The disappeared Castle – The Return of the Horneburg in Virtual and Augmented Reality

Thomas P. Kersten[1], Malte Marsmann[1], Florian Timm[1]

[1] HafenCity University Hamburg, Photogrammetry & Laser Scanning Lab, Henning-Voscherau-Platz 1, 20457 Hamburg, Germany
[Thomas.Kersten, Florian.Timm]@hcu-hamburg.de, Malte.Marsmann@icloud.com

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Abstract

Technological advances in virtual reality (VR) in recent years have the potential to impact our everyday lives increasingly. VR enables us to explore a digital world through an immersive experience with a head-mounted display (HMD). When combined with tools for 3D documentation and modelling, as well as software for creating interactive virtual worlds, VR can play a significant role in preserving and visualising cultural heritage for museums, educational institutions, and other cultural sectors. VR opens up a new form of scientific communication that can benefit damaged, destroyed or distant historical and cultural heritage objects. On the other hand, augmented reality (AR) can resurrect and display forgotten and lost cultural heritage objects and monuments in their original locations via mobile devices.

This paper presents the development of a VR and AR application of the disappeared Horneburg castle, which does not exist anymore since almost 400 years. These applications will serve as tourist attractions for visitors to the municipality of Horneburg, enabling them to experience the castle's historic life in an immersive way at the museum and interactively on site. Based on the uncovering of the underground remains of the castle by geomagnetic prospecting the Horneburg Castle was reconstructed using a derived 2D site plan and architectural drawings of the castle buildings. The 3D models of the buildings were constructed using the 2D drawings, which were then transferred to the game engine Unreal 5 for texture mapping and immersive visualisation. The AR app was developed to visualise the whole building ensemble with the wooden palisade around the castle or each individual building on mobile android and iOS devices using WebXR and Three.js on site in nature (option 1) and location-independent (option 2). The technical implementation of the VR and AR applications is presented in this article.

1. Introduction

In recent years, there has been a notable increase in focus on virtual reality (VR) applications for digitally reconstructing and representing historic buildings, cities and monuments. VR applications enable users to create, explore and experience virtual environments. Notably, it allows users to visualise objects that no longer exist (Deggim et al., 2017a) or only exist in plans and drafts. Virtual environments have the capacity to closely replicate reality and offer a wide range of representations. These novel VR technologies facilitate immersive experiences in computer-generated environments. Furthermore, developing and implementing a VR application could represent a new approach to knowledge transfer, as users could interact within the virtual environment to obtain information. Kersten et al. (2020) describe the development of a VR application for the four-masted steel barque Peking, a historic ship built from 1910 to 1911 by the Blohm + Voss shipyard in Hamburg for the F. Laeisz shipping company. In this VR application, the significance of the sails and various flags is interactively explained, as well as working steps of photogrammetric data acquisition and modelling.

In contrast, augmented reality (AR) is a technology that overlays digital information, such as images, 3D models or text, onto the real world in real time, enhancing human perception without replacing it. Experienced via devices such as smartphones, tablets or special AR glasses (e.g. Google Glass and Microsoft HoloLens 2), AR has a variety of applications, including entertainment (e.g. Pokémon Go), industry (e.g. maintenance) and marketing (e.g. virtual fitting rooms). Unlike virtual reality (VR), AR allows you to remain in your real environment while supplementing it with digital elements. AR is also increasingly being used in the field of cultural heritage. For example, it can be used to display buildings, monuments or other objects that no longer exist in their original location, and to provide additional information about them, via mobile devices.

This paper describes the development of a VR and AR application that brings the now-defunct Horneburg castle back to life for users, whether they are in the museum with a VR headset or at the original site with an AR device. The project aimed to rebuild the castle and visualise its reconstructed environment. Section 2 summarises related work in VR and AR, while section 3 describes the history of Horneburg Castle. The 3D reconstruction of the castle is presented in section 4. Section 5 introduces the game engine and VR head-mounted display used, while in the following two sections the implementation of the VR (section 6) and AR (section 7) application is described.

