience.

3.7.2 Reversal theory and designing for a rich experience

Rich experiences are an important design principle to utilise if the designer wants the user to become invested in their product. Humans are dynamic and complex creatures, and a mistake often made by designers is to develop a static product [63]. The reversal theory allows designers to use a more holistic approach to product development. Fokkinga and Desmet [63] propose six design opportunities when designing for rich experiences, where parapathic emotions are essential in two of them. Parapathic emotions in reversal theory mean that every negative emotion has a corresponding positive emotion, and vice versa for positive emotions [63]. When designing for rich experiences, the product can be better if the designers can evoke

both of the corresponding parapathic emotions. One study [64] described numerous stages where a person experiences parapathic emotions, where the one described as *"The scandalous"* will be relevant to this thesis. The scandalous experience occurs when a person experiences something morally ambiguous and unjust (negative emotion), and they become fascinated by the event (positive emotion) [64]. During our experience, the user will see and feel the violence between the protesters and police, which will hopefully evoke ambiguous feelings within the user.

3.7.3 Protective frame

Protective frames are a mental defence mechanism humans utilise to distance themselves emotionally from unpleasant situations [65]. These frames are psychological constructs, which means that it is not about whether a person is physically safe but if she believes she is safe. One of the protective frames, the detachment frame, occurs within a person when they are experiencing something they find scary but know that it is not in their direct vicinity. The protective frame has been used for centuries by authors and movie makers [65]. It lets a person observe an unpleasant occurrence without being part of the event. In our thesis, it will work as a psychological defence mechanism that protects the user from the periodically intense experience.

4

Methodology

During this thesis, different methods will be used. These are explained in detail in this chapter.

4.1 Planning

We will use a Gantt chart for the work process and time management. It is a valuable and efficient tool for planning and providing an overview of project steps and their duration [66, 67]. Following Wadsworth [68], the chart will also be revised after the methods have been decided to ensure that it is relevant and covers all steps in the process.

4.2 Resource gathering

Even though the prestudy and the data gathering are two different process steps, the same methods will be applied; a simplified literature review and the method "Written records, accounts and diaries" [68]. This is to provide general knowledge about the selected area. In the former case books and scientific articles will be collected and summarised to learn from previous research and find related work [68]. During the latter case, historical records such as news articles and other files and documentation from the event will be gathered. According to Wadsworth [68], this data can be indirect evidence of the event. Either way, it is important to be aware that they can be biased depending on the source [68].

4.3 Hardware and software

Two software programs will be used to create a proof of concept; Unity and Blender. The concept will then be experienced in VR with the help of the headset Oculus Quest 2. These are explained in detail below.

4.3.1 Unity

Since its release in 2005, Unity has become one of the most used and best game engines available [69, 70]. Unity's primary focus is to provide various tools for the

developers and supply an easy-to-use engine regardless of skill level. Unity is at the forefront of providing developers with tools and packages for VR development. It has packages for almost every hardware on the market, and they constantly update the engine to keep it up to date with the new technology [69].

A competitor to Unity is Unreal Engine which is in the same price range and has a similar learning curve [70]. The choice between these two was not apparent to us. However, early in the project, we came across well-made tutorials for Unity where they developed VR experiences. We felt this would speed up the software learning process and thus became the deciding factor in choosing Unity.

4.3.2 Blender

Blender is a free and open-source 3D design platform used for the entire 3D modelling process; modelling, rigging, animation, simulation, rendering, compositing and motion tracking [71]. The software can be used by individuals who want to play around with the program, as well as professional studios working in 3D environments [71].

Similar software on the market are Maya and SketchUp. Our choice regarding which one to use was made in discussion with our supervisor, who mentioned that Blender is easier to learn and a better fit for our small-scale project. Furthermore, if we would need help with Blender during the project, our supervisor had knowledge of it. This simplified the process of receiving help, unlike other software, where we would need to rely on online sources.

4.3.3 Oculus Quest 2

This thesis will use a head-mounted display (HMD) which is a fully immersive system [35]. Based on what was presented previously in the sections 3.1.1 *Fidelity*, 3.1.2 *Immersion*, and 3.1.3 *Presence*, this means that the user uses both visuals and sound to get the ultimate experience. The choice regarding which headset to use was based on close dialogue with our supervisor and preference on our part. We were torn between the Oculus Quest 2 headset and the HTC Vive Pro. Although the Vive had better specs, it was more inconvenient to have on the go due to its so-called base stations. These track the user's movements in the room while wearing the headset and holding the controls. For this reason, Oculus Quest 2 was chosen to be tethered with a link cable to a computer to provide better rendering quality.

4.4 Modelling

When working with design, it is essential to communicate ideas clearly to move forward to the next step in the process [72, 73]. One way of doing this is by creating prototypes. By showcasing prototypes to others, evaluating, refining, and improving the concepts will be easier. During this project, prototypes will be created using the software 3D Blender and Unity 3D, which was mentioned previously. These proto-

types will include a 3D model of Vasaplatsen in Gothenburg, a VR user interface, and a VR reconstruction of the event.

4.4.1 Chronological timeline

Timelines are used to display how events unfold in chronological order [74]. Depending on the field of interest, timelines can be used to display aeons of time or a couple of minutes. Either way, the purpose is still the same; show when events occur and highlight key events. This makes it easier for the person looking at the timeline to understand what was important for the event. We used a chronological timeline to keep track of how key persons during the event moved and what actions they took.

4.4.2 Storyboard

To create an overview of the Gothenburg riots, we will create a storyboard with the key scenes we want to include. According to Krause [75], this will be supplemented with visualisations in the form of sketches and short captions. Our storyboard contained five pictures depicting how we wanted to form the experience.

4.4.3 Digital twin

The 3D model of Vasaplatsen in the reconstruction will be based on the digital twin of Gothenburg that is available [76]. A digital twin is a 3D model of a physical object, for example, a city or a process [77], in this case, the city of Gothenburg [76]. The twin is created by the city planning office to facilitate the planning of future projects, understand what consequences these projects may have, and also create a basis for making the city more efficient [77, 78, 76].

4.5 User testing

An essential part of projects is to receive user input regarding the concept to discover future improvements and existing problems [72, 79]. In this project, user testing is also important for gaining insight into how the users think the reconstruction reflects reality and how it affects them emotionally. The aim will be to gather three to five intended users of the product [72, 79]. Through a qualitative approach, the goal will be to gather insights regarding the general experience of using the product [79]. The method applied will be think-aloud, where the users will be prompted to share their thoughts and feelings when using the product [80, 79]. The results from the think-aloud method will be sorted and analysed with the help of affinity diagrams [81].

4.5.1 Think-aloud

To help evaluate the VR experience, the think-aloud method will be used [80]. It is used to evaluate prototypes, where the participants are asked to speak out loud

when trying a product. The method is used to understand *what* is working or not rather than *why* it is working or not. Think-aloud can help developers understand the user's feelings and thoughts about the product. The method is suitable when the product, or part of a product, being tested is narrow [80]. This is the reason we are using it as a method, in addition to it being an adequate evaluation method, since our VR experience is relatively simple. We will note what the users are doing and saying when using the method.

4.5.2 Interviews

To supplement the think-aloud testing, semi-structured interviews will be conducted. Interviews in research can be conducted in structured, semi-structured, or unstructured format [80]. For the user testing, we will be using the semi-structured interview format. Semi-structured interviews are based on questions that are asked to all of the participants. Depending on how the participants answer the questions, the interview can morph from a more clinical conversation to a more conversational and everyday-like one. It all depends on what the interviewee finds interesting. The test leader has predetermined questions they can use if the conversation starts to trail off the subject too much. [80].

4.5.3 Affinity diagramming

Affinity diagramming is a method to sort qualitative data [81]. The persons that partake in the affinity diagramming write down a piece of known information about the product on a sticky note. The notes are placed on a whiteboard when all the information is written down. The partakers then start to sort the notes into groups and start to look for patterns or similarities. After an affinity diagramming session, the tester should have insight into what they are developing and be able to create a plan moving forward [81]. In our thesis, we will use affinity diagrams to structure the data collected from the think-aloud method. The insights will be used to provide notes on what is possible in future work with the project.

5

Execution and Process

Since this thesis is more technical, we have not used a traditional design process with steps such as user data collection or a phase dedicated to ideation. Instead, the project has been based on the clear vision for the thesis: to create a reconstruction of a historical event in virtual reality. However, the process has not been straightforward and linear. There have been many ambiguities regarding the application's design such as motion tracking, locomotion and manipulation of time. The focus has further been on the actual design of the final concept and what level of fidelity it should have. This has consisted of several process steps that will be presented below.

5.1 Planning

Based on previous experience and the fact that the project will contain several entirely new approaches to us, we decided that a Gantt chart would be used for planning the work. This chart was revised several times during the project, and the final version can be seen in Appendix B.

When creating the Gantt chart, we had in mind that some parts could take longer to execute than expected. This primarily concerned steps *"6. Create 3D model"* and *"7. Implement VR in Unity"*. In both of these steps, we would use the software Blender and Unity, which we did not have experience using before. In addition, it was in step 7 that many of the project's ambiguities would take place, for example how the user should move in the experience, how the animations should be implemented and how the 3D model should be combined with the VR experience.

5.2 Prestudy

The process started with a preliminary study where we looked for information about virtual reality, the Gothenburg riots and the design and use of reconstructions today. This resulted in us gaining knowledge regarding physical and digital reconstructions and how virtual reality can be used. We also gained a deeper understanding of the Gothenburg riots, its impact on society and the process of achieving justice.

5.3 Data gathering and analysis

Collecting enough source material was necessary to design the reconstruction in virtual reality. This included, among other things, video footage, pictures from the demonstration, and maps of the place of action. In this step, the documentary "Skotten på Vasaplatsen" by Göran du Rées and its clips from Uppdrag Granskning were of great help [2].

The documentary facilitated the categorisation of material, setting and synchronising time stamps, as well as understanding the positioning of the various cameras filming the event. The camera positioning can be seen in Figure 5.1. The cameras that were most important to us were those in positions 1-2, 4, 6, 8-9 and unknown, see Figure 5.1.

