DEVELOPMENT OF A VIRTUAL REALITY APPLICATION FOR A HISTORIC VILLA AND THREE CONSTRUCTION PHASES

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Commission II

KEY WORDS: 3D, Game Engine, Immersive, Laser Scanning, Reconstruction, UAV, Visualisation, VR.

ABSTRACT:

The use of Virtual Reality (VR) is becoming increasingly important and popular. This technology is widely used in various fields such as industry, construction, architecture, medicine and scientific research. With the rapid development of VR technology, the cost of the required hardware is decreasing, making this technology available to a wider range of users. VR applications offer many opportunities to present different topics in a novel and informative way. This paper presents the development of a VR application for the "Villa Michaelsen" (hosting the Falkenstein Doll Museum) in Hamburg, Germany for the 100 years anniversary. It offers the possibility to move in and around the architectural historic building, designed and built 1923 by the architect Karl Schneider, a representative of the New Building Movement, and to look at different information, photos as well as construction phases and drafts.

1. INTRODUCTION

In recent years, virtual reality (VR) applications have received increasing attention in the field of digital reconstruction and representation of historic buildings. In VR applications, virtual, artificial environments can be created, explored and experienced immersively (Dörner et al., 2019). In particular, objects that no longer exist or exist only in plans and drawings can be visualised. The virtual environment can closely mimic reality and offer a wide range of different representations. Using these new VR technologies, VR applications can give users the experience of being part of this artificial environment (Knoll & Stieglitz, 2022). Furthermore, VR offers new opportunities for the user to acquire knowledge through playful interaction within a virtual environment. Kersten et al. (2020) describe the development and implementation of a new form of knowledge transfer based on interactivity within a VR system. The specific use case discussed is a VR application focused on the four-masted barque (ship) Peking. Kuliga et al. (2015) conclude that VR has great potential to be used as an empirical research tool in psychological and architectural research, and that future studies could complement behavioural validation.

In order to use this technology for an immersive experience, the following requirements must be met: (a) a virtual 3D environment must be constructed and textured in an Integrated Development Environment (IDE, e.g. in a game engine), (b) the developed and executable VR application must be connected to a head-mounted display (HMD) via appropriate software (e.g. Steam VR), and (c) the user's movements must be controlled and tracked via the controller and HMD.

This paper presents the development of a VR application for the villa Michaelsen (Fig. 1). The historic building was built in 1923 according to the designs of the architect Karl Schneider and is considered a pioneering building of the New Building Movement. Since 1986, the entire building complex, including the white side walls, which are adapted to the topography of the site, has been listed as a cultural monument.
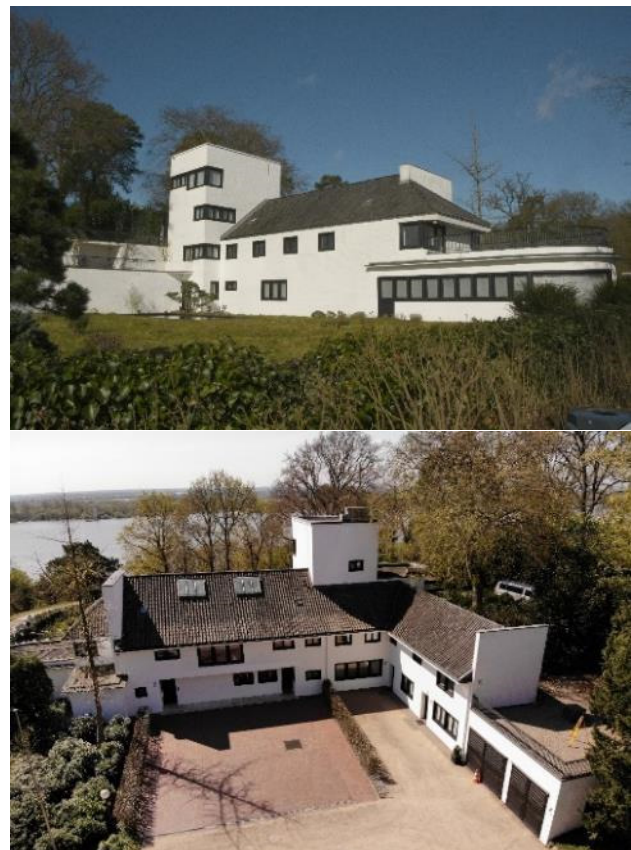

Figure 1. Historic villa Michaelsen in Hamburg-Blankenese - view from south (left) and view from north (right) with the river Elbe in the background.

