Step into Virtual Reality—Visiting Past Monuments in Video Sequences and as Immersive Experiences

Thomas P. Kersten [a], **Felix Tschirschwitz** [a], **Simon Deggim** [a] and **Maren Lindstaedt** [a]

HafenCity University Hamburg, Photogrammetry & Laser Scanning Lab, Überseeallee 16, D-20457 Hamburg, Germany; (Thomas.Kersten, Felix.Tschirschwitz, Simon.Deggim, Maren.Lindstaedt)@hcu-hamburg.de

Abstract: Recent advances in contemporary Virtual Reality (VR) technologies are going to have a significant impact on everyday life. Through VR, it is possible to virtually explore a computer-generated environment as a different reality, and to immerse oneself into the past or in a virtual museum without leaving the current real-life situation. Cultural heritage monuments are ideally suited both for thorough multi-dimensional geometric documentation and for realistic interactive visualisation in immersive VR applications. In this contribution, the generation of virtual 3D models of past monuments in Bad Segeberg, Germany, and its processing for data integration into the game engine Unreal is presented. The workflow from data acquisition via 3D modelling to VR visualisation using the VR system HTC Vive, including the necessary programming for navigation, is described. Furthermore, the use (including simultaneous multiple-user environments) of such a VR visualisation for Cultural Heritage (CH) monuments is discussed in this contribution.

Keywords: 3D; 4D; cultural heritage; HTC Vive; monuments; reconstruction; virtual museum

1. Introduction

1.1. Virtual Reality

Virtual Reality (VR) will change our future life. Although VR is not very new, it is currently at the beginning of a technological transition. The term Virtual Reality was introduced by the author Damien Broderick in his science fiction novel *The Judas Mandala* published in 1982. As early as 1962, Morton Heilig built the Sensorama, a machine that is one of the earliest known examples of immersive, multi-sensory (now known as multimodal) technology and which could be named as the first VR system (Rheingold, 1991). Nevertheless, it took another thirty years

until the first Head-Mounted Display (HMD) for the mass market was released with the VFX 1 from Forte (Cochrane, 1994). Unfortunately, this headset caused nausea and disturbances of equilibrium for users due to the long latency when visually updating the display. After almost another twenty years, the new HMD Oculus Rift was announced by Palmer Luckey, which really worked and which rang in the new era (Desai et al., 2014).

It is already obvious that this new technology will offer great opportunities for many applications such as medicine, engineering, computer sciences, architecture, cultural heritage and virtual restoration. VR typically refers to computer technologies that use software to generate the realistic images, sounds and interactions that replicate a real environment, and simulate a user's physical presence in this environment. Furthermore, VR has been defined as a realistic and immersive simulation of a three-dimensional environment, created using interactive software and hardware, and experienced or controlled by movement of the user´s body or as an immersive, interactive experience generated by a computer. VR offers an attractive opportunity to visit objects in the past (Gaitatzes et al., 2001) or places, which are not easily accessible, often from positions which are not possible in real life. Moreover, these fundamental options are increasingly being implemented today through so-called "serious games", which embed information in a virtual world and create an entertaining experience (edutainment) through the flow of and interaction with the game (Anderson et al., 2010; Mortara et al., 2014). The first virtual museum using the VR system HTC Vive as a HMD for immersive experiences was introduced by Kersten et al. (2017).

1.2. Virtual Museum

The function of a museum is to aid non-specialists in understanding information and context via an interaction of short duration. Ideally, museums should also deepen visitors' interest in the subjects that they present. In accordance with their educational mission, museums must constantly present and re-present complex issues in ways that are both informative and entertaining, thus providing access to a wide target audience. Visitors with prerequisite knowledge, prior experiences, as well as associated individual interests and objectives tend to take a more active role in engaging with museums (Reussner, 2007). Today, these fundamental ideas are transferred to the digital world through so-called "serious games", which embed information in a virtual world and create an entertaining experience through the flow of and interaction with the game (Mortara et al., 2014).

For the museum field, the consolidation and implementation of culture and information technology is often called Virtual Museum (VM). The definition of a Virtual Museum is, however, not fixed. Since the 1990s, many different definitions for a VM have been published with significant differences depending on the contemporary status of information and communication technology (ICT)

(Shaw, 1991; Schweibenz, 1998; Jones and Christal, 2002; Petridis et al., 2005; Ivarsson, 2009; Styliani et al., 2009). According to V-MusT (2011), "a virtual museum is a digital entity that draws on the characteristics of a museum, in order to complement, enhance, or augment the museum experience through personalization, interactivity and richness of content. Virtual museums can perform as the digital footprint of a physical museum, or can act independently […]". Pujol and Lorente (2013) use the term VM to refer to a digital spatial environment, located in the WWW or in the exhibition, which reconstructs a real place and/or acts as a knowledge metaphor, and in which visitors can communicate, explore and modify spaces and digital or digitalized objects. Pescarin et al. (2013) evaluated VMs. They found that the impact of interactive applications on the user seems to depend on the capability of the technology to be "invisible" and to allow a range of possibilities for accessing content. To achieve this, VMs need a more integrated approach between cultural content, interfaces, and social and behavioural studies. Content presentation ranges from text, images, sound and videos to interactive techniques such as animated 3D models, to act as a central platform for the informative supplement of the real museum visit (Samida, 2002). The design of the VM varies from simple Web pages (Bauer, 2001) to panorama-based virtual tours (Kersten and Lindstaedt, 2012) to interactive apps for smartphones or tablets (Gütt, 2010). A good example for a VM is AfricanFossils.org, which presents a spectacular digital collection of fossils and artefacts found mostly at Lake Turkana in East Africa in a three-dimensional virtual lab space on a website (http://africanfossils.org/). The digital collection of animals, human ancestors, and ancient stone tools offers a unique tool for scholars and enthusiasts to explore and interact with the collection online. Another example for a digital collection of exhibits is Smithsonian X 3D (https://3d.si.edu/), for which various 3D capture methods are applied to digitize iconic collection objects. The idea of Smithsonian X 3D is to promote the use of 3D data for many different applications for professional and laymen users alike.