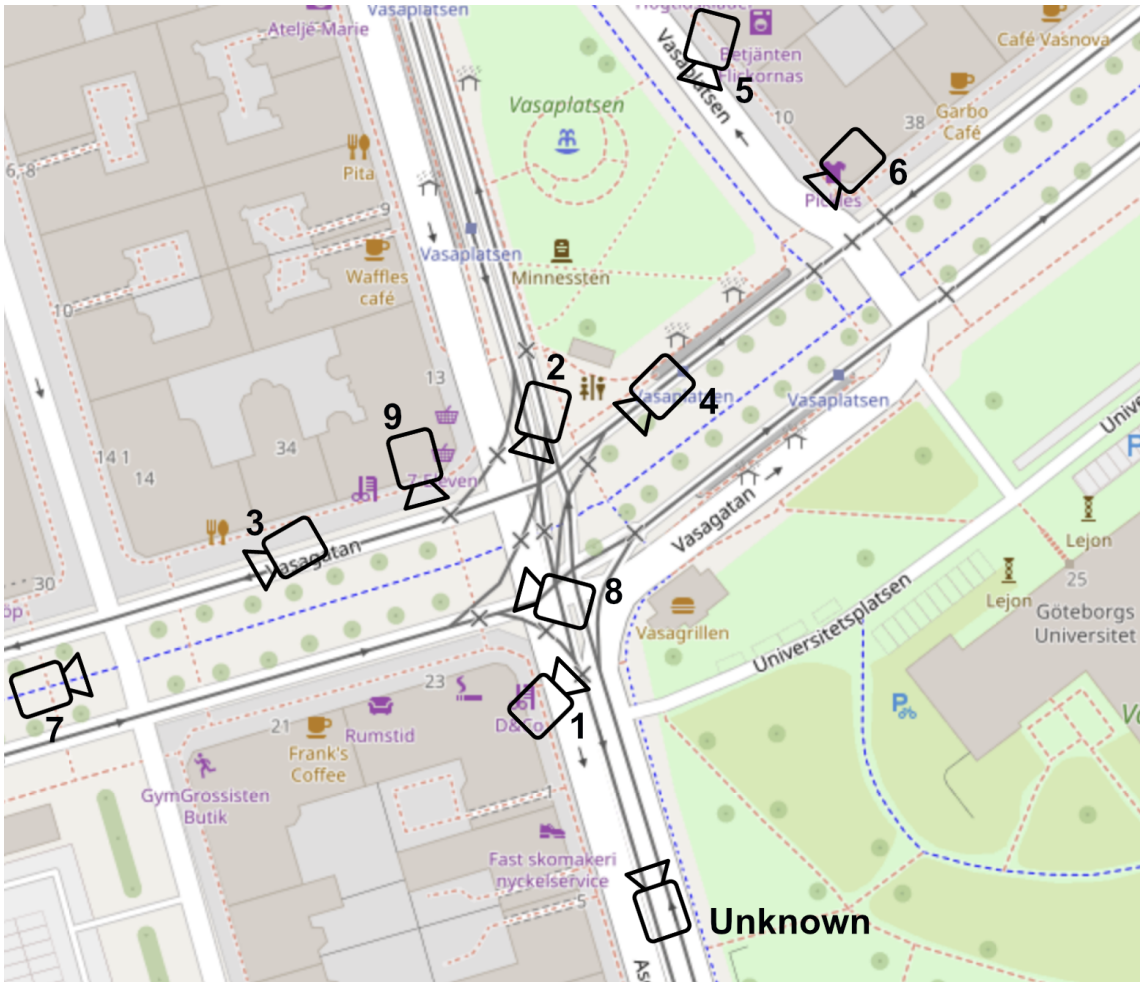

Figure 5.1: A map of the camera positions used in du Rées' documentary

We also created a storyboard with illustrations to get an overview of important key scenes and moments from the event, see Figure 5.2. However, after creating the storyboard, it turned out that it sounded more rewarding in theory than in practice. This is because the du Rées' documentary functioned to some extent as a storyboard.

1. Crowds that contribute to chaos and result in the police backing down to some extent

2. The police fire warning shots as the chaos escalates

3. Police reinforcements arriving to Vasaplatsen

4. Hannes throws stones at the police and his actions and behavior begin to escalate

5. One of the policemen in the group Hannes throws stones at shoots and hits him

Figure 5.2: Storyboard of the Gothenburg riots

5.4 Motion tracking of key persons

The riots at Vasaplatsen escalated quickly and many people were involved. However, due to limitations in time and resources, not all individuals could be modelled or motion tracked. This resulted in us selecting key individuals and groups that we felt were most relevant to the event. The choice was also based on who were the easiest to identify in the film clips, as there were many clips and the quality was often low. The people we chose to motion track were Hannes Westberg and the two largest police groups; those stoned at the beginning of du Rées' reconstruction (police group 1) and the reinforcement group seen a few moments before Hannes was shot (police group 2).

The documentary by Göran du Rées also proved relevant when we were to track people's movements. At first, we decided that markerless motion tracking using deep learning would be the best option for us. This is because there was not enough time or resources to recreate the riot movements in real life and perform marker-based motion tracking. However, one can conclude that a good prerequisite for markerless motion tracking is good-quality film sequences so that deep learning can track people. This was not the case with the clips we had access to. The key people we were interested in were not always in frame, and the general quality of the clips was not always optimal. We did not do any testing, but based on these theoretical findings, we made an educated estimation that manual motion tracking would be the most suitable for us. This involved watching the documentary, identifying relevant people in the various clips throughout the event and noting their positions and

actions. At first, we tried to do this by placing them visually on a map, see Figure 5.3. Arrows indicated which way they were facing, and different colours indicated actions and positioning:

- Green dots meant that we were sure of their positions and actions
- Yellow dots meant that we were not sure of their positions and actions
- Smaller light grey dots indicated that stones had been thrown
- Larger darker grey dots indicated that shots were fired
- Red dots indicated that a shot had hit someone

Figure 5.3: Positioning of police groups 1 and 2 and Hannes based on du Rées' documentary

However, we soon realised this was not detailed enough to base a reconstruction on. There needed to be more clarity regarding which time stamps applied, what actions the people did and in what order everything happened. Due to this, we restarted the process and instead used the chronological timeline, see Appendix C. There we wrote

down actions and positioning together with time stamps. This method also made it easier to understand exactly during which sequences our persons of interest were visible and not. Empty boxes mean the person or group has not yet been shown for the first time. Hyphen "-" means that the person or group is not visible but has been in frame before. The yellow marking implies uncertainty about positioning and/or action. Furthermore, in some cases, during the video sequences, it was possible for us to make educated guesses. These guesses have been based on what is happening around the characters and their actions before and after. We wanted the scene to flow effortlessly and without any seemingly weird teleportation from the characters, since we thought it would lower the immersion and presence. Because of this, there are sequences in the VR experience where characters are visible and moving, even though we are not completely sure what the characters did at those moments in the real-life event. These have been marked with "guess" in the script.

5.5 Learning Unity

After our prestudy and collection of source material were finished, the idea was to start the 3D modelling of the Vasaplatsen. However, due to various blockages and bottlenecks such as postponed meetings and not having access to the right VR equipment or a computer with adequate performance, we had to come up with things to work with. However, this turned out to be a blessing in disguise as we got time to learn Unity thoroughly, as it had a central role in our work. We focused on learning the program's interface, how to code in the program, and approaches when developing games and VR experiences.

To apply what we learned and make a first project draft, we created a very simple model resembling Vasaplatsen, see Figure 5.4. By making this model, we learned about scale in Unity, how to download assets, and how to work with so-called prefabs. According to [82], prefabs facilitate and streamline the work where one creates a base game object that one then uses instances of to fill the game environment. An example in our case was the trees on Vasaplatsen. Instead of modelling each tree individually, we could make one base model, and use copies. In this way, we could, for example, change the colour of all instances by only changing it on the base object.

5.6 Create the 3D model

At first, our idea was to model the Vasaplatsen from scratch in Blender. This idea turned out to be more time-consuming than we initially thought, which resulted in us contacting Gothenburg's state building office (SBK) on the recommendation of our supervisor. Through them, we gained access to the digital twin over Gothenburg, see Figure 5.5, and aerial photos, which made the work significantly more efficient, even though it was only a primitive model. For our project, the model only needed to be supplemented with house facades and city objects, such as benches and traffic signs, as the buildings already had the correct dimensions, green areas and roads were laid out. It is worth noting that Vasaplatsen in this model could potentially

differ from Vasaplatsen during the riots since it is a model of how Vasaplatsen looks today, and not back in 2001. We believe that Vasaplatsen is a well-preserved area that the differences are not decisive for the reconstruction.

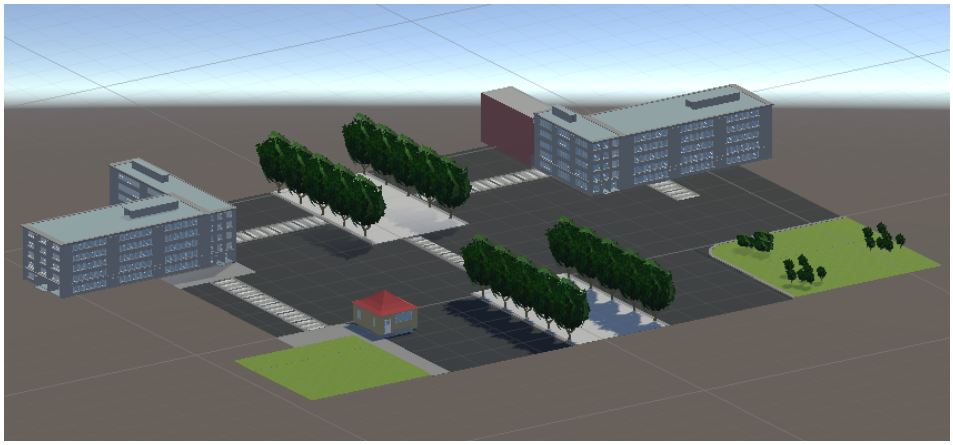

Figure 5.4: First prototype of Vasaplatsen in Unity

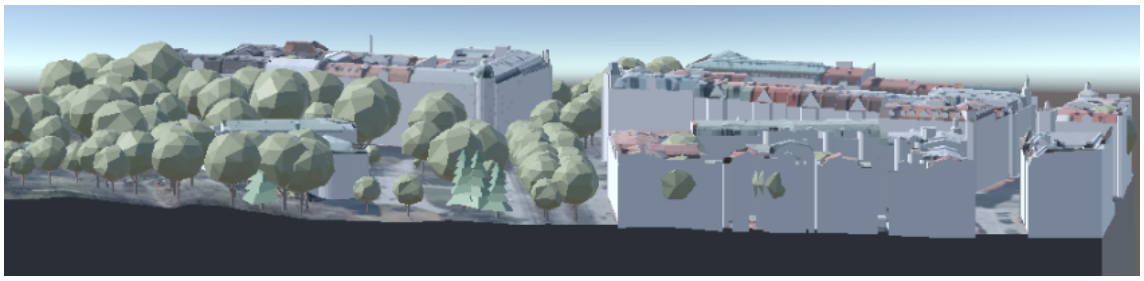

Figure 5.5: Excerpt of Vasaplatsen from Gothenburg's digital twin

House facades were not made for all buildings due to time constraints. However, the facades made were created by our supervisor with the help of photographs from the facades on Vasaplatsen. These images were then modified in Photoshop, where objects such as trees and cars were removed to create an image with a flat house facade, see Figure 5.6. The finished image was then projected onto the digital twin. Further, regarding city objects, a package was downloaded in Unity containing basic city objects that could be placed in our 3D environment.

5.7 Prepare for virtual reality

During the Unity introduction tutorial described in section 5.5 *Learning Unity*, they recommended using their pre-made VR package for Unity as a starting point when creating VR experiences. This package included many of the parts that we would otherwise have had to create ourselves. For example, there were scripts for different types of locomotion, finished hand models and ray interactors. This made the work significantly more efficient. In addition, we learned later in the process that this is standard practice when developing with Unity. Unity provides templates that provide the best pre-settings for the type of project that is going to be developed.

Figure 5.6: House facade from Vasaplatsen

Unity also provided a design document during the tutorial, which they recommended filling in before creating VR projects. With the help of the document, we determined, among other things, how the user can interact during the experience and how we can optimise the experience performance. This also facilitated the work as we got a clear picture of what we would develop and which videos from the Unity tutorial could be relevant. The document can be seen in Appendix A

5.8 Creating the virtual reality experience

Once the tutorial was finished and the 3D model of Vasaplatsen was in place, it was imported to Unity so we could start creating the VR experience. On recommendation from the AR & VR agency OutHere, we decided to use pre-made 3D animations and characters from the free online library Mixamo [83]. Through the library, an animation can be applied to the desired character and then downloaded and used in, for example, Unity. It is possible to use one of their pre-made characters or upload a customised one. However, the principle is the same; all characters can be combined with a large number of animations available, but only one animation at a time can be applied to the character.