2. Related Work

Virtual reality (VR) is playing a significant role in advancing the field of virtual cultural heritage. It enables a new way of communicating with the public and the scientific community, particularly regarding historical artefacts and monuments that are damaged, destroyed or located far from potential visitors (Addison, 2000; Affleck and Thomas, 2005; Stone and Ojika, 2005).

However, VR and AR increasingly play an important role in education as analysed by Al-Ansi et al. (2023). The results of their evaluation reveal that the adoption of AR and VR in education has grown exponentially in recent years, with wearable devices accounting for a large portion of this development. Based on further investigations, the results also reveal a gap in the quick implementation and customisation of these technologies in

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educational institutions. As AR and VR technologies continue to develop and mature, more educational applications are emerging in the learning process.

Some virtual reality applications have been developed at HafenCity University Hamburg, particularly focusing on historic architectural objects and monuments such as cultural and religious sites, including a wooden replica of Solomon's Temple (Kersten et al., 2018), the Selimiye Mosque of Edirne, Turkey (Kersten et al. 2017) and the Imperial Cathedral in Königslutter, Germany. The latter uses 360° panorama photographs to create an immersive, real-time visualisation (Walmsley and Kersten, 2020). Additionally, a virtual reality application has been developed for the OTTOMAN Fortress in Istanbul (Tschirschwitz et al., 2019a) and the Al Zubarah fortress in Qatar (Kersten et al., 2021). Furthermore, three historical German cities and their surrounding areas have been developed as virtual reality experiences: These are Duisburg in 1566 (Tschirschwitz et al., 2019b), Segeberg in 1600 (Deggim et al., 2017b) and Stade in 1620 (Walmsley and Kersten, 2019). Examples for other VR applications for historic monuments and sites are published by various authors among others (Medyńska-Gulij and Zagata, 2020; Bożorghi and Lischer-Katz, 2020; Edler et al., 2019; Janovský et al., 2022).

Some authors provide an overview of augmented reality (Azuma, 1997; Carmigniani and Furht, 2011; Arena et al., 2022), while others survey augmented reality technologies, their applications, and their limitations (van Krevelen and Poelman, 2010). Vertucci et al. (2023) summarise the historical evolution of AR since its inception. Azuma (1999) discusses the challenge of making AR work outdoors, while Kee et al. (2019) present the best AR practices for history. Teruggi and Fassi (2022) describe an interesting AR application using the Microsoft HoloLens 2 for spatial indoor mapping capabilities in the vast monumental heritage environment of Milan Cathedral, for example. Grimm et al. (2022) give an overview of VR/AR Input Devices and Tracking.

3. The History of the Castle Horneburg

Horneburg Castle is a late medieval moated castle located in the municipality of Horneburg, in the district of Stade, in the state of Lower Saxony, Germany. The castle stood about 12 kilometres southeast of the district town of Stade and around 30 kilometres west of Hamburg. It was built in 1255 on behalf of the Archbishop of Bremen on the grounds of Harsefeld Monastery. It was situated on a circular, marshy island in the floodplain, measuring approximately 77 metres in diameter. It was surrounded by a section of the Lühe river, approximately eight metres wide. The castle itself consisted of an 'inner' castle and an outer bailey. The 'inner' castle was fortified with a rampart and palisades. It contained a stone residential tower, stables, warehouses and a separate house for each burgher family. The 'inner' castle could be accessed from the outer bailey via a drawbridge. The outer bailey was also fortified and surrounded by a branch of the river. It could only be reached via a drawbridge.

The castle remained inhabited until 1510. After that, the families who lived there gradually moved out of the outer bailey and into newly built manor houses in the surrounding area. From then on, the castle was used only as a place of refuge in the event of an attack. During the Thirty Years' War, Horneburg was captured by the Spanish-Dutch commander Tilly on 11 October 1627. Gustav II Adolf, King of Sweden, recaptured Horneburg in 1632. Large parts of Horneburg Castle were burned down and destroyed in both 1627 and 1632 (only the burgrave's house was spared). In 1645, the Swedes occupied Horneburg Castle. The castle lost its defensive importance and was finally destroyed (Ahrens, 2010).