A VM that is retrievable on the Internet would offer the possibility of making a time- and location-independent virtual visit to the museum. It would also facilitate preparation for and evaluation of an actual museum visit, as this medium stimulates the attention of the visitor while also providing further information. The great strength of a VM is the ability to utilise current ICT to supplement conventional exhibition techniques via the presentation and integration of content into the real exhibition, thus significantly contributing to a visitor's understanding.

1.3. Past and Preserved Monuments

Cultural Heritage (CH) monuments are significant testimonies of the human past. These memorials are in danger around the world today due to increasing devastation by war, terrorism and vandalism, as well as by creeping weathering.

For many CH objects, it is already too late, i.e., they were destroyed in the past and they are probably already forgotten. Examples of such meaningless destruction are, among many others, the Great Buddha statues from Bamiyan in Afghanistan (Gruen et al., 2002), blown up in March 2001 by the Taliban, the Minaret of the Umayyad Mosque of the UNESCO heritage site of the ancient city of Aleppo (Fangi and Wahbeh, 2013), which was destroyed during the current Syrian civil war and the Great temple of Bel in the archaeological momentous site Palmyra in Syria (Wahbeh et al., 2016), one of the most important Syrian heritage monuments, which was destroyed in September 2015 by the so-called "Islamic State". These terrible acts of destruction demonstrate clearly that metric documentation of (important) ancient monuments is an essential and very useful reference for a future reconstruction or restoration of those CH objects. However, a metric documentation is very often not available due to missing appropriate recording techniques and systems in the past. Photography and photogrammetry have been used for the documentation of buildings and monuments since the late 19th century (Meydenbauer, 1867). Wiedemann et al. (2000) used, for example, photographic glass plates from the Meydenbauer archives for reconstructing the historical commandant's office building in Berlin, which was destroyed in WW II. Another example for the documentation of historic buildings such as North-German castles by digital photogrammetry is given by Kersten et al. (2004). The advantages of another technique, terrestrial laser scanning for the documentation of huge historic buildings such as the Imperial Cathedral (Kaiserdom) of Königslutter, Germany, are described in Kersten and Lindstaedt (2012).

However, such modern metric documentation techniques were not available for lost places such as the Siegesburg, which is also known as Segeberg castle (Figure 1), an ancient monument from the Dark Ages and the Early Modern Age (from a time more than 500 years ago), which was destroyed in the 17th century and demolished during the following centuries. In this contribution, the return of the Siegesburg by 3D virtual reconstruction is presented. The laboratory for Photogrammetry & Laser Scanning of the HafenCity University Hamburg carried out this reconstruction in co-operation with the museum Old-Segeberg Town House (Alt-Segeberger Bürgerhaus) using historic sources such as paintings, engravings and isometric maps to reerect the important monument. The reconstruction has been conducted in three different phases: (a) reconstruction of the Kalkberg, (b) reconstruction of the castle in AutoCAD and (c) texture mapping and visualisation of the castle with Lumion 3D. A detailed workflow of this project is described in Deggim (2015).

Additionally, a VM has been developed for the museum of Old-Segeberg town house, an example of preserved monuments representing the past, as an interactive tour for a Windows-based computer system and as a virtual reality application in 3D using the Virtual Reality System HTC Vive. Based on this

concrete example, this contribution provides examples of how museums can fulfil the technological and media requirements in the 21st century using detailed geo data and appropriate ICT.

2. The Cultural Heritage Monuments

2.1. The Siegesburg in Segeberg—The Lost Monument

The first castle on the Kalkberg was built in the first half of the 12th century (1128) by the Danish Duke Knud Lavard, but it was already destroyed in 1130 by the Schauenburg count Adolf I, who felt threatened by the fortress. The Roman-German Emperor Lothar of Supplinburg (Lothar III) ordered to build a new castle on the Kalkberg following the advice of the missionary Vicelinus in 1134. The castle should serve as a base for the Christianisation at the edge of the border to the Slavic tribes. In the course of various armed conflicts in the following centuries, the castle was besieged several times by enemy troops, sometimes destroyed, and then rebuilt. However, the centrality of the Siegesburg increasingly strengthened its suitability as a centre of political power and as a residence. After the owners of the castle, the Schauenburg family, died out in the 15th century, the castle and the County of Holstein passed on to the Danish King Christian I in 1459. However, the castle was so badly damaged in 1534 by a devastating city fire that the Danish Governor and bailiff Heinrich Rantzau ordered the restoration of the dilapidated Siegesburg as an extensive building complex as is shown in the engraving by Braun-Hogenberg from 1588 and the contemporary illustration from 1595 (Figure 1). After the outbreak of the Thirty Years' War, the castle underwent various occupations. From 1627 until 1629, imperial troops of Wallenstein occupied Segeberg and took the unfortified castle on the Kalkberg without a fight. In retaliation, the open castle was burned down at the end of the Thirty Years' War in 1644 by the Swedish troops. After centuries of intensive mining of the Kalkberg, only the lower half of the sole castle fountain of Northern Germany, approximately 42 meters in depth, reflects the once-powerful Siegesburg. It was driven into the rock and is today located in a steep reduction wall. Between 1934 and 1937, the Reich Labor Service built the Kalkberg Stadium in the pit created by gypsum mining. This is an outdoor stage with about 7800 seats and standing room for 12,000. The Karl May Festival (open-air theatre festival about Karl May's adventure novels about the Wild West) has been held here every year since 1952.