2. RELATED WORK

The Oxford English Dictionary defines VR as a computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors. Merriam-Webster (2023) defines VR as 'an artificial environment experienced through sensory stimuli provided by a computer, in which one's actions partially determine what happens in the environment.

VR has been instrumental in the development of the field of virtual heritage. It opens up a new form of public and scholarly communication, particularly for historical objects and monuments that are either damaged, destroyed or too far away from potential visitors (Addison, 2000; Stone and Ojika, 2005; Affleck and Thomas, 2005). Zhang (2021) describes a research study with the goal to learn about the end users' experiences while reconnoitring the virtually reconstructed model in order to determine the aspects that influence their cultural learning in a virtual heritage environment context. His results suggest that while creating virtual heritage applications, a mix of information design, content delivery, user experience, and guidance system should be addressed.

Medyńska-Gulij and Zagata (2020) evaluate the effect of immersion in a specific historical-geographical virtual space for experts and gamers, using the fortress in Ostrów Lednicki (Poland) as a case study. Bozorgi and Lischer-Katz (2020) present the Virtual Ganjali Khan Project, an ongoing research initiative using 3D and VR technologies to support the preservation of the cultural heritage of the Ganjali Khan complex, a vast historical landmark in the desert city of Kerman, Iran. Edler et al. (2019) present how the use of VR-based 3D environments (based on the Unreal Engine 4) can be enriched to support the district development of a restructured post-industrial area, using the VR model of the 'Zeche Holland' area in Bochum-Wattenscheid as a representative former industrial area in the German Ruhr region.

Several VR applications have been created at HafenCity University Hamburg, focusing on historic architecture. One such example is the Bad Segeberg museum, situated in a townhouse from the sixteenth century, which has been digitally reconstructed in four dimensions (3D model including six construction phases from 1541 until 1963) for VR immersion using the HTC Vive Pro (Kersten et al., 2017b). Additionally, three historical German cities and their surrounding areas have been developed as VR experiences. Duisburg in 1566 (Tschirschwitz et al., 2019b), Segeberg in 1600 (Deggim et al., 2017; Kersten et al., 2018a), and Stade in 1620 (Walmsley and Kersten, 2019). Furthermore, VR experiences of three cultural and religious sites are available: the Selimiye Mosque in Edirne, Turkey (Kersten et al., 2017a), a wooden replica of Solomon's Temple (Kersten et al., 2018b), and the imperial cathedral in Königslutter, Germany which utilizes 360° panorama photographs to create an immersive real-time visualization (Walmsley and Kersten, 2020). Additionally, virtual reality applications have been developed for fortification systems. Tschirschwitz et al. (2019a) detail the creation of a virtual 3D model of Rumeli Hisarı, an Ottoman fortress located at the Bosporus in Istanbul, Turkey. The resulting model was visualised within the Unity game engine. Similarly, Kersten et al. (2021) describe the development of a VR application that showcases the fortress Al Zubarah in Qatar.