In recent years, Castle Island has mainly been used as an allotment garden (Figure 1, top). The only way to access the island is via an overgrown footbridge on the north-west side. The area of the former outer bailey now contains a half-timbered manor house dating from 1840 and a castle park. Today, nothing remains of Horneburg Castle.

Figure 1. Horneburg Castle – Old nadir view of the historic ground (top, photo Hartmann, DLRG Horneburg), floor plan of the historic castle complex (bottom, Mennenga, 2020).

4. The Reconstruction of the Castle

The idea to resurrect the invisible Horneburg Castle (Figure 1, top) and turn it into a park and museum attraction arose in the municipality of Flecken Horneburg. Therefore, geomagnetic prospecting was carried out in October 2020 by archaeologists from the University of Hamburg (Institute for Prehistoric and Early History Archaeology) to provide initial insights into the layout and components of the castle's buildings. The results are shown in Figure 1 (bottom), which shows the number and size of the individual buildings in the 'inner' castle. It is said that a residential tower, a bakery, four farm buildings and four Ganerben (residential units belonging to a community of heirs) were present in the castle. Using the results of the geomagnetic prospecting data, along with the findings of archaeologists and information from comparable castles, Dr Joachim Zeune from the Office for Castle Research in Bavaria and Menno Mennenga from Reunion Media reconstructed the castle complex. Their 2D architectural drawings of the buildings (Figure 2) formed the basis for the historic Horneburg to be reconstructed in 3D at the HCU Hamburg before its destruction in the Thirty Years' War. The 3D construction of the buildings was carried out using the 2D drawings in AutoCAD software. Figure 3 shows exemplarily the front and back facade of the building model Ganerben IV as 3D solid.

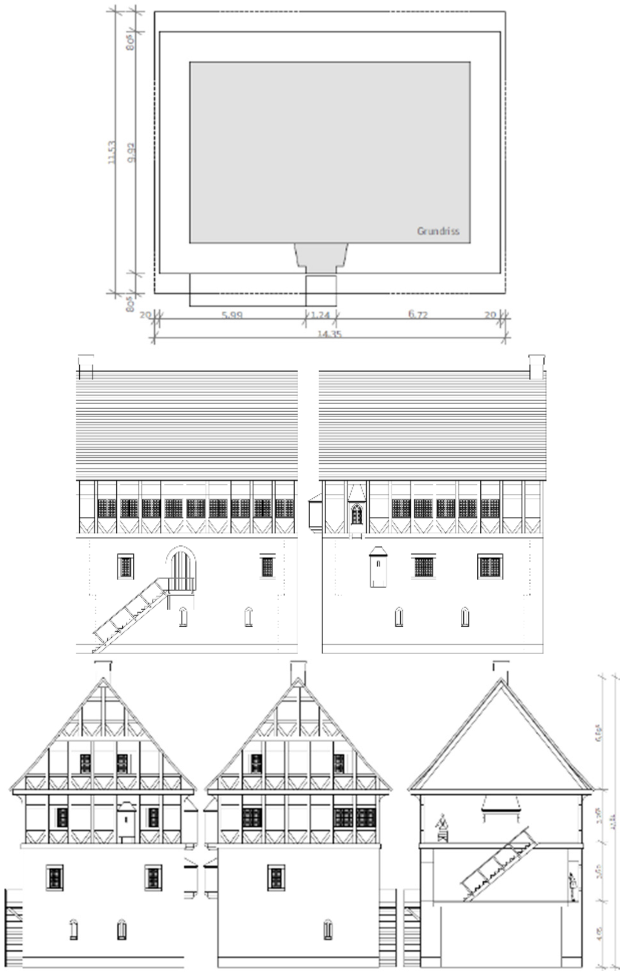

Figure 2. 2D architectural drawings (ground plan and facades) of the residential tower of the Horneburg Castle (© Reunion Media, Emden, Germany; Mennenga, 2020).