Figure 1. Isometric map of Segeberg including the castle Siegesburg and the Old-Segeberg Town House in the year 1588 from Braun-Hogenberg (view from North to South, top left) and a contemporary illustration of the Siegesburg on top of the Kalkberg from 1595 (view from southeast, top right). Photo ((bottom left) and synthetic view (bottom right) of the front façade of the Old-Segeberg Town House.

2.2. The Old-Segeberg Town House—The Preserved Monument

Even at the end of the 19th century, the Old-Segeberg Town House (Figure 1 bottom), located in the city of Bad Segeberg 40 km northeast of Hamburg, was already known as the oldest house of the city. Today, it is one of only a few well-preserved, small urban town houses from the beginning of the early modern period in the federate state of Schleswig-Holstein. In the newly installed council book from 1539, the building was already included in the historic rent listing. After Segeberg was almost completely destroyed in June 1534 during the Count feud from 1533–1536/37, the town house was re-established in 1541. First, as a simple

hall building with a single-storey, in-frame construction with brick-bracing to the property that is today's Lübecker Straße No. 15. The method of construction was poor and building materials from neighbouring ruined properties (e.g., in the roof framing) were partly recycled. However, the basic structure of the framework construction was established from fresh wood (oak). It is presumed that the cellar with walls, constructed from boulders, hailed from the medieval predecessor building (Reimers and Hinrichsen, 2015). Later, in the following centuries, the house was extended and converted several times.

With the support of a historian and based on historical sources (Reimers and Hinrichsen, 2015), six construction phases of the building could be identified. These were each modelled in AutoCAD and are presented in chronological order in Figures 2 and 3, from left to right: (1) construction work (1541), (2) the first extension (around 1587), (3) Stall addition at the south front (before 1805), (4) extension of the living space (from 1814), (5) renovation and conversion of the front façade (ca. 1890), and (6) refurbishment of the building and conversion to a museum (1963/64). A detailed description of the six construction phases of the building is presented in Kersten et al. (2014).

After the refurbishment in 1963–1964, the building contained the local museum of the City Bad Segeberg. For the next few decades, exhibits from the petty-bourgeois living and working environment of the 19th and 20th centuries were shown in its historic rooms. After the adult education centre (Volkshochschule), Bad Segeberg took over sponsorship of the museum in 2012; it was renamed "Museum Alt-Segeberger Bürgerhaus" and successive permanent exhibitions on the topics "500 years development of civic culture in the mirror of a 470-year-old house" and "800 years history of the city of Segeberg - from the medieval castle settlement to the modern resort" were hosted.
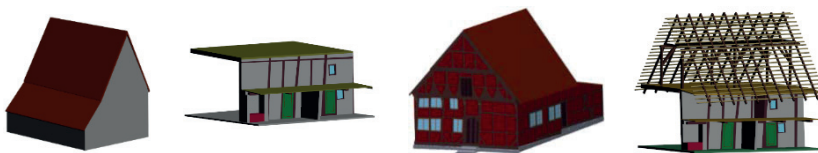

Figure 2. 3D model of Old-Segeberg town house. From left to right: 1541 outside, 1541 inside, 1584–1588 outside and 1584–1588 inside (Kersten et al., 2014).

Figure 3. 3D model of Old-Segeberg town house. From left to right: 1814 outside, 1814/1890 inside, 1890 outside and 1964 outside/inside (Kersten et al., 2014).

3. Reconstruction and Modelling

3.1. The Kalkberg and the Siegesburg

The initial step of the project was the reconstruction of the historic Kalkberg. First, the modelling of the Kalkberg was carried out with butter in order to derive just the shape of the mountain without any scale using historic sources such as paintings, isometric maps and descriptions. Secondly, today´s existing landscape has been modelled by meshing of airborne laser scanning (ALS) data from the national survey of Schleswig-Holstein. Figure 4 (left) illustrates the ALS data as a mesh including the current Kalkberg and the open-air stage of the Karl May Festival in Bad Segeberg. From this DEM, sections with a spacing of 10 m were generated and plotted in a scale of 1:330. These sections were transferred to cardboards, cut out and then fixed upright on a planar platform (Figure 4 centre) for further modelling with gypsum (Figure 4 right). Third, the shape of the modelled butter mountain coming out of the fridge was visually transferred to the physical 3D model by manual modelling. The finished physical 3D model of the historic Kalkberg (Figure 5 left) was photographed with a Nikon D800 for digitisation using dense image matching. The final meshed model is illustrated in Figure 5 (centre), which was combined with the meshed model from ALS data after scaling (Figure 5 right). This combined meshed 3D model was the base for the modelling of the Siegesburg.

Figure 4. The reconstruction of the Kalkberg from airborne laser scanning data: digital elevation model (original data, left), printed scaled sections of the DEM (centre) and physical 3D model of today´s existing Kalkberg (right). Photos centre and right: Nils Hinrichsen.