3. THE HISTORIC VILLA MICHAELSEN

The villa Michaelsen is an extraordinary villa at Grotiusweg 79 in Hamburg's Blankenese district, which was built in the architectural style of "Neues Bauen" (the "New Building Movement") (Fig. 1). Neues Bauen is an architectural-historical style term for the formally and technically progressive architecture after the First World War, i.e. it was a movement in architecture in the period from the 1910s to the 1930s, which was generally characterised by cubic rectangular shapes and flat roofs (Lübbeke, 2022). The villa Michaelsen is an L-shaped complex consisting of a main building, a four-storey tower, a terrace, a retaining wall supplemented by the north wing and the garage (Fig. 2). The main building has a pantile-covered hipped roof, which is atypical of the New Architecture movement of the time. At the same time, traditional flat roof elements of the Modern architecture movement are transcended throughout the building complex. The entire villa is built with bricks, which are painted with a glossy white colour and provide the tactile stimuli of a radiant light effect. The building also has a characteristic feature: the semi-circular living room with a large semi-circular window, which was unique for the time in which the building was constructed.

Figure 2. The villa Michaelsen in the year 1930 (Dröscher and Grunert, 2023).

The building application for the villa of the client Elise Michaelsen was signed on 27 March 1923. The architect, Karl Schneider, designed and built the house on his own initiative, creating a pioneering building for the Modern architecture movement of the time. Even during the design phase, the plans were characterised by preliminary studies and variants, which later contributed to the revision and modification of the buildings. As a result of the dialogue between the architect and the client, Elise Michaelsen, and the young architect's orientation in his transitional phase of architectural development at the time, the result was a prime example of a villa from the 1920s. In December 1923, an application was made for an extension to the living room and the construction of a studio and a stable building. In 1925, a north wing with a double garage was added to the building. This time, however, without the involvement of architect Karl Schneider. In the period from 1925 to 1955, the entire property remained unchanged apart from the addition of a garage to the west wall of the tower and the installation of a large window on the south side of the house in 1951. On 17 March 1955, Mrs Michaelsen sold the property together with the 2.8 hectares of land to Mr Axel Springer. As early as 1957, he had the stable building demolished and made structural alterations - including the installation of a large window on the south side of

the house. On 23 July 1970, the first demolition order for the entire building was issued, stating the following reason for demolition following reason for demolition: dilapidation, poor condition of the foundation masonry and sanitary facilities. However, the demolition was not completed on time. In 1980, Axel Springer donated the entire building complex, which had been vacant for over 10 years, as well as the entire property of 42,000 square metres to the Free and Hanseatic City of Hamburg on condition that the buildings will be used "for charitable purposes recognised as particularly worthy of support".

Figure 3. The villa Michaelsen as a ruin in 1984 (Dröscher and Grunert, 2023).

The entire building complex was in an almost completely ruined state (Fig. 3) when, in 1985, the gallery owner Mrs Elke Dröscher made the city government an offer to restore the house at her own expense. After negotiations with the city government, Mrs Dröscher was given a 75-year usage contract. She then had the entire building rebuilt and renovated (Wiensowski, 2011). After the renovation, Mrs Dröscher opened a gallery and a doll museum in the building, whose collection consists of around 500 dolls and 60 doll's houses. Since 1986, the building, together with the walls of the gardens, has been a listed building. The history and the architecture of the historic building has been described by various authors in Dröscher and Grunert (2023).

4. DATA ACQUISITION AND 3D RECONSTRUCTION

A 3D CAD model of the building complex served as the foundation for the VR application, created by students from HCU Hamburg in the lecture "Architectural Photogrammetry". The building was recorded by terrestrial laser scanning and terrestrial and UAV photogrammetry on April 25th, 2022. The laser scanner Z+F IMAGER 5010 was used for scanning the outside of the building and its surroundings, while the Faro Focus³D X330 was used for scanning the interior of the building. Additionally, the building was photographed using a Nikon D800 and the UAV DJI Mavic 2. In order to get the data from both recording methods into a common coordinate system, 22 black and white target signs were placed well distributed on the building. These targets were measured by a Leica total station to determine the XYZ coordinates in a local geodetic network for the georeferencing of the photos and scans. The IMAGER 5010 scans were processed in Z+F LaserControl, while all Faro scans were registered and georeferenced in Faro Scene. After filtering and cleaning of the scans a point cloud was exported for both data sets. The point cloud from laser scanning is illustrated in Fig. 4. For photogrammetric data processing in Agisoft Metashape 1.8.4, which included calibration of the cameras and the determination of the exterior orientation parameters of the images, the following