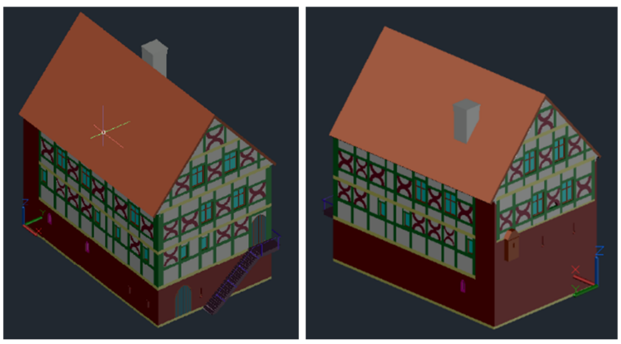

Figure 3. Exemplary 3D reconstructed building (front and back facade of Ganerben IV) of the Horneburg Castle.

5. The Game Engine and the VR System used

5.1 The game engine used

A game engine is a software framework designed for the creation and development of video games. The core functionality typically provided by a game engine includes a rendering engine for 3D graphics to display textured 3D models (spatial data), a physics engine with collision detection for object interaction and an audio system to emit sounds.

Unreal Engine 5 (UE5) is the latest version of the Unreal Engine software developed by Epic Games. It was unveiled in May 2020 and officially released in April 2022. UE5 includes several upgrades and new features, such as Nanite, which automatically adjusts the level of detail of meshes, and Lumen, which is a dynamic global illumination and reflections system that uses software and hardware-accelerated ray tracing. UE5 was selected because it offers the opportunity to develop application and interaction logic using a visual programming language called Blueprints. With Blueprints, visual programming does not require the writing of machine-compliant source code. UE5 version 5.4.4 was used for this project.

5.2 The VR system used

The Pico 4 was used as a head mounted display (HMD) for the development of this VR app. The PICO 4 is an all-in-one VR headset for gaming and immersive experiences. The headset is equipped with two 2.56-inch Fast-LCD screens that deliver 105° field of view for more immersion. Thanks to its 4K+ LCD displays (2160×2160 pixel per eye), pancake lenses and 90 Hz refresh rate, it delivers sharp images and smooth performance. Powered by a Qualcomm Snapdragon XR2 processor (8 GB RAM), it features inside-out tracking via four cameras and precise controller tracking. This enables both wireless standalone gaming and PC VR streaming. The headset is lightweight (586g) and has a balanced design, as well as a padded face cushion for comfortable use, making it ergonomic. The PICO 4 Ultra will then be used for the virtual reality (VR) app demonstrations at the local craft museum.

Figure 4. PICO 4 all-in-one VR headset with controllers.

6. Implementation of the VR Application

The implementation of the VR app involves several processes, including data processing. These processes are described in the following subchapters.

6.1 Landscape and vegetation

UE5 gives developers the option to use their own editor mode (the Landscape tool) to model and texture the landscape. To adapt the terrain of Horneburg Castle to the current topography, the publicly available DGM1 digital terrain model from LGLN

Lower Saxony, with a 1 m × 1 m grid, was used. The Landscape tool was then used to smooth the terrain and adjust the water areas around the castle. Light fog was added to give the landscape a realistic horizon in combination with trees and other vegetation. To achieve this, typical North German vegetation, such as European hornbeam (with 27 unique tree assets: 10 forest trees, 4 field trees, 8 saplings and 5 seedlings), full-geometry European beech trees and various grasses, was downloaded from the Unreal Engine Marketplace. The Foliage function was then used to randomly generate different sizes and rotations, and the data volume was reduced by lowering the triangle mesh count. Additionally, automatic triangle reduction was implemented at a corresponding distance from the player.

6.2 Lighting

UE5 offers a variety of light sources, each with different parameters and functions. The VR template provides everything needed to design the sky and set up daylight in advance. The SkyLight was set to 'static', meaning the lighting of the textures and light source only needed to be calculated once, significantly improving performance. The light was not completely perpendicular to the landscape, and the colour was adjusted to create a medieval atmosphere.

6.3 Texture mapping of buildings

The building models could be imported directly into the project as FBX files. Correct scaling had to be ensured during import. The site plan was used to align the nine models. Realistic textures were chosen to reflect the location and history. Houses from the early, high and late Middle Ages were primarily constructed from wood or clay, or in a half-timbered style with wattle-and-daub walls made from straw or reeds. Some permanent houses from that period were also built using stone, mostly fieldstone and granite. The textures were chosen accordingly. They were selected in consultation with the archaeologist to ensure the use of realistic, contemporary colours and materials. Depending on the texture's material, its reflection strength and properties such as roughness were adjusted. A texture was applied to the water surface, with the change in texture being controlled by a blueprint to ensure water movements with different reflection properties and height changes.