Figure 5. The historic physical 3D model of the Kalkberg (left), the historic digital 3D model from dense image matching (centre) and the combination of two DEMs from both today (orange) and the past (green) (right).

The first virtual 3D model of the Kalkberg and the Siegesburg (Figure 6 left) was created in Cinema 4D by Dipl.-Ing. Uwe Oswald, lecturer for 3D design at HTK – Academy of Design in Hamburg, some years ago. However, this virtual object includes some small false assumptions about the shape of the castle and it was not reconstructed with great detail. Nevertheless, a second virtual model was created and adapted to the reconstructed digital terrain model of the Kalkberg in Cinema 4D using the expertise of a historian (Figure 4 centre). This was used by a model builder to create a physical castle model on top of the Kalkberg for the museum exhibition (Figure 6 right).
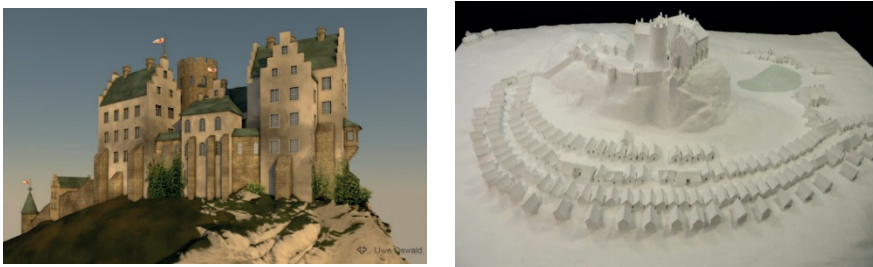

Figure 6. The first virtual 3D model of the Kalkberg and the Siegesburg (left) created by Dipl.-Ing. Uwe Oswald in Cinema 4D, and the final physical castle model in the museum exhibition (right).

The initial CAD model shows the rough position and size of the castle, but it lacks any details which are necessary for the generation of a video sequence allowing close-up shots from the castle to be focused on. Thus, the basic CAD model (Figure 6 left), the physical model in the museum and the available historic illustrations were used as the base for the new model to be constructed. The first step was to research typical elements of Northern European castles in the Early Modern Age and to collect example images. The Siegesburg had existed already for over 450 years in the year 1600 AD and had often been attacked, partly

destroyed, rebuilt, renovated and expanded. Thus, the castle should not have a continuous style but should consist of various architectural elements.

The 3D modelling has been carried out with Autodesk AutoCAD. Due to the size of the castle, it was split into different object parts, constructed individually and was later merged in the visualisation software Lumion 3D. The balance between details and data reduction should be considered, since a high number of polygons results in performance problems of the computer system during the work process (Deggim, 2016). This is a very significant factor to be considered, especially if the models are reused for real-time virtual reality applications as used later in an ongoing project.

The modelled buildings are based on the image collection. They combine elements from various sources or are based on single images. The shape of each building, given by the initial CAD model, was the starting point for the construction and correction of each object to be modelled. Afterwards, doors, windows, roofs and other details such as a stepped gable or timber framework were added to the building models (Figure 5 and Figure 6 top).

To increase the degree of reality, the former use of each building was taken into account. Tower platforms and the defence galleries are reachable via ladders or staircases or they can be accessed from adjacent buildings. Walls without a defence gallery were modelled with arrow slits and machicolations were placed at reasonable locations. The former use of each individual building of the castle is not known in general. However, a typical storehouse scene with a crane was added to the main castle to make the scene lively. For additional variety, small objects such as chests, buckets, fences, boxes, torches, tables, benches, cups, weapons, wheels and many other small constructions such as a wooden shelter and a cart were modelled and placed in the scene (Figure 12 bottom). In total, 21 buildings and 31 scenery objects were modelled and later integrated into the castle scenery.

Figure 7. Comparison between the initial and final model for the keep (left), a building at the main castle (centre) and the drawbridge (right).

3.2. The Old-Segeberg Town House

The entire museum Old-Segeberg Town House was modelled in 3D so that visitors could virtually explore the exterior and interior of the building in close

relationship to the various exhibits in the museum. Special focus was given to developing visitors' understanding of the complex history of the building via an interactive visualisation of the nearly 500-year-old museum building's extensive construction history.

The 3D object recording was conducted over two separate acquisition campaigns, on 21 April and 2 August 2011, using the IMAGER 5006h terrestrial laser scanner and two digital SLR cameras, Nikon D40 and D90, for the exterior and interior areas, respectively. The base for the development of the virtual museum was this detailed 3D recording of the exterior and interior of the building using digital photogrammetry and terrestrial laser scanning. Intensive 3D CAD modelling, using coloured point clouds from laser scanning and manually-measured photogrammetric 3D points, represented the second stage of activity. For the 3D modelling and visualisation of huge point clouds in AutoCAD, the plug-in PointCloud (today Faro PointSense), from the company Kubit in Dresden, Germany, was used. Using this plug-in, CAD elements, e.g., surfaces such as the half-timbered bars, could be directly digitised in the point cloud. In the oriented images, each object point was measured manually in at least four photos from different camera stations. After the manual image point measurements were completed for one object element, for example a window, the computed 3D object points for this element were transferred to AutoCAD. There, polylines were generated from these points, and these were later used to generate surfaces. Simple object parts were constructed using geometrical primitives (e.g., cuboid, pyramid, cylinder, cone, sphere, torus, etc.), while some more complex object parts were created with the Boolean operators in CAD (union, subtraction and intersection). Kersten et al. (2014) give a detailed description of the data acquisition and modelling of the town house.