photos were used: UAV Mavic 2 (4.5 mm lens) 59, Nikon D800 with 24 mm lens 155, and 159 photos with 20 mm lens. In the bundle block adjustment, a precision of 2 cm was obtained for the XYZ residuals of the signalised ground control points. Finally, a dense point cloud with almost 43 million points was generated in Metashape (Fig. 5), which was used for digital 3D construction of the building in combination with the point cloud from laser scanning depending on the part of the building.
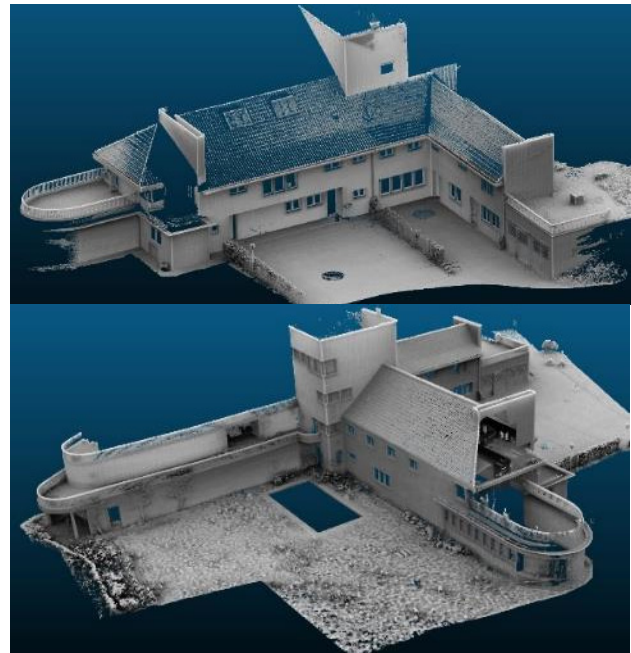

Figure 4. Point cloud from terrestrial laser scanning (top view from north-east, and bottom view from south-east).

Figure 5. Coloured point cloud from terrestrial and UAV photogrammetry.

The detailed 3D modelling of the building complex and its individual construction phases were performed in AutoCAD (Fig. 6).
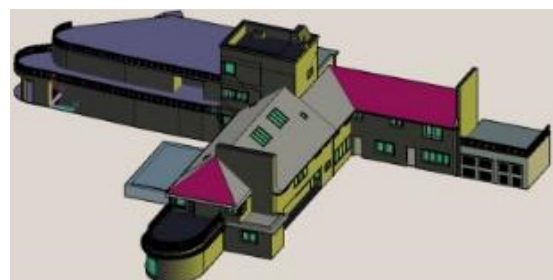

Figure 6. 3D CAD model of the building complex villa Michaelsen.

For additional documentation of the building 25 panoramic photographs were taken using a Nikon D800 camera with a fisheye lens 10.5 mm on nodal point adapter. Each set of a panoramic photograph consists of 12-14 images – one pointing towards the sky, two towards the ground and the other photos for the 360° circle in the horizontal position. The software PTGui (https://ptgui.com/) automatically generated a spherical panorama with 11,900 × 5900 pixels (ca. 12 MB) for each camera station. These panorama images were converted into a set of six cube images (in total ca. 5 MB). The panorama viewing software KRpano (https://krpano.com) was initially used to generate an interactive virtual tour for web browsers (Figure 7). The tour can currently be viewed at the following link. http://www.geomatik.hamburg/virtual_tours/vtour_puppenmuse um/start_tour.html. In this browser-based tour, all spherical panoramas are linked to each other via hotspots or via the overview map (bottom-right corner). This provides a quick and convenient way of navigating through the panoramas inside and outside the building, simply by clicking on the relevant map icon.