The Mixamo process was iterative, where we started with finding a character that resembled Hannes and animations similar to his movements in the du Rées reconstruction. These were then downloaded one by one. This process was also done with police group 1 (stone throwing) and police group 2 (the reinforcement). For the groups, the same character was used together with various animations. In Unity, multiple instances of this character were then used to create the groups.

One of the difficulties in this phase was determining the speed at which the characters moved. We had to guess the values by looking at how long it took them to move from point A to B in the du Rées documentary. Additionally, the scale of the characters placed in the digital twin was challenging to determine and based on

guesswork. The third difficulty was that we sometimes could not find animations and characters that resemble reality enough. We had to modify or settle for slightly different in those cases. Examples are the characters' clothes, equipment, and some of the movement. An example is shown in Figure 5.7 where the clothes Hannes is wearing in the reconstruction, and the hand he is pointing with differ from reality.

Figure 5.7: Comparision between Hannes in reality and the reconstruction

An attempt was made to modify clothes and add equipment such as weapons and batons in Blender, this turned out to be significantly more advanced than expected. It was not only about modelling the clothes and equipment but also modifying them to follow the characters' movements. Due to time constraints, complexity, and difficulty level, we chose to keep the original Mixamo characters as they were.

5.8.1 Unity timeline

We used the Unity timeline to apply the animations in the VR world. The timeline allows developers to create cinematic content by adding audio sequences, working with several animations simultaneously, placing them out in time and modifying game objects [84]. Worth noting is that this timeline is different from the previously mentioned in section 4.4.1 *Chronological timeline*.

With the animations downloaded from Mixamo, each character had its own animation track customised, see Figure 5.8. As mentioned previously, we did manual motion tracking by looking at the documentary by du Rées, noting down positions and actions, and then implementing them in Unity. Even though this script was detailed, we still needed to switch between the documentary and Unity during the process. Second by second, we then made sure that the animations in Unity resembled what was shown in the documentary. In total, ten characters were motion tracked after their exact behaviour in the documentary and added to the VR experience. The process was iterative and needed a high level of precision. It took approximately four weeks to achieve a reasonably good result.

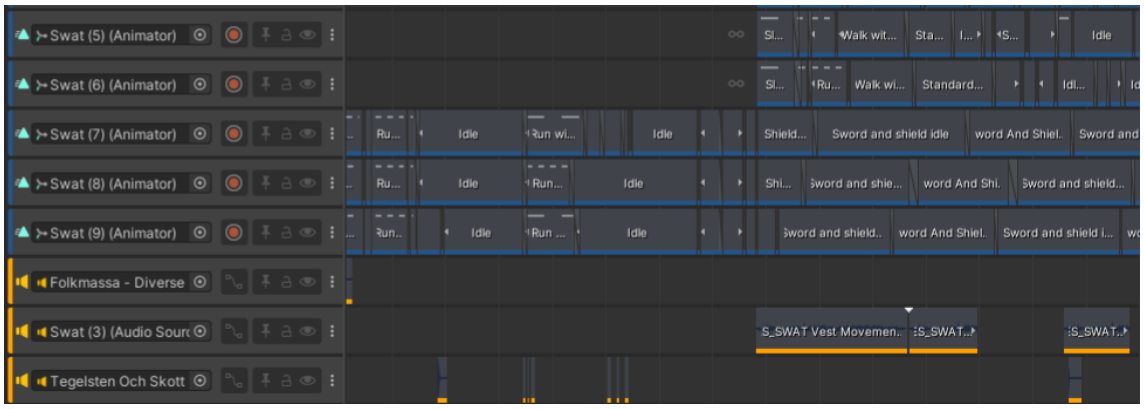

Figure 5.8: Animation tracks in Unity timeline

5.8.2 Visualising uncertainties

In those cases where the characters' positioning and movement could not be seen or documented, we applied a visual effect to the characters. Based on the previously presented literature in section 3.3 *Managing uncertainties*, we tried different visual cues to communicate the uncertainties to the users. We discussed if a coloured or blurry filter could represent the uncertainties, or if the characters could become more transparent or desaturated. We also tried different types of so-called particle systems, such as "flying" squares around the character and a cloud variant. According to Unity [85], a particle system can be used on numerous occasions to apply a visual effect. The transparency, cloud and flying squares effect can be seen in Figure 5.9

There were advantages and disadvantages with all of the effects we tested. The majority of the drawbacks were that the techniques attracted too much attention or resembled something else. For example, the "flying squares" made it look like the characters were on fire, which was not what we sought.

Figure 5.9: Different ways of visualising uncertainties

The technique we settled on at last, was transparency as we felt it was attention-grabbing enough without becoming too distracting. Furthermore, since this reconstruction will be stripped down regarding the number of characters, the main focus

will be Hannes and the police groups. We, therefore, believe that subtle differences, such as changes in transparency, are noticeable enough to the user.

5.8.3 Sound and Light

The AR & VR agency OutHere told us that one of the most important aspects of developing VR is the audio in the experience. At first, we planned to use the audio from the du Rées documentary [2], which would give the experience the most authentic reconstruction soundwise. Due to copyright, which has been discussed previously, we decided that the simplest way to solve this problem is to receive permission from Göran du Rées himself. As a result, we contacted him and got permission to use his material as we wished.

Shortly after, we started to explore the audio functions that Unity had. One function was the ability to create 3D sound, which can enhance the VR experience [86]. This means that we could create different sound sources, place them at accurate locations in the experience relative to the real-life events counterpart, and increase the immersion. In connection with this, however, we discovered that the audio from the documentary would not be suitable for creating 3D audio in the experience. It was only one sound file, meaning we could not isolate the sound from important events in the documentary, such as single gunshots. The audio was too flat, and sound from other sources blended in.

As a result, we instead decided to use sound from the audio library Epidemic Sound [87]. It is an extensive audio library with royalty-free music, that had all the audio we strived to include in the VR experience. The audio we used from Epidemic Sound were all isolated audio files and worked well in the experience. Since the audio files were separated, we could create 3D sounds of them and make the VR experience more immersive.

Moving to light in the experience, Unity provides natural light when starting up a new project. The developers can then manipulate the light in the scene depending on how they want it to look. The shootings and demonstrations on Vasaplatsen took place in the evening, and the sun was on its way down over the horizon. To provide a high level of immersion and presence, we aimed to simulate the same light effect in our recreation as it was in the source material.

5.8.4 Interface

The idea throughout the project has been to have an introductory scene with background information about the event for the user before they see the actual reconstruction. It turned out that working with a lot of text in VR proved challenging during the development. It became uninteresting and annoying. Furthermore, the text is also no longer read statically in VR, but can be influenced by movements and rendering functionality [88].

In communication with the company OutHere who also confirmed the difficulties with text in VR, we concluded that a simple solution would be a voice-over. We

could either record it ourselves or use an AI voice generator that uses text-to-speech. We discussed both approaches but concluded that the most flexible would be to use artificial intelligence.

We tested several websites that generated AI voices but finally landed on the page Play.ht [89], which we felt gave the most natural voice and did not have the typical robot pitch. This process was iterative, where we started by writing a short script and then generating the voice-over. The script was modified several times, and so was the voice-over. Play.ht focuses on creating natural voice results, making each voice sample unique. For this reason, certain words could be emphasised differently and in some cases, we were unsatisfied and had to generate a new sample.

5.8.5 Optimise performance

We followed Meta's recommendations regarding what is a good performance for a VR experience on an Oculus 2[90]. We aimed for:

- 72 frames per second
- 13.9 milliseconds per frame
- 750k-1.0m triangles per frame
- 200-300 draw calls per frame

When developing the experience, we knew it would be a smaller project and would not need too much computational power. There are no high poly objects and no mechanics that demand much of the computer. We will also play the experience with a link cable connected to a computer and therefore, estimated that the performance never really would be a problem. The computer that we used for developing the VR experience used a Nvidia 2060 RTX graphic card, which is recognised as a powerful graphic card.

When we were done with the VR experience, we met our conditions for the frame per second and milliseconds per frame. We generally had lower triangles per frame than what we wrote in the design document. This was because the models we used were lower in triangles, and we did not add more objects to the experience. The same goes for draw calls per frame; we had many more draw calls per frame than our goal. This is again due to our VR experience not demanding much of the computer and headset. The performance we got out of our product was enough to satisfy our goal.

5.9 Visit to Hagabion

When we emailed du Rées regarding copyright, he also mentioned that he would be coming to Hagabion in Gothenburg to show his documentary "Skotten på Vasaplatsen", which has been of great help during this thesis. The same evening, a new documentary by another director would also be shown: "På Hvitfeldska bodde vi".

In this case, the director was one of the protesters who were detained at Hvitfeldska by the police, see section 2.1.1 *The barricading of the Hvitfeldska gymnasium*. After the documentaries were shown, the audience was allowed to ask questions, and it emerged that many in the audience had taken part in the demonstrations. During the discussions, there were also students who attended Hvitfeldska today who, despite attending the school, had never heard of the barricading of the school.

During the discussions and in the documentary "På Hvitfeldtska bode vi", it emerged that those involved felt hopeless that their perspective of the events was not taken seriously. Many felt that what the media had reported was biased or one-sided, and they felt that people would not believe them if they told their side. For example, after du Rées' documentary, someone mentioned that she had heard 13 shots, in contrast to the prosecutor's six and du Rées' eight. It also emerged during the same discussion that much of the film evidence had disappeared as the police had no computational space nor knowledge to save it, which could have resulted in the differences in numbers.

Before the visit, we had worked clinically and scientifically with the events and riots. The visit gave us a new perspective and understanding of what happened those days in 2001. People in Gothenburg still have strong emotions towards the event, and many are still emotionally hurt. The visit invited humanity to our thesis and understanding of it. It solidifies that the events are still relevant, even though more than 20 years have passed.

5.10 User testing and compilation

During the work, we discussed user tests several times and when they would be appropriate. We felt that it would not give us much if we were to carry out user tests relatively early in the project, for example with a first draft of the 3D model and some simple character animations. Therefore, it was important for us to create an experience with sufficiently high fidelity, immersion and presence before presenting it to users. This aimed to get feedback based on the user's more concrete feelings and thoughts regarding the VR experience and its content.

As a result, developing the VR experience took most of the project's time. For this reason, we decided that the purpose of the user tests is to create a basis for future work and if someone else continues the project. In other words, none of the feedback was implemented in the VR experience presented in this thesis. It will instead be compiled and presented under section 6.3 *Results from the user tests*.

5.10.1 Execution of user tests

The participants were collected through a convenience selection and were persons close to High and Low in Kuggen at Chalmers Lindholmen. We gathered five participants, all students of the Interaction Design and Technologies (IXD) program at Chalmers University of Technology and were versed in UX design. All of the participants received verbal information about how we would conduct the tests and

how their answers would be used. Through this, we also received their informed consent.

None of the tests were recorded. However, we used Microsoft Teams' transcription tool to make the analysis of the responses easier and more time-efficient. Furthermore, we decided beforehand that one of us would ask the questions, and the other would take notes of the participants' answers.

The tests were conducted individually, starting with a brief introduction about our project, how they can navigate in the VR world and an explanation of the buttons on the controllers. Before the participants could start the VR experience, we also asked them about their previous experience with VR. The participants then put on the VR glasses and we checked the size and fit. During the VR experience itself, we encouraged them to describe out loud what they saw and felt instead of us asking continuous questions.

After the experience, we asked questions about where they think this type of concept can be used, their development suggestions, and if they understood all the parts they saw. All questions before, during and after testing the VR experience can be found in Appendix D.