Based on this reconstructed 3D model, further 3D modelling was carried out to fulfil the requirements for the development of the virtual museum. To bring the interior to life, the most important exhibits, information panels and furnishings were also modelled and placed in their appropriate places within the building. Additionally, the six different historical construction stages of the Old-Segeberg Town House were modelled, in collaboration with the historian Nils Hinrichsen (Director of the Museum Old-Segeberg town house). The appearance of the building, in particular for the early construction phases, is only ensured for building parts based on historical scientific evidence collected in recent years. For example, a dendrochronological analysis of individual timbers was conducted, which determines the age of various parts of the building and which could be assigned to the corresponding construction phases (Reimers and Hinrichsen, 2015). For data reduction, the six construction phases were modelled together, i.e., objects, which occur in several construction phases, were created only once and stored in a database, thus allowing utilisation by the program in multiple phases.

Figure 3 shows the first four construction stages and their most distinctive changes from the same perspective. Finally, based on terrestrial photos and Google Earth data, the environment of the building was also reconstructed to ensure that this historic building was embedded in its current urban environment. As a stylistic device, the surrounding buildings were coloured grey to emphasize the museum in the visualisation.

The texture mapping of the model was carried out using the software Autodesk 3ds Max. The photos used for texturing were mainly images taken in situ. However, textures that were freely available online were also integrated after appropriate editing. Furthermore, bump and alpha textures were used to improve the depth effect and the appearance of details. In total, 239 textures were used for visualisation.
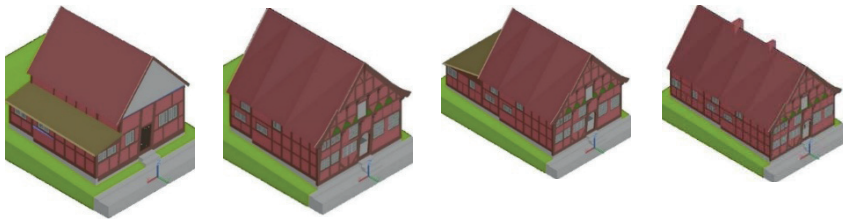

Figure 8. Advanced 3D models of the different construction stages of the town house. From left to right: 1541–1585, 1585–ca. 1805, ca. 1805–1814 and 1814–ca. 1890.

4. Visualisation

4.1. The Generation of a Video Sequence for the SIEGESBURG

4.1.1. Software

The software package "Lumion 3D" is a visualisation software. Its main target audience is architects and designers. It comes with a material library, foliage items, landscape tools and a high-speed renderer. Compared to established software packages such as 3ds Max, Cinema 4D and many others, it has only minor texture settings explicitly well-prepared for architectural visualisation and a complete lack of export functionality. It is, on the other hand, an easy-to-learn software with a fast workflow and a high number of video and graphic settings. This software was used for texture mapping and all following processing steps such as environment modelling, animation and video production for this project.

4.1.2. Texture Mapping

The material library of Lumion mainly consists of modern architectural textures. Consequently, the textures had to be edited in several ways to fit the old, rough appearance of a post-medieval castle: A) up-scaling of most of the textures, especially the ones including stones, B) creating and integrating normal maps to provide reliefs, which supply an overall more realistic look, especially when light sources (e.g., sun) are included in the scene and C) colour correction. Figure 9 shows the non-textured (left/centre) and textured (right) models of the same building. Further aging of the objects could be achieved by placing small fauna objects on and at the bottom of a wall, e.g., stones and ivy (Figure 10).

Figure 9. Development of a building in the outer ward: Initial CAD model (left), detailed model (centre), textured model in Lumion 3D (right).

4.1.3. Environment

Landscape: The landscape underneath and around the castle was modelled with the Lumion landscape tools using the 3D reconstruction of the Kalkberg as a basis. Steep parts were mapped with rock textures, while shallow parts were designed as a combination between grass and dirt (Figure 10). An additional 3D effect was applied to the grass parts, showing individual blades of grass when the camera moves closer to the object.

Figure 10. Landscape with rock, grass and trees beneath the west side of the castle (left) and view into the main street of the town Segeberg (right).

The surrounding landscape was modelled afterwards based on both today's and the historic appearance of the area. As the past 400 years extensively changed the landscape, only the rough pattern of the present look can be used. The historic sources, on the other hand, are known to be inaccurate at some points, e.g., the distribution of hills around the village Segeberg. The shape and position of both lakes near the castle were derived from current aerial photographs. The environment around the urban area was modelled with typical agricultural elements, such as farms and grazing land with fences between them. Small forests were added where they are shown in historic sources. Over 6000 trees and plants were placed in the whole scenery. To block the visual axis in the distance, a slight fog was added, not only providing a realistic feeling of distance but also limiting the area, which had to be filled with landscape elements and 3D objects. Figure 11 (left) shows the whole scenery of the castle and its environment from an aerial perspective.

Figure 11. Perspective view of the castle including the village Segeberg (left) and the rural area around the castle (right).

Urban area: The village of Segeberg (the "Bad" (bath) was not added until the end of the 19th century) itself consisted of approximately a hundred buildings at that time, which were located mainly at the north side of the Kalkberg along the main road from east to west (Lübecker Straße), following the curvature of the terrain. The positions of the buildings are shown in high detail on the isometric map of Braun-Hogenberg (Figure 1). This source was used for the placement of all buildings for the physical model. The resulting ground plan was the basis for the creation of the digital model (Figure 12). Although the focus of this project was on the castle, the surrounding area should nevertheless be historically correct and provide a consistent impression of the background scenery. To facilitate the workload for this reconstruction part, only one building was modelled, having four slightly different sides, which allows for many different appearances due to rotation and combination of two or more copies of the same model. Furthermore, the model was imported twice into the object library using two different textures to allow for a higher variety. Additionally, some of the smaller castle buildings were reused as city buildings.