Figure 5. User view of the castle when starting the application (top) and perspective view of the castle (bottom).

Figure 6. User's view of the castle entrance area (top) and view to the residential tower (bottom).

6.4 Navigation and collision

The user starts outside the castle in the VR app, in front of the drawbridge (Figure 5), visit and explore the Horneburg Castle (Figure 6). Ego motion and navigation are controlled by continuous, smooth movement rather than teleportation via a button on the controller. This provides a fluid and intuitive navigation experience for the user. However, this movement requires significant computer processing power, which can slow down the VR app to the point where motion sickness may occur. To limit navigation to a specific area and avoid collisions, blocking boxes were set up to prevent the user from falling into the water or entering the houses, for example (Figure 7, top). Navigation areas were also defined for people and animals inside and outside the castle (Figure 7, bottom).

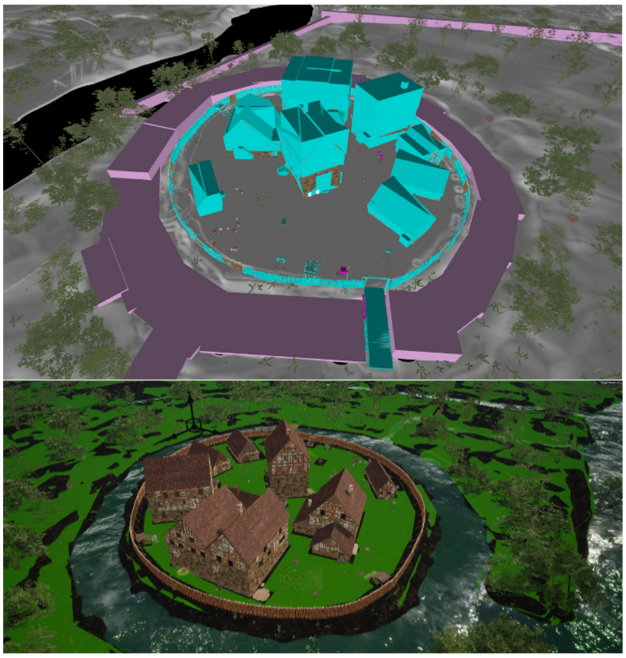

Figure 7. Collision areas outside and inside of the castle (blue and pink, top); navigation areas (green, bottom).

6.5 Interactions and animations

All interactions were created using the Blueprint Visual Scripting System. Users are shown how to interact with the app in the form of a tutorial on the castle grounds, which they can access by pressing the reset button on the controller. The VR app has three built-in interactions that allow users to perform certain activities in the VR environment, such as archery, raising the drawbridge and drawing water from the well for the animals to drink. Animals such as cows, horses, pigs, deer, roe deer, goats and chickens are integrated into the VR scene alongside a few people wearing medieval clothing and walking around inside the castle (Walmsley and Kersten, 2019). Movement is controlled by a randomly generated target point that changes every 3 to 10 seconds.

Figure 8. Various interactions in the VR environment, such as archery (top), raising the drawbridge with the button on the controller specified (centre) and drawing water from the well for the animal trough (bottom).

Archery can be practised near the target. The bow is hung on the wall of a nearby house (Figure 8, top). It can be picked up with one hand while holding the string with the other. Pulling the string releases an arrow, which is then shot when the string is released. The speed of the arrow depends on how tightly the bow is drawn. As soon as you shoot at people or animals, a warning appears and individual sequences are triggered.

The castle's drawbridge can be raised and lowered using the crank wheel, which is connected to the winch by a moving rope ((Figure 8, centre). Turning the crank makes a creaking sound.

To fill the cattle trough, players can grab a bucket and place it in the well. The bucket is then filled with water, which can be poured into the trough (Figure 8, bottom).