5.10.2 Compilation of user tests

After all the tests were finished, we went through the auto-generated transcriptions, all of which had many disjointed parts. As mentioned earlier, the goal of the tests was to create a basis for future work, and therefore we did not see the need to have direct quotes from the users. Instead, we wanted to receive some suggestions for future work. For this reason, to make the transcriptions reasonably easy to understand, we went through each transcription, removed unnecessary filler words, and rewrote disjointed sentences.

We then reviewed each revised transcription and copied relevant parts to sticky notes. When all parts were extracted, we began to group the various notes, see Appendix E. These groups then contributed to concluding what the participants considered opportunities for future work. This is explained in section 6.3 *Results from the user tests*.

Worth mentioning is that during the tests it emerged that all participants previously had little to no experience with VR. This is a factor that could have affected their input since their focus most likely was on the VR technology itself. That, in turn, may have limited the amount of in-depth analysis and suggestions we received. On the other hand, this is a proof of concept where there is still a need for more details, and for that reason, perhaps the possibility for an in-depth analysis was limited already for that very reason.

6

Results

Our final concept is a VR reconstruction of the Vasaplatsen shooting during the Gothenburg riots in 2001. During this reconstruction, the user can see Vasaplatsen and the sequence of events from stone throwing at the police officers to the shooting of Hannes Westberg. The reconstructed experience is a total of 2 minutes and 10 seconds long. A link to a part of the reconstruction can be seen in Appendix F

To avoid the user being just thrown into the experience and seeing the chaos unfold, a text box greets them with background information about the event, see Figure 6.1. The information is also presented verbally by an AI voiceover to avoid missing information due to difficulties with long texts in virtual reality. In this scene, the user can only rotate his head and hands to look around and interact with the interface. Furthermore, the textbox, and all other buttons, sliders and controls the user will be met by are set to world space. This means that they are placed in the virtual world where users can interact with them.

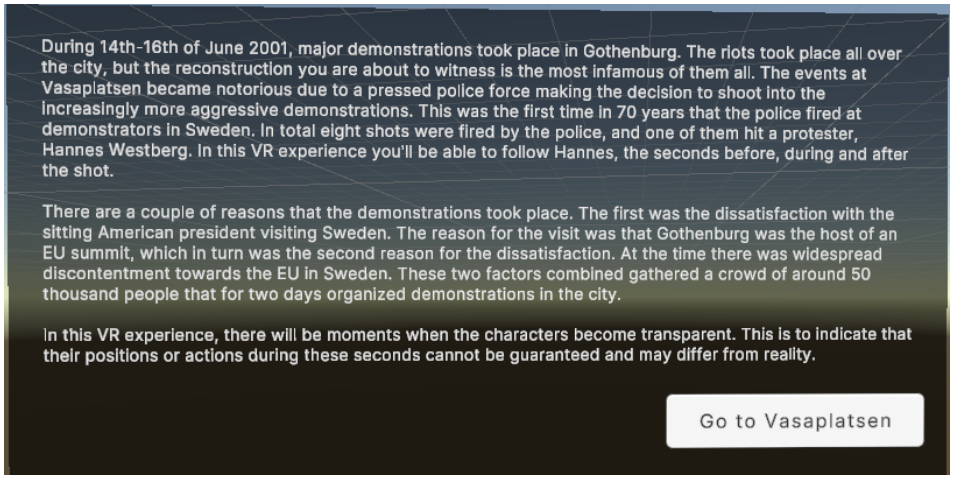

Figure 6.1: The introduction scene

When the users feel ready, they can press the button *"Go to Vasaplatsen"* to be moved to the reconstruction scene. Here the user is loaded into Vasaplatsen and another button that says "*Start experience*", see Figure 6.2. The reason for the additional button is to allow the user to learn the controls and navigation before the reconstruction sequence begins. This is to give them the best possible chance of

not missing any information or event. We also wanted the button to be one of the first things the user sees, and therefore it is not placed on their wrist.

Figure 6.2: The second button on the reconstruction scene

So-called rays are used to navigate around the world, see Figure 6.3. These are red lines that beam out of the virtual hands. By clicking the buttons on the physical controls, users can activate the locomotion pointing and teleportation by clicking the buttons on the physical controls and getting from points A to B. The user will also receive haptic feedback in the form of vibrations in the controllers when navigating through the scene.

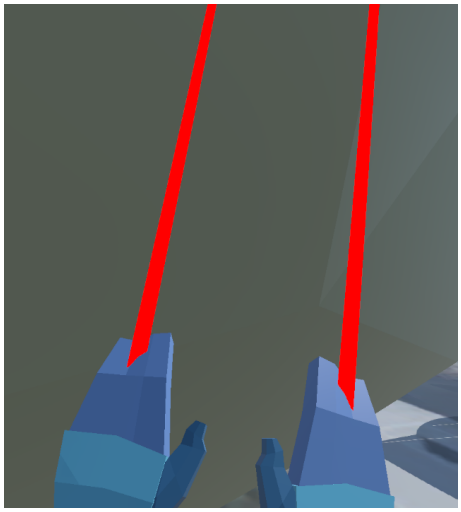

Figure 6.3: Rays used by the user for locomotion and interactions

Constraints have been set up to prevent users from entering buildings or going outside the world. These constraints are not visible in the experience, but they are highlighted in red in Figure 6.4. Users can press the "*Start experience*" button to start the animations when they feel comfortable with the settings and controls.

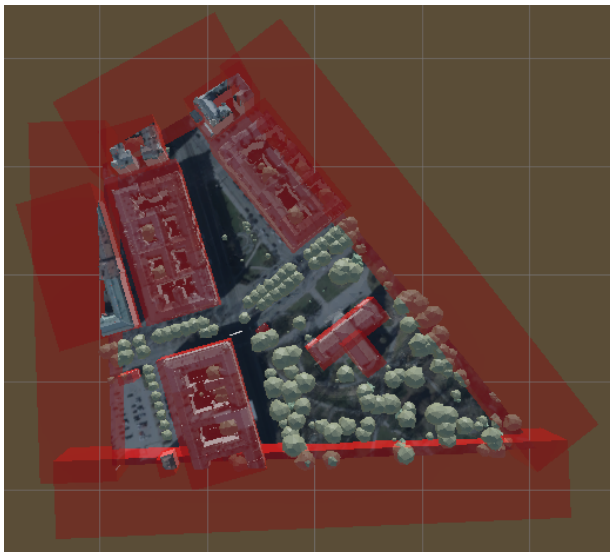

Figure 6.4: Overview of the constraints

6.1 The reconstruction

Hannes and the police groups are embodied by so-called non-player characters (NPC), see Figures 6.5 - 6.6. These have been designed to make the same or similar movements as their real counterpart that can be discerned in du Rées' documentary. Hannes and police group 1 (stone throwing) are visible throughout the whole experience, while police group 2 (the reinforcement) are visible from 01:24. Furthermore, during the experience, there will be sequences where characters are semi-transparent. This is to visualise the uncertainty regarding their actions, positions or both.

Figure 6.5: Hannes and police group 1

The reconstruction starts with the user facing Vasagrillen and seeing Hannes and police group 1, see Figure 6.7. Until police group 2 comes into the picture, there is stone throwing and chasing from both sides. When group 2 becomes visible, they focus on contributing reinforcements to group 1, resulting in them forming a larger group. At the same time, Hannes is shot and begins to limp towards the Vasagrillen, see Figure 6.8. In this context, it is important to remember that Hannes was not alone and had many protesters around him. However, this is not visible in the reconstruction, making it look like Hannes is alone against the police groups.

Figure 6.6: Police group 2

Figure 6.7: Start scene

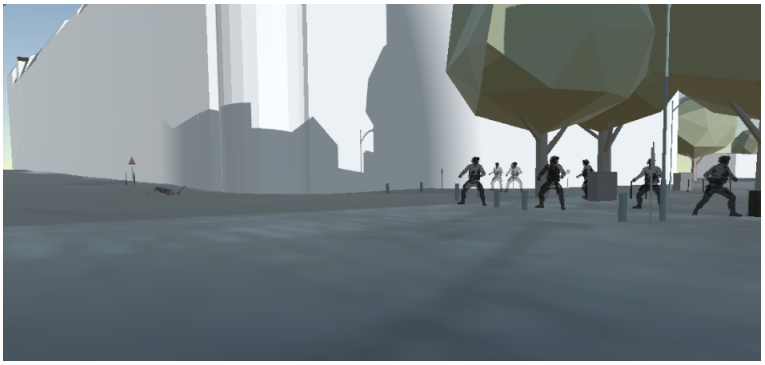

Figure 6.8: End scene

6.2 Manipulating time

While the user sees the reconstruction unfold, they can manipulate the time through a square "tablet" on their arm, see Figure 6.9. The tablet is attached to the user's left arm, and they can interact with it with their right hand. On the tablet, there is a short functionality instruction, the number of seconds of the reconstruction that has passed and a slider to rewind and fast forward the time. There is no delay between user interaction with the slider and updates in the reconstruction sequence.

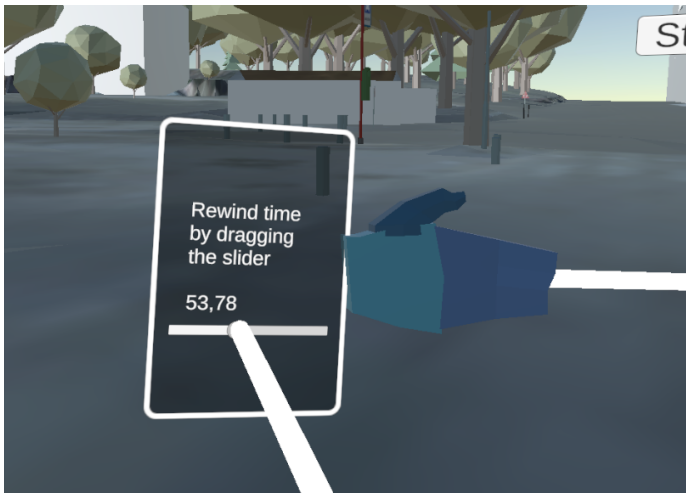

Figure 6.9: Time manipulation tablet

6.3 Results from the user tests

The five user tests we gathered, see section 5.10.1 *Execution of user tests*, provided numerous possibilities for future work. These are presented below.

6.3.1 Other use cases

Reconstructions similar to this one, and VR reconstructions, in general, can be used for tourists and educational purposes. For example, VR reconstructions can be available at museums and exhibitions. Through it, one can reenact historical events, participate in them, and learn more. VR reconstructions can also be suitable for guided tours of places one does not have the opportunity to visit due to various reasons such as time, money or inaccessible places.

6.3.2 Improvements for visualising uncertainties

When visualising uncertainties, participants felt that there should be different visualisation techniques. Specifically for the reconstruction made in this thesis, it needed to become clearer what was uncertain and what was not. The users felt they missed the semi-transparent effect on the characters during different time sequences. In addition, it emerged that turning the uncertainty visualisation on and off would be appreciated to get the optimal experience.

6.3.3 Improve presence and immersion

Precisely for this reconstruction, it emerged that there is a need for more people and crowds to create a higher level of presence and immersion. This would also increase with the help of other details, such as the implementation of weapons and stones. It also emerged that most of the participants could locate it as Vasaplatsen without us mentioning it. However, according to some participants, it needed to be shown

more clearly, for example, through signs that say "Vasaplatsen". One suggestion was to have these signs at the bus and tram stops.