Figure 7. Virtual tour of the villa Michaelsen and the Falkenstein Doll Museum using 360° panorama images.

5. CONSTRUCTION PHASES

Using archival documents such as construction plans, sketches, and photographs, two construction phases and one proposed design were identified (Fig. 8). Consequently, the 3D model of the current building complex was modified and adapted to represent each construction phase. Construction phase 1 showcases the original building design by Karl Schneider from 1923. Phase 1 shows the greatest differences from the completed building. The most obvious difference is the sun terrace. This is supported by two columns, so the ground floor living room was planned to be much shorter. As can be seen in Figure 8 (top), windows of different sizes were planned. Phase 2 shows the building in its current state with minor alterations made between 1924 and 1957 (Figure 8 centre). In this model, the window sizes and positions have been adjusted. Construction phase 3 is a design by Axel Springer from 1972. Figure 8 (bottom) shows the 3D model of the villa Michaelsen with a flat roof. In addition to this major change the windows on the south side of the building were modified. However, this draft was never realised. In addition to phase 3, the horse stable was also modelled. However, no building plans or information on the exact size of the stable building could be found. The model created is therefore based on archive photographs, which partially show the position and appearance of the stable building. A simple 3D model was created based on the information gathered.
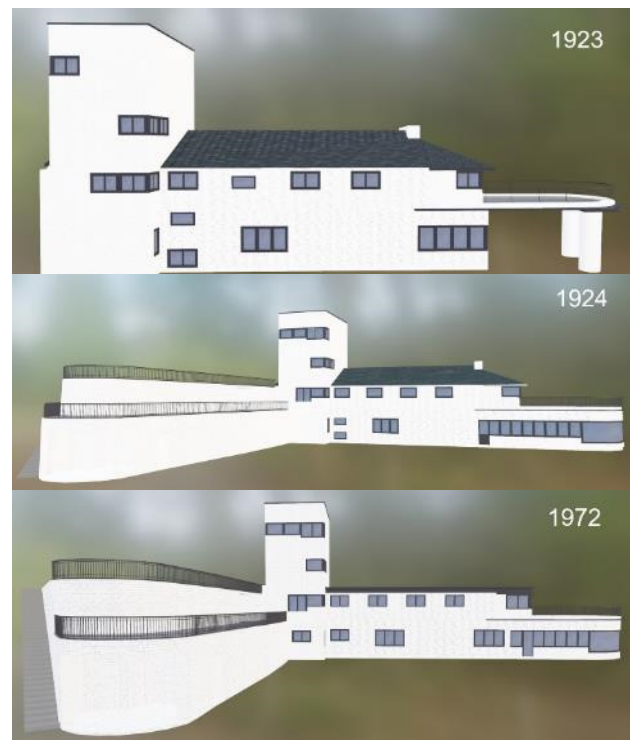

Figure 8. Construction phases of the villa Michaelsen – 1923 (top), 1924 (centre) and unrealised design from 1972 (bottom).

6. THE VIRTUAL REALITY APPLICATION

Following the 3D modelling of the building complex and its individual construction phases in AutoCAD (Fig. 6 and Fig. 8), the models were integrated into Unreal Engine 4.26 using the file format FBX. Within this engine, both the building complex and its surroundings were modelled in detail to closely resemble the real situation. To achieve a high degree of realism, the virtual environment incorporated various components: the landscape and environment (vegetation, lighting), the building complex (textured 3D model including the interiors), an image gallery (archival photographs and information about the building and its construction phases), audio (bird sounds for the environment and accompanying audio for each construction phase), and video (about the villa Michaelsen).

When starting the application, the user is positioned at the in front of the house. An information panel is installed on the right to provide the user with information on how to control the application (Figure 9).

Figure 9. Information panel with instructions for the user at the start position of the VR application.

There is another information board in front of the building briefly describing the history of the building (Figure 10 top). Another information board is installed on the meadow, displaying information and archive photos about the horse stable (Figure 10 bottom). Touching the 'Show stable' button will display the stable in its original position.