Figure 12. Map of the present city (green) with the state of 1600 as overlay (red, not complete) (left) and as a complete overlay (white/red) in Google Earth (right) with reverse map orientation (top = north facing). Figures: Nils Hinrichsen.

4.1.4. Video with Lumion

Depending on the potential target group, there are several possibilities to generate a video sequence. The camera path, use of special effects, lighting, cutting and choice of background music may influence both the atmosphere and the message of the video. The aim of this project was a trailer-like sequence, which could be used both for advertisement of the Siegesburg as well as for information purposes in a museum context. The following concepts and effects were used to create the video using the software Lumion.

1) Camera: To capture the Siegesburg both as an entire ensemble in the context of the urban surrounding as well as the details inside the castle, a carefully planned camera path was essential. During the whole sequence, the viewer should not become lost, i.e., he should always be aware of where the current camera position is located in relation to earlier shots. Therefore, several long tracking shots were created and each following shot starts at a position which has already been shown in an earlier shot. Thus, different areas of the castle can be shown without having the location of each area established after each cut.

The video can be partitioned in different sections: A) introduction sequence, with some written information and short cuts with glimpses on some details of the castle to create a sense of excitement; B) overview shot to establish the whole scene with a wide shot, approaching the urban and surrounding area of the castle once; C) first part of the castle tour including the change of the camera angle to eye-level in front of the main gate and keeping the human observer perspective for most of the following sequences. This creates an immersive feeling for the viewer while the camera shows some details in the outer ward; D) tour around the main castle showing the camera view mostly from below to have a more imposing view of the buildings. For a fluent tracking shot, the camera follows objects in the foreground while moving around, e.g., the rope of a little crane or the handrails of a staircase; E) night scenes consisting of short shots for a similar atmosphere as for the

introduction; F) closing credits showing the castle in the background. The visualisation is based on the drawing of the scene in the foreground (Figure 13). All scenes were created with the video editor in Lumion, within which all camera views were defined with snapshots of the scene. The software then smoothly interpolates between those frames to render each frame in between.

Figure 13. Drawing of the castle as shown in the closing credits of the video sequence.

2) Visual Effects: The raw version of the video sequence of the 3D environment has been manipulated in the video editor to enhance the graphical quality of specific scenes. The video editor offers a library of effects. Each effect can be applied for specific parts of the video and is variable in length and intensity. In total, this video used 17 different types of effects, the most important of which are described below: (A) Clouds and fog were used to create the impression of a long distance towards the border of the scene in order to hide the skyline; (B) depth of field to blur objects very distant or very close to the camera resulting in a more realistic look. Incidentally, this effect can be used to guide the viewers' attention to a certain point in the video; (C) titles for implementing writing of the opening titles and the closing credits; (D) vignette effect for creating a soft black frame at the border of the image to restrict the field of view, letting the viewer focus on the shown part in the centre; (E) editing of the position and intensity of the sun for simulating the course of the day; (F) colour correction allowing the editing of the RGB-values of the images. This was used to apply a red shade to opening titles and the closing credits sequences to create the atmosphere of morning/evening; (G) volume sunlight and lens flare effects for editing the sunlight at particular angles.

Both visual effects and animations are managed by placing markers on a timeline to specify fixed conditions between which the software interpolates. Figure 14 shows an example of the changes in the same image, created by visual effects.

Figure 14. A frame of the opening sequence without (left) and with (right) volumetric sunlight and colour correction. Both images already have the vignette effect (borders fade to black).

3) Rendering: The rendering time depends on the following criteria: the number of effects, processing demands of these effects, length of the video sequence, frames per second (fps) rate, resolution and content of each frame. The video was rendered in 720p (1280 × 720 pixel) using 30 frames per second. The generated video consists of 11,370 frames, which corresponds to a length of 6.19 min, resulting in a rendering time of about 36 hours. In addition to the 2D version, a 3D video version was generated in Lumion. Therefore, the library of effects provides an effect with stereoscopic options. With the specification of eye distance and focal length, the software renders two camera parts slightly off centre to the original one. Since there is only one calculation for lighting and shadows for the stereo images, the rendering time for the 3D version takes only eight hours longer than the 2D version providing MP4 file formats for both versions. Consequently, the 3D video version needs a 3D screen for correct display. The two final Lumion videos (2D/3D) have a length of 6:19 min and a file size of ca. 700Mb (2D) and ca. 950 Mb (3D) using the file format MP4. The 2D video version with the title "Siegesburg Segeberg 1588" is available for free viewing on the YouTube channel "HCUHamburgGeomatics" of the Hafencity University Hamburg at the following link: https://www.youtube.com/watch?v=M1pQnAhvQ4w. Additionally, some single high-resolution still images were rendered for additional use in the museum exhibition (Figure 15).

4.1.5. Audio

The background music of the video is a very important tool to influence the spirit of the video and to support or highlight certain elements. Since no appropriate, publicly available soundtrack for this Lumion video could be found

on the Internet, the music integrated in the video sequence was self-composed. This allowed for fine-tuning between audio and video, so that both media form a harmonic unit. Visual atmospheres are supported by a corresponding use of instruments, rhythms and sounds. Thus, camera path and movements and even individual cuts could be set in the appropriate musical theme.