Information about the implemented interactions is triggered by spatial boxes within which the user is located. This means that the information boards only appear when you are in the correct box and are always aligned with you.

6.6 Audio

Audio input is important for providing an immersive experience for the user. To maintain consistency with the environment, forest sounds in the form of wind noise were chosen. An MP3 file was downloaded from the internet and converted to a WAV file using an online converter. This was then imported into the project, since only WAV files can be read by Unreal Engine. This was then used to create a sound clip that could be placed anywhere in the level. Volume attenuation can be used to select the areas in which the audio should be heard. Using a random timer, the animals emit sounds that are distributed realistically throughout the room, with the volume depending on the distance from the user. When the cattle trough is filled, the sound of water can be heard, and when the drawbridge is moved, the sound of creaking can be heard.

7. Implementation of the AR Application

The initial version of the AR app was developed in Unity 2023 as part of a master thesis (Becker, 2024). To this end, two different AR tracking functions were investigated to visualise the reconstructed buildings at their historical location and via QR codes at any location (Figure 9). Unity offers an XR plugin for this purpose, providing an AR kit, among other things. This kit integrates sensor data from the end device to create a joint display of the environment and generated 3D data.

In the on-site view variant, the camera, GNSS, magnetometer (compass) and gyroscope are used, as well as the acceleration sensors. In order to calculate the correct image, the position and orientation of the mobile device must first be determined. In this case, the camera data is only used for background information purposes and is not included in the positioning process. Therefore, the positional accuracy of the system depends on the accuracy of the GNSS and compass. Although there are already ways to improve this through pattern recognition, these approaches are mainly intended for urban environments (Rzeszewski and Orylski, 2021), which offer many different surfaces that change little or not at all in appearance. However, the terrain in the former Horneburg is currently characterised by a meadow with trees, offering only limited visibility of existing buildings (Figure 12).

Figure 9. First visualisation of the Horneburg Castle in Augmented Reality – QR code-based AR visualisation of a single building (left and centre top) and of the building ensemble (right top) and sensor-based visualisation (with GNSS and IMU) on a smartphone on site (bottom).

Image tracking using QR codes was employed as a location-independent alternative. Initial positioning is achieved through pattern recognition of the camera image. Once the stored images have been recognised, the corresponding 3D model is positioned and displayed on the screen. If the pattern is no longer recognised in the current camera image, all positions and orientations of the device can then be integrated using the gyroscope and acceleration sensor after the device has been moved. However, this leads to the drift commonly associated with dead reckoning.

However, the disadvantage of the Unity native app was that further development and maintenance relied heavily on the Unity engine. Even two years later, large parts of it were no longer supported in this form. Additionally, the app was intended to be accessible to visitors on site. It was questionable whether users would install such a large app for a one-time visit to the island. Furthermore, maintaining the app for the two major mobile platforms, Android and iOS, and their respective app stores was considered too costly. Therefore, the 3D building data was embedded in a web app using WebXR and Three.js. The advantages of this solution are broad support for end devices and easier maintenance. Although it is technically a normal website, its design and functions are similar to those of a native app. This eliminates the need for distribution via app stores, as a web server is sufficient. Although installation on the user's device is not necessary, it is possible for offline use. Maclntyre and Smith (2018) describe their thoughts on the future of WebXR and the immersive web, while Renius (2019) technically evaluated the WebXR Device API for Developing Augmented Reality Web Applications.