6.3.4 Information during the experience

The users appreciated the information in the text box before the experience started, but it appeared that much information was quickly forgotten. For this reason, it would be appreciated to have information continuously throughout the experience, for example, by interacting with the characters and getting information from them while the event unfolds.

6.3.5 Audio in VR experiences

The sound was shown to be efficient for giving context and increasing immersion and presence. The participants experienced in this reconstruction sound made it clear that a lot was happening simultaneously; many people were present, shots were fired, and stones were thrown. However, there was a desire to distinguish important sounds and communicate to the user that their focus should be drawn to the sound source. This was because one of the participants missed the final shot that hit Hannes and had to replay the sequence.

7

Discussion

The Content-oriented model of user experience, mentioned in section 3.7.1 *Content-Oriented Model of User Experience*, and the keywords why, what and how have been used to try and keep the project on a linear track to reach an enjoyable user experience. The hardest part during the development was the "Why", not because we did not know what to include to make the recreation an exciting VR experience, but because we did not know how much we would manage to complete during this thesis. From the start, we knew that we wanted to make it possible to experience the Gothenburg riots in VR, recreate Vasaplatsen, and include some motion tracking. In the end, we managed to include these as well as audio, light, uncertainty, background information, time manipulation and street objects.

For the "What", we wanted to create a VR experience where the user, to some extent, gets to experience the Gothenburg riots and the shootings at Vasaplatsen. This meant that a digital reconstruction needed to be included. For the "How" we wanted the locomotion in the VR experience to be effortless, which was thoroughly researched. The choice of locomotion, namely pointing and teleporting, was mainly based on the fact that we did not want users to get affected by motion sickness. We also included a time manipulator which allowed the user to change the time in the event that they are in. "Why" ended up being the fact that one can experience something that has already happened and go back to it multiple times.

Since the user is experiencing a historical event we would not want them to interfere with the events in the VR experience. The user is therefore able to do two things in the VR experience; (1) move around in the world and (2) manipulate the time. For the "how" we mentioned that the project's aim was a proof of concept. This meant that the look and feel of the experience would have some rough edges and be in need of further work when the thesis is done. Our goal was however to have a VR experience that would resemble the real event enough so that the user would get an understanding of how the event unfolded back in 2001.

7.1 Motion tracking

A central difficulty during this thesis has been the motion tracking of relevant people. Although the event was at the time one of the most filmed, there is a lack of clips with sufficient resolution quality to be able to apply artificial intelligence or machine

learning for motion tracking. Also, as now noted, the film clips from the event are from different angles and not long enough for relevant key people always to be seen in the frame. Apart from this, there were also moments when Hannes and the police blended into the rest of the crowd. For this reason, it was of great importance for us to be transparent and visualise this uncertainty to achieve a credible result and counteract bias.

Some methods can create markerless motion tracking with unsynchronised video footage [50]. These methods have other ways to capture the people they want to motion track, for example through audio from multiple cameras or automatically reconstructing background geometry [50]. These methods are used when the person in the frame also is the focus of the video clip [50]. The video footage we have access to does not have these attributes. The biggest issue is the low resolution of the footage. The other is the chaotic scenes that we are depicting, where it is a cluster of people moving in front of each other, moving in and out of the frame. The audio comes from one channel through all of the footage, making it hard to distinguish from which camera the audio is coming from. All these reasons, and the fact that we had no prior knowledge about motion tracking, made us choose the manual method, described in section 5.4 *Motion tracking of key persons*.

The work has been based on the documentary by du Rées and clips from Uppdrag Granskning. Among other things, the documentary was used to note down important timestamps and write a script for the VR experience. This simplified the process, but may also have been a source of error as time synchronisation errors were discovered in some parts of the documentary. For example, if Hannes disappeared from the frame in clip A while we were analysing him, we had to rely on clip B where he was visible. Between these clips, sync errors could occur, meaning Hannes could appear a few seconds later than he originally would have done in the second clip. This may have resulted in Hannes being placed in the wrong place at a certain time in our VR experience. This also applies to other objects and people, for example, if stones are thrown at the right time or if the police teams enter the scene at the right time.

This error could be minimised or counteracted in some cases by a third camera being available and presenting clip C. This clip acted as a bridge between clips A and B, and thus Hannes was shown continuously using 3 different camera angles and clips. It is worth noting that the synchronisation error has not had any serious consequences for the work as it only differed by a few seconds, but it has nevertheless affected the final VR experience and its various time sequences.

The combination of multiple cameras can also further be used to reduce the uncertainty in our reconstruction. By projecting the video material from the du Rées documentary, as well as specifying the camera positions from the documentary onto the project in Unity, see Figure 5.1, one can more precisely motion track the key people. In the same way as above, one can see on camera A where the key person is, and then compare it with cameras B and C. Through this, one can triangulate the positioning and motion tracking and create a more reliable result in Unity.

Another aspect to remember is that the police officers were much easier to distinguish from the crowds than Hannes due to their uniforms. However, they were difficult to distinguish from each other, which in this work has led to us only identifying the police groups that were the largest (group 2, the reinforcement), or that had a central role in the incident (group 1, stone throwing). The difficulty in identifying individual police officers, as well as the lack of clips where they are always visible, has also led to us only being able to speculate about which police officer(s) fired the shots, including the one that hit Hannes.

7.2 Creating an immersive experience

In order to create an immersive experience, we have discovered the importance of details. It became evident during the work how much of a difference it made to apply sound, realistic light and correct environment objects. For example, getting access to Gothenburg's digital twin meant we no longer had to use simple rectangular blocks as buildings or create them ourselves in Blender. In addition, applying colours, for example, to the green area or getting details in the form of building facades, made a big difference in the result. We believe what had the greatest positive impact was implementing sound and light in the experience. As a user, one received a feeling that more closely resembled the chaos that actually took place during the Gothenburg riots.

Important to note is that Unity creates a default light when creating a VR file, otherwise the environment would be completely black. What we changed with the default light was to modify the hue and direction to make it better replicate the evening sun seen during du Rées' documentary. Furthermore, it should also be taken into account that sound and light have been covered in a general manner in this thesis and there is room for a more thorough investigation. This applies primarily to sound, which was one of the aspects manipulated and misrepresented during the prosecution's reconstruction.

It is important to realise that the level of presence can vary among individuals, and depends on the users' prerequisites and expectations. For example, for someone who knows Vasaplatsen well, the reconstruction seen in our experience can feel very stripped down. This could apply even if the model is very authentic. In contrast, for someone seeing it for the first time through our reconstruction, it can be experienced as very detailed and immersive.

An ongoing discussion during the development regarded the uncertainties and their impact on immersion and presence. Hannes' actions and movements were usually clear, but there were a few cases where he disappeared from the picture or could not be distinguished. The police who, on the other hand, moved in groups were more difficult to distinguish from each other, as was mentioned earlier. Sometimes their actions were indistinguishable, other times it was positioning, and in some cases, both. This meant they are transparent in large parts of the virtual reconstruction to visualise the uncertainty. This was a factor we felt would reduce the level of immersion and presence. However, one of the main reasons for creating this recon-

struction is the many uncertainties surrounding the shooting at Vasaplatsen. This was therefore used as an argument for prioritising uncertainty over presence and immersion.

7.2.1 Adding a crowd

Much of the sound added to the reconstruction was based on the sounds of the crowd in du Rées' reconstruction. This meant that some sound effects mimicked the sounds the crowds made during the riots. For this reason, and to make the experience more immersive, we considered adding more characters to the experience that would replicate the crowd. Problems occurred though:

1. The amount of motion tracking that would be needed.
2. Visualisation of uncertainties would lead to reduced presence and immersion in the experience.
3. Lack of clarity about who are key people.

Being able to motion track the crowd would be a challenging job and almost impossible. This is because the quality of the clips in du Rées was not optimal, and not all people were always visible, which meant it was impossible to distinguish individual people during the entire sequence of events. For that reason, if we included multiple characters representing crowds, they would be created and placed based on our speculation. This in turn means that they would need to be transparent to visualise the uncertainty to the user. In connection with this, we discussed whether this would reduce the level of presence and immersion in the experience. More people would also make it more challenging to distinguish Hannes and the police groups who were the key people in this experience.

During the experience, we have groups of people, namely the police groups. These are also semi-transparent through large parts of the VR experience. For this reason, one can argue that the crowd should be included and that it is okay for these to be semi-transparent throughout the experience. However, we felt that the police groups are more necessary to the sequence of events than the crowd which we consider in this reconstruction to be nice to have but not necessary. This is based on the fact that Hannes mainly interacts directly with the police, while the crowd is something he has in the background. In connection with this, we also noted the fact that in the VR reconstruction, it looks like it was only Hannes against several police officers during the Vasa shooting, which presents a distorted picture.

The decision was ultimately not to include the crowds for several reasons that outweighed the reasons for including them. The level of immersion and presence is highly valued in this work and we felt that having crowds where we are neither sure of the people, positioning or actions would reduce it significantly. More people would also mean that the key people in the reconstruction must be marked out more clearly. It could be solved in different ways, for example through a colour marking or that the camera follows Hannes and the police. In the last case, difficulties arise

in that the camera "is" the user. If the camera were to control instead of the person wearing the VR headset, it would mean that the user virtually is dragged around, like a rollercoaster ride. This could lead to, for example, motion sickness.

7.2.2 Rich experience and protective frame

For an increased immersive experience, we aimed to create a rich experience and utilise the protective frame. These were presented in the theory section.

7.2.2.1 The scandalous

For the rich experience, we decided on "The scandalous" which was discussed in section 3.7.2 *Reversal theory and designing for a rich experience*. It is a stage where a person becomes fascinated (positive emotion) while experiencing something morally ambiguous (negative emotion).

During the development we tried to treat the subject of police brutality and aggressive protester with respect, meaning that we wanted the recreation to be as authentic and accurate as possible to the real-life event. This means depicting a sequence where a person gets shot and consequently gets severely injured. In the documentary, the feeling of unease grows in one's self when watching it, yet one can not look away. We hope to give the user of our VR experience the same feeling; what they are experiencing is wrong but they still want to see how it ends. It creates an unsettling feeling for the user when they see the police using that type of violence towards a citizen. Hannes' behaviour also raises interest for the user, since we know that we are not supposed to throw rocks at the police. There are many aspects of the event that might awake some feeling of unease in the user, knowing they are witnessing something morally ambiguous.

7.2.2.2 Detachment frame

The protective frame we used was the "Detachment frame" which was discussed under 3.7.3 *Protective frame*, and is a mental defence mechanism where a person experiences something scary but understands that it is not in their direct vicinity.

It is hard to say how the detachment frame is used in VR, where we have found little to no research testing this. It is known that VR has a higher level of immersion and people experience feelings more intensely than in other media. As a result, we are hoping that a VR experience, as well as the high level of immersion and presence, will not alter the way humans are affected by the detachment frame. Our ambition is that the detachment frame will work as it does during a scary movie for example. More research on the subject needs to be done, and we can not make any conclusion on how it works in our VR experience.

7.3 Generalisability

The result of this work can be interesting for many different parties and therefore have high generalisability. For example, it can be interesting for those involved in the Gothenburg riots to see and experience the event again. It can also be a concept that raises curiosity among those who have a general interest in the event.