4.1.6. Video with 3ds Max

As already mentioned, a second modelling and visualisation project ran in parallel using 3ds Max as visualisation software and focussing on a more realistic Brick Gothic Texture for the castle. The resulting video is also available for free viewing on the same YouTube channel at the following link: https://www.youtube.com/watch?v=V-hESSCwOe0. A detailed description of the 3D reconstruction and visualisation of the Siegesburg using AutoCAD und 3ds Max is presented in Herzberg (2015). Two perspective views of the Siegesburg with Brick Gothic textures are illustrated in Figure 16.
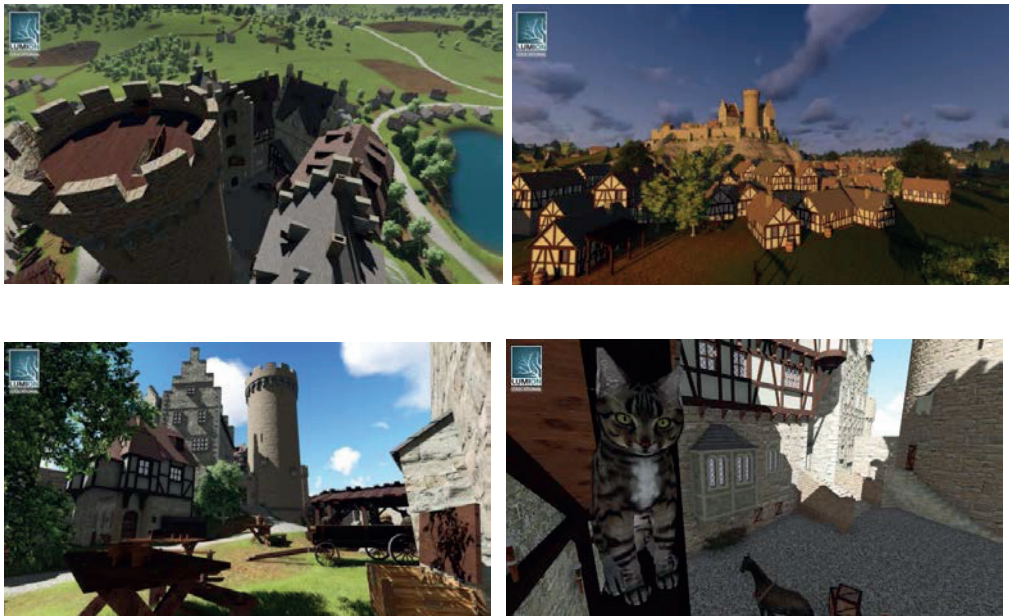

Figure 15. Views from the castle keep (top left), from the north (top right) and from the castle yards (bottom) generated with Lumion.

Figure 16. Two perspective views of the Siegesburg with realistic Brick Gothic Texture on top of the Kalkberg rendered with 3ds Max (Herzberg 2015).

4.2. The Old-Segeberg Town House in Virtual Reality Application

4.2.1. Game Engine Unreal

A game engine is a software framework designed for the creation and development of video games for consoles, mobile devices and personal computers. The core functionality typically provided by a game engine includes a rendering engine for 2D or 3D graphics to display textured 3D models (spatial data), a physics engine or collision detection (and collision response) for the interaction of objects, an audio system to emit sound, scripting, animation, artificial intelligence, networking, streaming, memory management, threading, localisation support, scene graph, and may include video support for cinematics. A game engine controls the course of the game and is responsible for the visual appearance of the game rules. For the development of a virtual museum, game engines offer many necessary concepts with much functionality so that users can interact with the VM.

In the past, the development of game engines was mostly based on the development of a specific game with paid licensing to external game developers. In recent years, however, most of the large engine providers have focused more on the advancement of engines and additionally offer free access for developers. Examples of game engines with free potential use are the engine Unity from Unity Technologies, the CryEngine of the German development studio Crytek, and the engine Unreal from Epic Games (www.epicgames.com). A current overview and comparison of different game engines can be found, e.g., in O'Flanagan (2014) and Lawson (2016). The selection of the appropriate engine for a project is based on the provided components mentioned above, the adaptability in the existing work processes as well as special preferences of the (game) developer. In the framework of this project, the game engine Unreal was selected due to the opportunity to develop application and interaction logics using a visual programming language, the so-called Blueprints. Visual programming with Blueprints does not require the

writing of machine-compliant source code. Thus, it provides opportunities for non-computer scientists to program all functions for a VM using graphic elements. The saving in time associated with this method of software development allows for the generation of additional scenarios and for more intensive user testing. Game engines are, therefore, very well-suited to the development of virtual museums.

4.2.2. Virtual Reality System HTC Vive

HTC Vive (www.vive.com) is a virtual reality headset (with a weight of 555 grams, Figure 17) for room-scale virtual reality. It was developed by HTC and by Valve Corporation. It was released on April 5, 2016, and it is currently available on the market for EUR 899. Basic components are the headset for the immersive experience, two controllers for user interactions and two "Lighthouse" base stations for tracking the user's movement.
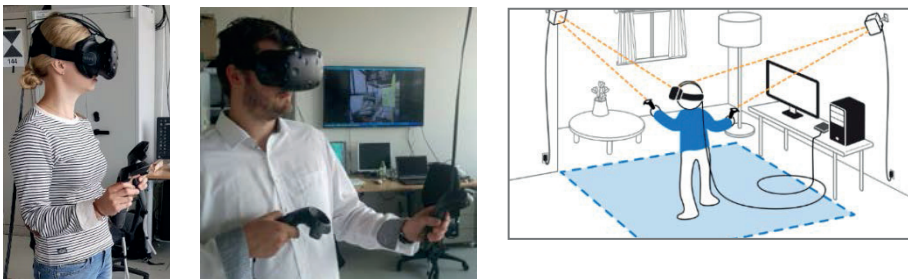

Figure 17. The virtual reality system HTC Vive in use (left). The screen in the background shows the same sequence as it appears to the user in the VR glasses (centre). The setup of the Virtual Reality System HTC Vive (right, HTC Corporation, 2017).