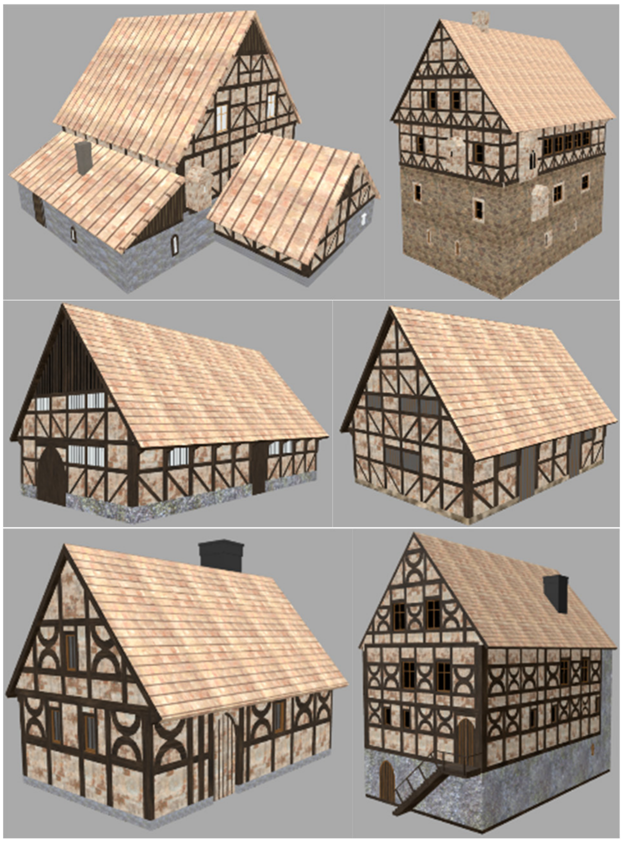

Figure 10. ThreeJS visualisation of six individual buildings of the Horneburg Castle in the WebXR app.

WebXR offers a range of functions similar to those used in Unity's ARKit. Consequently, QR code tracking was rejected, eliminating the need to attach QR codes on site. For the 3D view of the buildings the Three.js JavaScript library was used, in which users can rotate the 3D model themselves and view it from all sides (Figure 10), as is also familiar from sales and product platforms (Jawale et al., 2024). This enables users to utilise familiar functions.

In line with planned mobile use, the building data was retextured using the same textures as the VR app but significantly reducing the data volume from ca. 300 MB to 10 MB per 3D model. This not only improved loading speed but also increased performance on mobile devices with lower-spec hardware. Figure 11 illustrates the interface of the WebXR application for the AR visualisation of the castle and individual buildings.

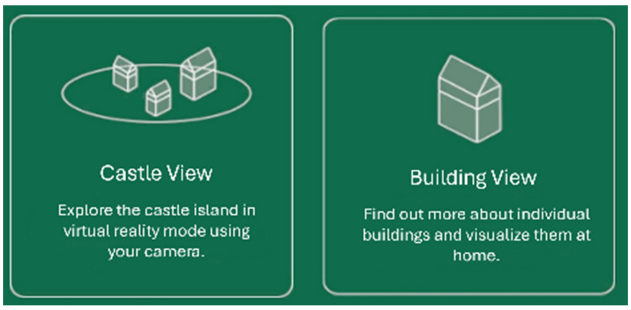

Figure 11. Application interface for WebXR visualisation of the Horneburg Castle and of individual buildings on the mobile device.

8. Conclusion and outlook

This article has used the example of the invisible Horneburg Castle to show how history can be brought back to life through VR and AR applications, making the castle visible again as one of the first cultural heritage monuments in Germany using this technology. You can now enter and explore Horneburg Castle immersively in the VR app, experiencing life in the medieval castle complex. Various interactions and animations support this exploration, allowing users to actively participate in castle life and enhancing the immersive experience. In the future, the VR app could be expanded to include additional interactions, storytelling and serious games. The aim would then be to explore the castle and medieval life in an engaging way to acquire knowledge in a playful way to learn more about the history of the castle and the period in which it was built.

An additional feature of the AR app allows visitors to view the castle buildings directly on site on their mobile device (Android or iOS). The app shows either individual houses or the entire building complex with the palisade and can be accessed via the device's internal sensor technology. Figure 13 illustrates the current situation of the landscape of the castle island.

In the future, the VR application will be presented to visitors at the Horneburg Craft Museum (Figure 13), which is situated a mere 50 metres from the present entrance to the castle island. This will enable visitors to explore Horneburg virtually and immerse themselves in the experience with the assistance of VR glasses such as the Pico 4 Ultra. In addition, the augmented reality application will be accessible online via Internet, enabling visitors to Horneburg to view the castle in its medieval state on site with a mobile device.

Figure 12. Newly designed landscape of Horneburg Castle Island (Photo: Landschaftsarchitektur+).

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