Figure 10. Information panel describing the history of the building (top) and information panel with information and archive photos about the horse stable and interacting the appearance of the stable in the VR application (bottom).
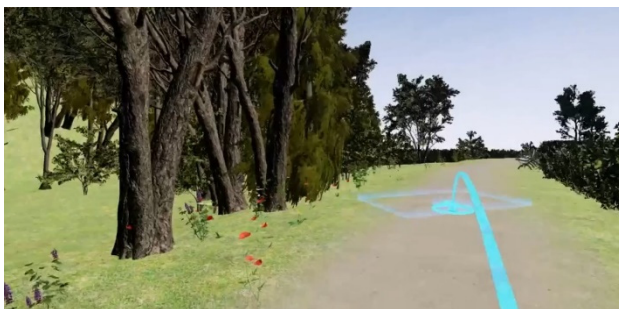

Figure 11. Teleportation for navigation and proper motion of the user in the VR application.

With the help of the teleport function, the user can navigate and move around both outside and inside the building complex to view it from all sides (Fig. 11). On the backside of the building, next to the retaining wall, is a 'Back to Entrance' teleport (Fig. 12 top). The same option is also possible for a direct teleport from the entrance to the models of the construction phases (Fig. 12 bottom). This allows the user to quickly teleport to the entrance or to the models without having to walk all the way around or inside the building.

The construction phase models are displayed in a large room on the ground floor. The "model within a model" method was used to represent the construction phases according to the idea of the Old Segeberg town house (Kersten et al., 2017) - each of the three construction phase models was placed as a small model in the interior, allowing for detailed examination (Fig. 15). Additionally, information panels were installed in the environment, serving the dual purpose of explaining the VR

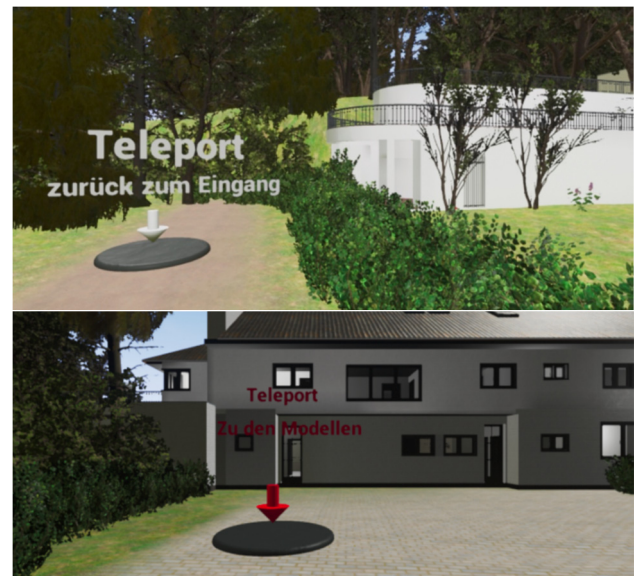functions to the user and providing extensive information about the building and its history.

Figure 12. Direct teleportation to the entrance of the building (top) or to the models of the construction phases (bottom) by virtually stepping on the grey platform.

Another exhibition is located in the large room on the floor above. The user can either take the stairs to the photo gallery or use the teleport 'To the photo gallery'. The archive photos and short texts are hung on the walls to give the user more information about the condition of the Villa Michaelsen over the years.

Figure 13. Photo gallery with archive photos in the VR application.

In this room on the right-hand side of the wall, there is a button to start a video, which can be triggered by a hand movement (Figure 14). The video is ten minutes long and runs continuously, so the user can either just enjoy the video or listen to it in the background while viewing the archive photos.