If one looks at a VR reconstruction of an actual event in general, it can also be interesting for the judicial system. Looking at reconstructions of crime investigations in general, we have great confidence that virtual reality reconstructions of crime scenes can contribute to an increased understanding of the incident. We see it as beneficial to have a "digital" version of the crime scene that is always available and not contaminated by, for example, crime-scene investigators who want to take samples and collect physical evidence. Furthermore, a VR reconstruction makes it possible for a user to be placed into the perspectives of different actors such as witnesses, perpetrators or victims. This allows the creation of an overall picture of the event. The latter is something that, in our opinion, would have been of great importance and value during the legal proceedings of the Gothenburg riots. For this reason, we have great confidence that if this concept had existed during the Gothenburg riots, it would have contributed to more transparency, understanding and clarity during the trial processes and the follow-up work.

7.4 Ethical and societal aspects

During the project, there have been several ethical concerns, which will be presented below. These points are all important aspects that need to be considered when designing a VR experience. In addition, since the technology is relatively novel, we had to be cautious while designing our VR experience.

7.4.1 Anonymisation

One concern has been regarding the act of recreating an event that has taken place, which in this case also was a crime scene with victims. All of the investigations are inert, but it is still people who are alive today that are reanimated in the experience. If people are to be involved in the work, for example through user testing, it is essential with informed consent and anonymisation [91]. They should be informed about what data will be collected, how it will be collected, potential risks or benefits during the process, and lastly information about how they can withdraw from the project at any time [92, 91].

In this case, anonymisation refers to the participants in the user tests. This, therefore, does not include anonymising the people who are visible in the reconstruction since the reconstruction then would not be possible. This mainly applies to Hannes, who cannot be anonymised in the reconstruction as he had such a central role in the events and received a lot of media attention. Even if we were to make an effort to anonymise Hannes in the reconstruction, it would still be possible to figure

out who it is based on the movement pattern and actions by comparing it with other sources. In other words, Hannes could be anonymous to someone who knows nothing about the Gothenburg riots, and sees our reconstruction for the first time. However, for someone who has knowledge of the event, it is difficult to make Hannes unidentifiable.

Depending on the level of detail, the police groups can also be anonymised to some extent. This is because they were created as a group rather than as individuals in this reconstruction. But even here one could find out which police officers belonged to which groups depending on what sources from the event one has access to and can confirm with. Similar reasoning can also be applied to other groups involved, if these were to be reconstructed.

7.4.2 Bias and interpretation

Another ethical issue is regarding us as the authors of this project and our perception of the event. There is a risk that we were biased and became selective in what we included in the work, even though we tried to make it as transparent and objective as possible. Everything we have created or implemented in the final concept has our fingerprints on it, which removes an ounce of objectivity. We would not say that this is something that is unique to our VR experience, but rather to everything that is striving to represent reality.

Studies show that reconstructions that do not utilise all existing evidence and/or are shaped by speculations can influence the final verdict [8, 11]. This is particularly noticeable as our data is mainly based on information from others and videos from the event. VR is highly persuasive, where the subjective experience of VR can influence how a person feels about an event [93]. Persuasion can be used to persuade people for ill-intended purposes and to do something they do not want [93]. For this project, it could have been to increase sympathies for one of the two actors, for example, the protesters or the police. Therefore, our goal during this thesis was that the experience should not influence a person's thoughts about the Gothenburg riots, but rather retell the events as they unfold as objectively as possible. We hope this is achieved by the user not being able to interact with the course of events or the characters. In this way, we hope to minimise the risk of sympathy for one party or another.

7.4.3 Long-term consequences

The ethics of VR is still very much in its infancy, and due to the novelty of the technology, the knowledge concerning this is still quite limited [94]. A wide range of topics need to be considered when developing an experience for VR. In addition, concerns have risen because of the novelty of the technology and the wide spread of using the product at home. The research on long-term immersion is falling behind, especially regarding its consequences, which is important to notify private VR users about [94].

One area that needs more research but is deemed to influence a person using VR is agency and overall immorality [93]. In other digital outlets, for example, movies, the person consuming the product is passive. The action that occurs in a film is beyond the consumers' control, but when using VR, this is not the case. A person who is using VR is the active agent in the experience, and therefore there is a need for research regarding how this affects the person.

7.4.4 Preserving cultural heritage

We believe that a reconstruction as the one we have done in this thesis is important, not only from a crime investigation point of view but also from our shared history and culture. A reconstruction of an event that has happened gives persons who were not there the possibility to relive it. VR can transport people in time and space like no other medium. This opportunity allows us to see, hear, and feel how an event formed today's society. It is easy for a society to forget its history and understanding of why they are where they are. Our recreation of the Vasaplatsen shootings has opened new opportunities for a group of people who were too young or uninterested at the time to see how it all went down. Our reconstruction is only a proof of concept and needs more polishing before it is ready to be at an exhibition or used in school, but we can see its potential.

We also believe VR is a good medium for getting younger people interested in culture and history. The levels of immersion and presence are incomparable to other mediums, as it gives us a way, in a sense, to relive it again. We presented in the related work section 1.3.3 how other developers have created a reconstruction of cultural and historical events. The hope is that our reconstruction, if developed into a complete product, has the same relevance for the society and culture in Sweden in general and Gothenburg in particular as they have.

7.4.5 Intended target group

During this thesis, we have not designed for a specific target group. This is because the reconstruction can be adapted depending on the usage purpose and the users. If it is to be used in legal processes, it should be more clinical and show an overview without the users being able to interfere with the events. If it is for learning or entertainment purposes, it would be valuable to have a more gamified version where the user can, for example, see the stress levels and thoughts of the characters.

7.5 Future work

This was a very interesting project to undertake and we believe there is room for a variety of further work. The presented parts are our suggestions for future work. In cases where it is supplemented with the previously presented suggestions from the users, it will be mentioned in the text.

7.5.1 Increasing detail level

The VR experience itself can be developed by adding more details such as more people, adding tramways and also modifying existing characters to make them better resemble reality. This was also mentioned during the user tests together with the need to make it more clear that one is at Vasaplatsen during the VR experience. In addition, it is important to remember that the Gothenburg riots took place not only on Vasaplatsen but also in other areas nearby. Therefore, another possibility is to expand the area reconstructed for the VR experience.

In connection with this, looking more closely at the time manipulation aspect may also be interesting. Currently, the user can only rewind and fast forward the time. With more details and a larger reconstruction area, it can also be relevant to be able to adjust the speed of time to play the reconstruction faster or more slowly.

7.5.2 Visualising uncertainties

One should look more closely at how uncertainties can be visualised, such as people's positioning and their actions at different times. Developing functionality that allows users to change the amount of uncertainty visualisation through interactivity may be appropriate. This can be done for example by using a slider or a switch to increase or decrease the transparency effect in this case. We believe this could also solve the problem regarding the participants missing the uncertainty effect or overlooking it, which came up during the testing.

Depending on preferences, it can also be good to combine and/or develop different ways of visualising uncertainties. In connection with this, the user can choose which visualisation technique they want to use, which also was mentioned during the testing. These techniques can be, for example, those presented in section 3.3 *Manage uncertainties*.

In addition, there is a need for more research regarding source material from the event that can be used for the reconstruction to limit uncertainties. However, a relatively simple solution to reduce the uncertainty in our reconstruction can be to project the video material onto the project in Unity and triangulate the positioning, which was mentioned previously in section 3.2 *Motion tracking*.

7.5.3 Providing more information

It can be beneficial to have two parts of the reconstruction that the user can switch between; a passive and an active part. The passive part is similar to the reconstruction we have done where the user is a spectator and can see the events like a movie in VR. The active part, in turn, is more interactive where the user can click around to get more background information about the event and the people. We imagine that if the user switches to the active part, the screen image freezes and the only thing that moves in the virtual environment is the user himself. This is in accordance with what emerged during the user tests regarding a desire to receive more continuous information throughout the course of events.

In addition, it also emerged during the tests that one would like to see more guidance regarding where to look, for example through louder sounds. One possibility we see is to use graphics, for example, arrows on the user's field of vision that point in the direction they should look to avoid missing the next sequence of events. It is worth pointing out that this can reduce immersion and presence. It can potentially be countered by having a switch to turn the guidance functionality on and off.

7.5.4 Implementing perspectives

Another possibility for future work is the opportunity of implementing different perspectives and seeing the reconstruction from different angles. It can be beneficial for legal processes to be able to see reconstructions of similar events from the perspective and field of view of different spectators. For example, one can see the same event from the perspective of a spectator sitting in a car, or from the perspective of a person who is in a building. As a result, details can be found that would otherwise be missed.

7.5.5 Guidelines for reconstructions in VR

Based on this thesis and the six presented approaches presented in section 3.6 *Images as credible evidence*, we see a future opportunity to produce guidelines for future reconstructions in virtual reality.

The points presented during 3.6 *Images as credible evidenc*e, show great utility in creating a reconstruction with moving material from different sources. If this thesis did not have the documentary by du Rées as a basis, our work would have been more difficult. Based on this, we believe that the presented guidelines are better suited to the preliminary work of a VR reconstruction (creating a reconstruction film with collected material), rather than the VR reconstruction itself.

7.5.6 Preserve and learn from history

Making a reconstruction of a historical event can lead to learning material for the future. We hope that reconstructions of this type can serve as, for example, a handbook for police and demonstrators to see what was missing then and what can be supplemented now. This is to create more order and structure and hopefully avoid similar situations in the future having equally drastic results.

We also see it as an opportunity to preserve the history close to us. Provided that the reconstruction area is expanded, it may be an opportunity for students attending the Hvitfeldska or Schillerska gymnasium today to participate in what happened at the schools during the riots. The happenings at the gymnasiums were explained in section 2.1.1 *The barricading of the Hvidfeldska gymnasium*, and 2.1.5 *The storming of Schillerska gymnasium*. This is also per the results we obtained from the user tests, where they believed that VR reconstructions could have a wide range of uses both for fun and learning.

8

Conclusion

The aim of this thesis has been to create a reconstruction in VR of a historical event, which in this case has been the shooting at Vasaplatsen during the Gothenburg riots in 2001. To achieve this, the following research questions have been aimed at being answered:

1. RQ1: Which aspects of the Vasaplatsen shootings in 2001 can be reconstructed using VR technology?
    (a) Sub RQ1: What is the most efficient and reliable way of implementing motion tracking of people in VR from a real-life event?
    (b) Sub RQ2: Which factors are relevant to consider when reconstructing a real event in VR?
    (c) Sub RQ3: What aspects are important to create a high immersion and presence in virtual reality?
2. RQ2: Can a VR reconstruction of a crime scene contribute to an increased understanding of the event?

To answer RQ1, the aspects of the shooting that were possible to reconstruct were Vasaplatsen, audio, light, street objects and the relevant key people. The final VR experience also includes motion tracking, where the key persons move and behave as they did in real life. To achieve this manual markerless motion tracking was used, mainly due to the quality of the source material. However, to answer sub RQ1, we believe that the most optimal and reliable way of motion tracking people in VR from a real-life event would be to use *automated* markerless motion tracking. By automated, we mean using deep learning and artificial intelligence instead of tracking manually as we did. A prerequisite for this, however, is that one must have the time, the software and film clips with sufficient quality. The choice is based on marker-based tracking being resource-intensive and difficult to reproduce criminal acts. *Manual* markerless tracking, in turn, can through human error and calculations, result in both large and small misplacements of characters if not triangulated to some degree.

Several factors are important to consider when reconstructing a real event in VR, as an answer to our sub RQ2. We believe the main factor is the risk of bias and influence

from the developers. In our opinion, everything that strives to represent reality has the developer's fingerprint, even if one always tries to be as objective as possible. In addition, it should be avoided to include uncertainties, but in cases where this is not possible, it is important that these are marked out clearly for the sake of the user. This is especially important in judicial processes where a reconstruction like this can be used as evidence.