Figure 14. View in the VR application: video player installed on the wall of the photo gallery.
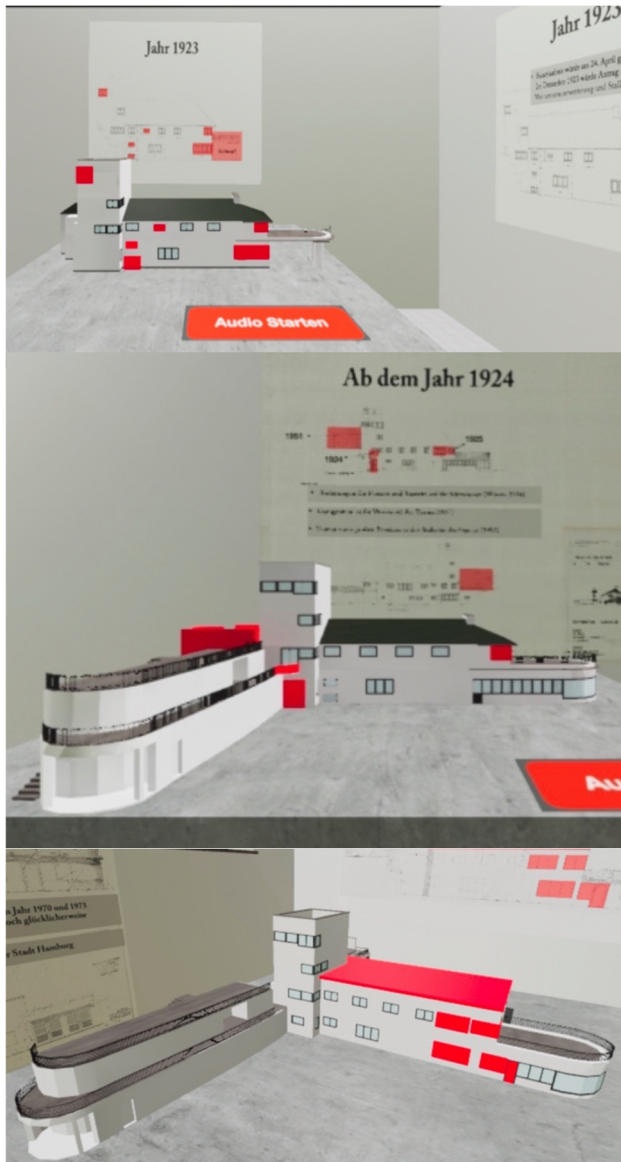
Figure 15. The construction phases of the villa Michaelsen – 1923 (top), 1924 (centre) and unrealised design from 1972 (bottom) – showing the changes in red in the VR application.

Figure 16 illustrates the building complex and environment of the villa Michaelsen in the VR application.

7. CONCLUSION AND OUTLOOK

This article outlines the process of developing a VR application for the villa Michaelsen, today also known as Falkenstein Doll Museum. The process includes data acquisition, 3D modelling, texturing, and immersive visualisation. The VR application showcases the historical evolution of the building complex designed by architect Karl Schneider, including an unrealised design. The VR application presents a detailed account of the architectural significance of the historic building complex, including the various construction phases and unrealised designs, as a new form of knowledge transfer. By using a VR head-mounted display, the user can freely explore the entire building complex from both the inside and outside within the defined navigation area. The user can independently explore the virtual environment and learn about the building's history and development through information panels, image galleries, and

models. A gallery displays numerous archive photographs, each described with a short text. The three construction phases are displayed as separate 3D models in a room, accompanied by information panels and audio to provide detailed information. The 3D model of the building complex has a level of detail equivalent to LoD3 or even LoD4 for 3D city models. The VR application was presented to a selected audience in time for the 100th anniversary of the building. Current 360-degree panoramas were also placed at appropriate points in the VR application. A virtual tour in and around the building using 360-degree panoramas is also available on the internet.

The project results suggest that the presentation of 3D models and the use of short texts, audio, and images in the VR environment are effective for conveying knowledge. VR is a valuable tool for reconstructing and visualising historical buildings, including their construction phases, to showcase their development and history.

Figure 16. Different views of the villa Michaelsen in the VR application - view from south (top, centre) and view from north (bottom).

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