To answer our sub RQ3, we have during the work with the VR experience speculated about immersion and presence and how to increase it for our project. We found that details and precision were fundamental aspects. The motion tracking and the digital twin increased the immersion and presence in the VR experience. It also increased with each iteration. In addition, audio also played a central role in immersion and presence. The audio is not the one from the actual event, but it closely resembles how it sounded. Visual-wise, Vasaplatsen has been recreated to look like its real-life counterpart thanks to the digital twin and other modifications. The same goes for light design in the VR experience, which provides the same ambience as in the source material.

To answer our RQ 2, we believe these types of reconstructions could benefit a crime case and investigation. The reconstruction would give access to the crime scene whenever someone wants to see it. It would also be a good tool to visualise the crime, but more research needs to be done to give a conclusive answer. Much like the prosecutor who excluded two gunshots in the Gothenburg riots trials, a reconstruction like ours can be used maliciously and have to be used cautiously. We can see how a reconstruction would be used to misrepresent what actually happened and not be truthful.

From the beginning of the project, we counted on the fact that things would take longer to create than we expected. This prophecy came true. Our struggle was the lack of knowledge of the software we used during the thesis, which required many hours of educating ourselves. Other bottlenecks were also present and delayed the work, which was mentioned previously. The process was often two steps forward and one step back, which was sometimes frustrating. Despite this, it has been very rewarding and educative work, where we have learned a lot. Before the thesis, we had no experience with either VR development or Unity. The thesis has been as much of an opportunity for us to try something new as it has been to learn how to develop a VR experience. We have also gathered an understanding of how essential it is to have a good basis with good quality to create a reconstruction of a real event in VR.

This thesis has included many steps, all of which have room for future work and have been presented during the discussion. This included, for example, expanding the reconstruction area, implementing perspectives and creating guidelines for future reconstruction in VR. Several recommendations for future work were also confirmed during the user tests carried out at the end of the work. However, for this thesis, we conclude that our VR reconstruction has been successful, and we have included the important aspects when recreating a real-life event in VR.

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A

Appendix A

VR Project Design Document

2023/03/14
Kalle Areschoug & Romina Asadi

1 App Info

Tentative Title:	VR reconstruction of the Gothenburg riots

✔	Education & Training		Mental Health & Fitness
	Travel & Discovery		Media & Entertainment
	Productivity & Collaboration		Gaming
✔	Art & Creativity	✔	Other: Profound & Emotional

2 Pitch

To goal is for users to [experience]:

the event themself and will help them create their own understanding of what happened during the Gothenburg riots.

This will be especially [impactful] in VR b/c:

It has not been done previously, and there are still uncertainties regarding the event and its outcome.

At a high level, during the app, users will:

Move around and see the event unfold from different views

This experience will be targeted at devices with:

[6]	degrees of freedom, giving users control over the	[movement & rotation]	of their head & controllers.

3 Basics

The app will take place in:

Vasaplatsen in Gothenburg

and the user will get around the scene with:

[teleport]	movement.

The user [will not] be able to grab:

- anything
-
-

There [will not] be sockets:

-
-
-

4 Events & Interactions

There will be haptic / audio feedback when:

- When the user teleports
- (Maybe when the event start)

There will also be 3D sound from:

- Important events in the experience.
-

If the user is holding:

The wristwatch	and presses the trigger,	The time will be manipulated.
pointing	and presses the trigger,	teleport
Start button	and presses the trigger,	The simulation will start.
		Suggestions: a UI change, a sound/video plays, a particle plays, an object is spawned or destroyed.

By default, the left hand will have a: [Ray] interactor.

and the right hand will have a: [Ray] interactor.

And you [will not] be able to toggle on a [Direct] interactor using the [thumbstick | button].

The main menu will be located:

On the right arm

and from the main menu, the user will be able to:

- Paus
- Restart

[Optional] There will be additional UI elements for:

- Time manipulation
- Introduction
- (Maybe for background information)

5 Optimization & Publishing

To make the user experience more accessible / comfortable:

- The user will be able to stay sit down through all of the experience.
-
-

Given that this app is targeting the [headset model], target metrics are:

Frames per second:	>= 72	FPS
Milliseconds per frame:	< 13.9ms	ms (= 1,000 / FPS)
Triangles per frame:	750K -1.0m	tris
Draw calls per frame:	200 - 300	batches

Lighting strategy:

✔	All baked		Mostly baked with some mixed		All real-time

Light probes [will not] be used for more realistic mixed lighting.

6 **Other features (Optional)**

-
-
-
-
-
-
-
-

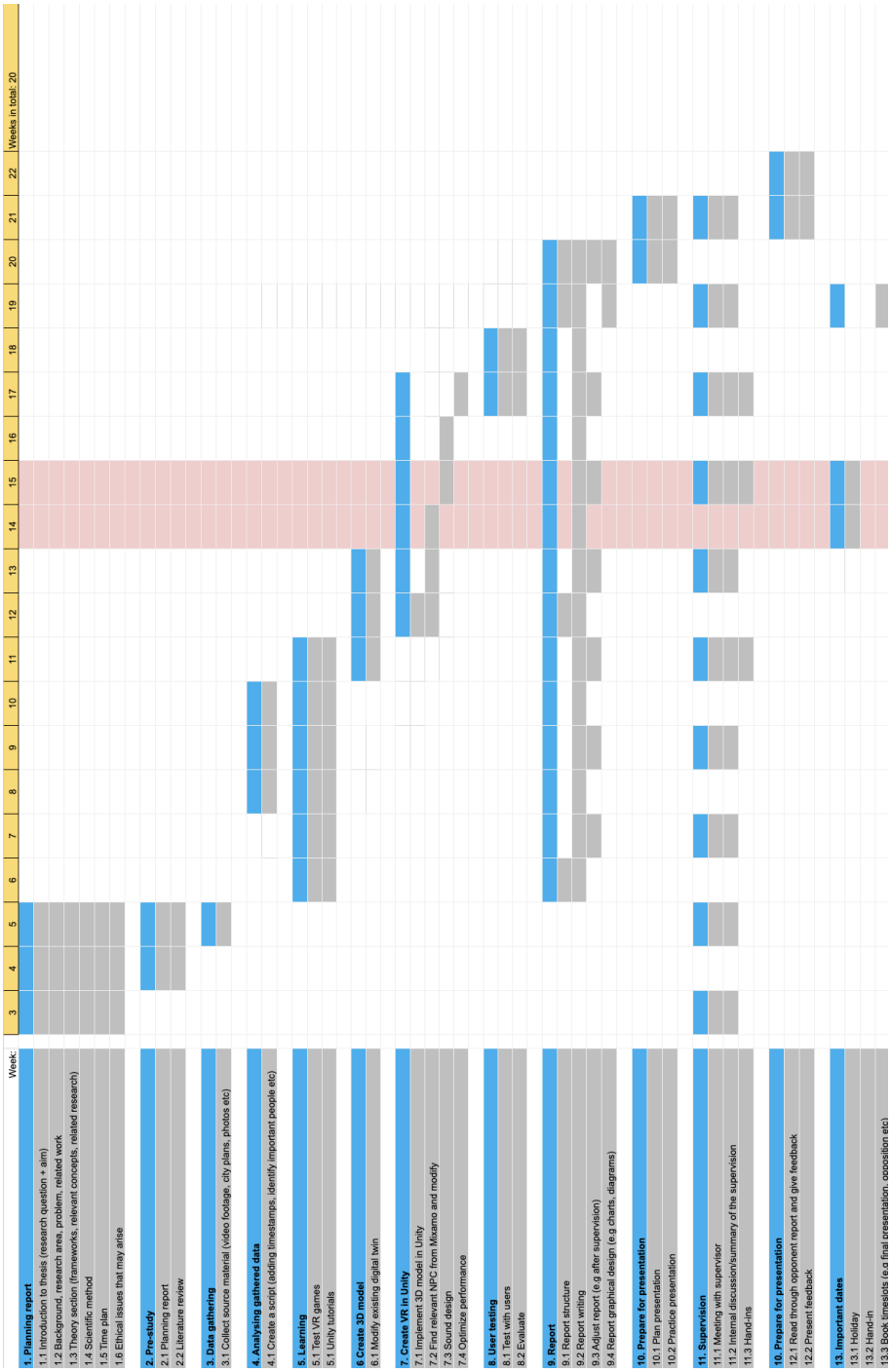
7 **Sketch (Optional)**

8 **Timeline (Optional)**

	Milestone	Date
1	- Implement the 3D-model	15/3
2	- Finish with animations	24/3
3	- Add audio	28/3
4	- Implement time manipulation	29/3
5	- First prototype completed	6/4

B

Appendix B


Week:
3
4
5
6
7
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11
12
13
14
15
16
17
18
19
20
21
22
Weeks in total: 20
1. Planning report
1.1 Introduction to thesis (research question + aim)
1.2 Background, research area, problem, related work
1.3 Theory section (frameworks, relevant concepts, related research)
1.4 Scientific method
1.5 Time plan
1.6 Ethical issues that may arise
2. Pre-study
2.1 Planning report
2.2 Literature review
3. Data gathering
3.1 Collect source material (video footage, city plans, photos etc)
4. Analysing gathered data
4.1 Create a script (adding timestamps, identify important people etc)
5. Learning
5.1 Test VR games
5.1 Unity tutorials
6 Create 3D model
6.1 Modify existing digital twin
7. Create VR in Unity
7.1 Implement 3D model in Unity
7.2 Find relevant NPC from Mixamo and modify
7.3 Sound design
7.4 Optimize performance
8. User testing
8.1 Test with users
8.2 Evaluate
9. Report
9.1 Report structure
9.2 Report writing
9.3 Adjust report (e.g after supervision)
9.4 Report graphical design (e.g charts, diagrams)
10. Prepare for presentation
10.1 Plan presentation
10.2 Practice presentation
11. Supervision
11.1 Meeting with supervisor
11.2 Internal discussion/summary of the supervision
11.3 Hand-ins
10. Prepare for presentation
12.1 Read through opponent report and give feedback
12.2 Present feedback
13. Important dates
13.1 Holiday
13.2 Hand-in
13.3 Book timeslots (e.g final oresentation, opposition etc)

C

Appendix C

Time (unity)	Time (real)	Hannes	Police group 1 (stone throw)	Police group 2 (reinforcement)	Shot
0:00:00	1:37:26		Standing in the middle of the road		
0:00:23	1:37:49		Backing towards the corner of Aschebergsgatan/ Vasagatan		
0:00:28	1:37:54	Visible for the first time	Stands with their backs against the corner facade at Aschebergsgatan/ Vasagatan		
0:00:33	1:37:59	Picks up the first stone	Same as above		
0:00:34	1:38:00	Runs forward	Standing closer to the wall with their shields up		
0:00:35	1:38:01	Throws first stone	Same as above but starting to slowly move sideways to Vasagatan		
0:00:39	1:38:05	Standing in front of police group 1	Walks to Vasagatan with their backs against the building facade		
0:00:41	1:38:07	Picks up the second stone	Same as above		
0:00:43	1:38:09	Throws second stone	Begins to back towards the street		
0:00:44	1:38:10	Not visible (until 1:38:14)	Same as above		
0:00:48	1:38:14	Barely visible	Same as above		
0:00:54	1:38:20	-	Not visible. Guess: probably one of them that shoots		1
0:01:02	1:38:28	-	Same as above		2-4

0:01:04	1:38:30	-	-		
0:01:06	1:38:32	Not visible. Guess: running back due to the sound of shooting	-		
0:01:08	1:38:34	-	Guess: the cop in the shooting position is from group 1		
0:01:10	1:38:36	-	Not visible Guess: Moving forward		5-7
0:01:12	1:38:38	-	-		
0:01:13	1:38:39	Barely visible	-		
0:01:15	1:38:41	-	-		
0:01:18	1:38:44	Visible	-		
0:01:21	1:38:47	-	Visible in the background (unclear)		
0:01:22	1:38:48	-	Guess: probably one of the cops with their weapon still visible		
0:01:24	1:38:50		Starting to form a group by the trees at Vasagatan	Visible for the first time. Coming towards Vasagatan from Aschebergsgatan in a group	
0:01:28	1:38:54	-	A bengal is lit	Same as above, turn to Vasagatan	
0:01:40	1:39:06	-	Guess: Probably the same group that is gathering at the back	Same as above	
0:01:47	1:39:13	Visible and running towards the cops	-	Same as above	
0:01:51	1:39:17	Picks up a third stone	-	Same as above, but begins to	

				gather in the center aisle on Vasagatan among the trees	
0:01:54	1:39:20	Throws third stone	Standing in front of Hannes, approx. 10m	Same as above	
0:02:00	1:39:26	Picks up fourth stone	Same as above, bigger distance, approx. 15m	Same as above	
0:02:02	1:39:28	Throws fourth stone	Same as above	Same as above	8
0:02:03	1:39:29	Is shot	Guess: Probably one of them pulls a gun on Hannes but is not visible. Could be him in the middle as it looks like he is doing a shooting motion.	Same as above	
0:02:05	1:39:31	Running towards the intersection (road) with his back to the police	-	Same as above	
0:02:11	1:39:37	Lays down	-	Starts forming a line	

D

Appendix D

Questions before

- Have you tried VR before?

Questions during

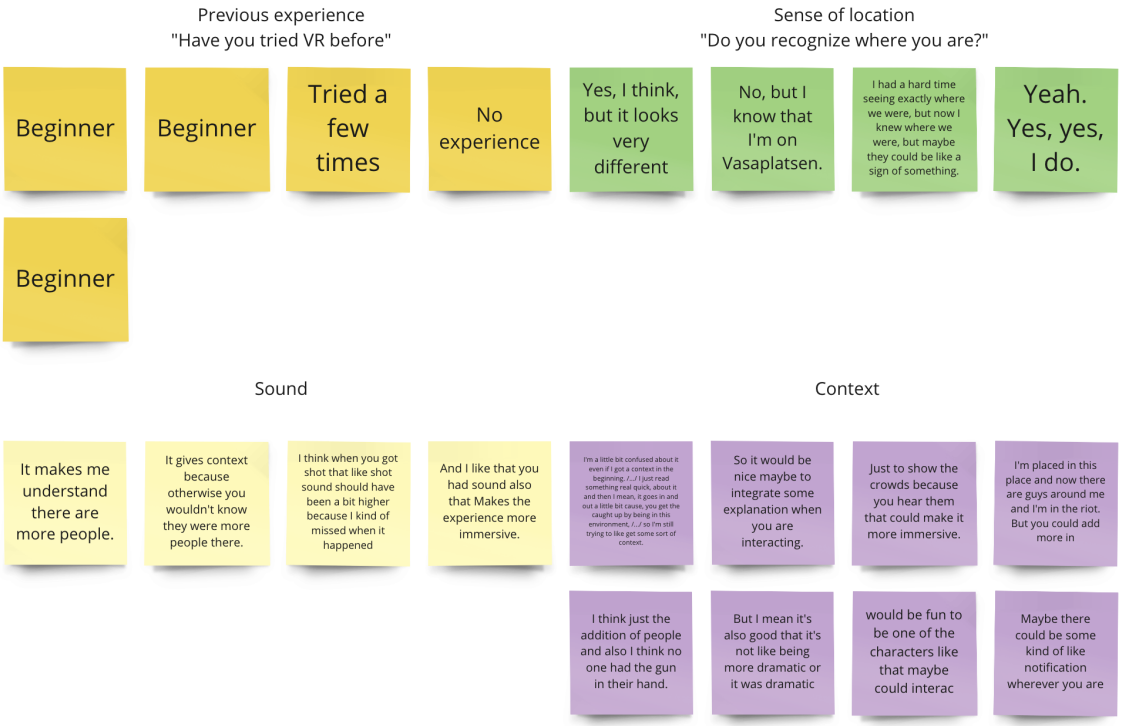
- Can you describe what you are seeing?
- What are your overall feelings toward the experience?
- On your left arm you have a tablet, can you use it and give your thoughts regarding it?
  - (What does it do and how easy is it to use?)

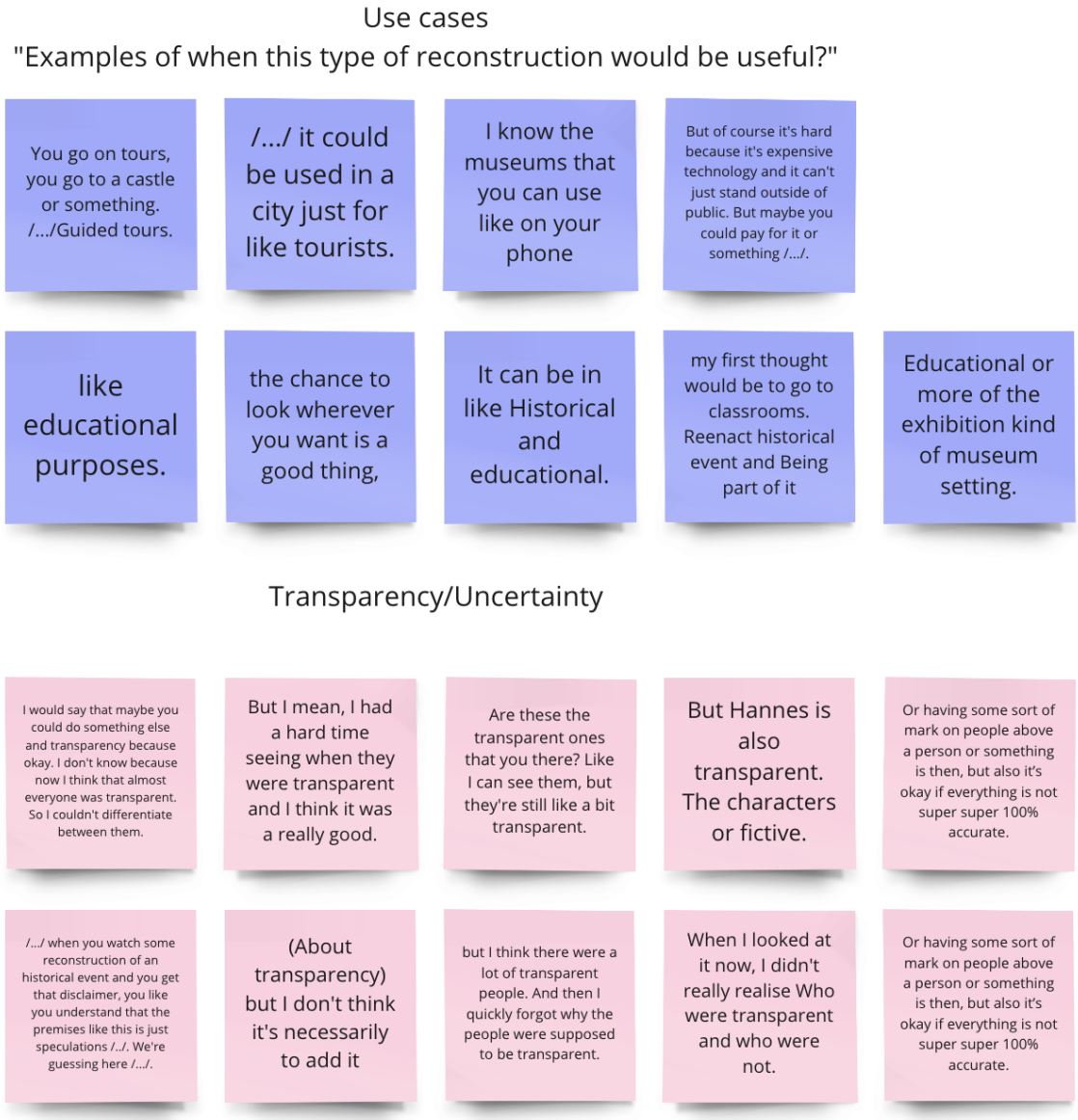
Questions afterwards

- Are you able to give examples of situations where you think that this type of reconstruction would be useful?
- This is a proof of concept. Which aspects of the reconstruction would you like to have more detailed?
- Did you feel immersed, do you have any suggestions on what would increase the immersion or presence?
- In some parts of the reconstructions, the characters were transparent. What do you think that means?
  - Did your attention go towards it or did you just pass it without further notice?
  - Was it an effective way? (to show uncertainties)

E

Appendix E


Previous experience
"Have you tried VR before"
Beginner
Beginner
Tried a few times
No experience
Beginner
Sense of location
"Do you recognize where you are?"
Yes, I think, but it looks very different
No, but I know that I'm on Vasaplatsen.
I had a hard time seeing exactly where we were, but now I knew where we were, but maybe they could be like a sign of something.
Yeah. Yes, yes, I do.
Sound
It makes me understand there are more people.
It gives context because otherwise you wouldn't know they were more people there.
I think when you got shot that like shot sound should have been a bit higher because I kind of missed when it happened
And I like that you had sound also that Makes the experience more immersive.
Context
I'm a little bit confused about it even if I got a context in the beginning. /.../ I just read something real quick, about it and then I mean, it goes in and out a little bit cause, you get the caught up by being in this environment, /.../ so I'm still trying to like get some sort of context.
So it would be nice maybe to integrate some explanation when you are interacting.
Just to show the crowds because you hear them that could make it more immersive.
I'm placed in this place and now there are guys around me and I'm in the riot. But you could add more in
I think just the addition of people and also I think no one had the gun in their hand.
But I mean it's also good that it's not like being more dramatic or it was dramatic
would be fun to be one of the characters like that maybe could interac
Maybe there could be some kind of like notification wherever you are


Use cases
"Examples of when this type of reconstruction would be useful?"
You go on tours, you go to a castle or something. /.../Guided tours.
/.../ it could be used in a city just for like tourists.
I know the museums that you can use like on your phone
But of course it's hard because it's expensive technology and it can't just stand outside of public. But maybe you could pay for it or something /.../.
like educational purposes.
the chance to look wherever you want is a good thing,
It can be in like Historical and educational.
my first thought would be to go to classrooms. Reenact historical event and Being part of it
Educational or more of the exhibition kind of museum setting.
Transparency/Uncertainty
I would say that maybe you could do something else and transparency because okay. I don't know because now I think that almost everyone was transparent. So I couldn't differentiate between them.
But I mean, I had a hard time seeing when they were transparent and I think it was a really good.
Are these the transparent ones that you there? Like I can see them, but they're still like a bit transparent.
But Hannes is also transparent. The characters or fictive.
Or having some sort of mark on people above a person or something is then, but also it's okay if everything is not super super 100% accurate.
/.../ when you watch some reconstruction of an historical event and you get that disclaimer, you like you understand that the premises like this is just speculations /../. We're guessing here /.../.
(About transparency) but I don't think it's necessarily to add it
but I think there were a lot of transparent people. And then I quickly forgot why the people were supposed to be transparent.
When I looked at it now, I didn't really realise Who were transparent and who were not.
Or having some sort of mark on people above a person or something is then, but also it's okay if everything is not super super 100% accurate.

F

Appendix F

A link to a clip from the reconstruction can be seen **here**.