The technical specifications of the HTC Vive are summarized in the following: (a) two screens with a field of view of approximately 110 degrees, one per eye, each having a display resolution of 1080x1200 with a refresh rate of 90 Hz; (b) more than 70 sensors including a MEMS (Microelectromechanical systems) gyroscope, accelerometer and laser position sensors; (c) 4.6 by 4.6 m tracking space for user operation using two "Lighthouse" base stations for tracking the user's movement with sub-millimetre precision by emitting pulsed IR lasers; (d) SteamVR running on Microsoft Windows as the platform/operating system; (e) Controller input by SteamVR wireless motion tracked controllers; and (f) a system for overlaying the real room's bounds for static objects in the real world called Chaperone and (g) a front-facing camera for looking around in the real world to identify any moving objects in a room as part of a safety system.

The following technical specification is required as the minimum for the computer to be used: processor Intel™ Core™ i5-4590 or AMD FX™ 8350, graphic

card NVIDIA GeForce™ GTX 1060 or AMD Radeon™ RX 480, 4 GB RAM, video output 1x HDMI 1.4-connection or DisplayPort 1.2 or newer, 1x USB 2.0-connection or newer, operating system Windows™ 7 SP1, Windows™ 8.1 or more up to date or Windows™ 10.

The device uses a gyroscope, accelerometer, and laser position sensor to track the head's movements as precisely as one-tenth of a degree. Wireless controllers in each hand, with precise SteamVR-tracking, enable the user to freely explore virtual objects, people and environments, and to interact with them. The VIVE-controller is specifically designed for VR with intuitive control and realistic haptic feedback. The Lighthouse system uses simple photo sensors on any object that needs to be captured. To avoid occlusion problems, this is combined with two lighthouse stations that sweep structured light lasers within a space.

4.2.3. Windows-Based VM Implementation

The major part of the work dealt with the programming of the user movement in the museum, with information queries and the corresponding animations in the game engine "Unreal Engine".

The intuitive handling of the program was an essential prerequisite, allowing also easy access to and use of the VMs for inexperienced PC users (Figure 18 left).
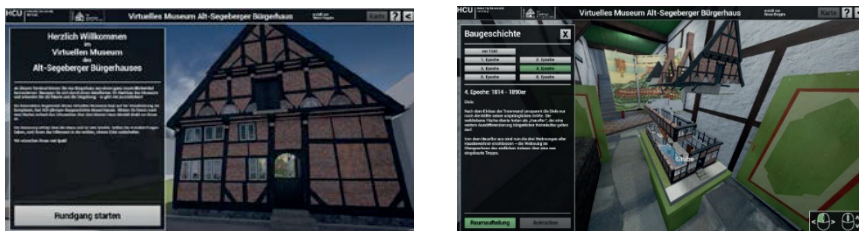

Figure 18. Graphical User Interface for the virtual museum tour (left) and graphical user interface for the building history with an animated view into the interior of a construction phase (right).

The control of the software is exclusively available via mouse interaction and is based on many well-distributed positions throughout the building, which can be directly selected by clicking on a map or approached using a defined camera path within the 3D environment. In these positions, the users can freely look around, as in a 360^0 panorama. Users can also zoom in and out, and click on the available information button. As a special highlight of the VM, the visualisation of the building history was realized with a "model in the model" (Figure 18 right and Figure 19 left).

At one station of the virtual tour, which is located in front of the model, the user can open this model to display and animate, upon request, each of the building states including all related information. The user can look at the building model from all sides using virtual rotation. In addition, with a mouse click, the roof can be removed, the individual floors can be driven apart by animation, and the appearance of the building interior in the respective building phase (Figure 8) will be shown. Each room can now be selected to display information about the development of building use. Furthermore, it is possible to start an animated transition from the activated construction phase, which shows and describes the structural changes to the next state for each construction phase. These animations required a subdivision of all 3D models into 387 smaller objects, to precisely control the movement of the objects for each animation. In the animation, the user is guided by predefined camera movements to appropriate viewpoints.

Figure 19. Impressions from the 3D environment of the virtual museum Old-Segeberg Town House including the model of the building (left), part of the exhibition (centre) and a view at the attic (right).

Menus and information boards, which can be opened during the individual tour using the info button placed next to the selected objects, were created for the exhibits. These menus include brief explanations and mostly a figure that can be enlarged via a mouse click. Some information is directly imparted using detailed point-of-view shots in the 3D environment. In such cases, cameras were distributed in the whole Museum at appropriate points. These can also be selected using the info button.

Finally, comfort functions were created such as tool tips, an overview map and a help menu. For quality assurance, the VM program has been tested by several people with different PC experience to subsequently customize the software details.

4.2.4. Virtual Reality Application with HTC Vive

Based on the modelled and textured 3D data in the game engine, an immersive virtual reality visit was developed utilizing the new Virtual Reality System HTC Vive. The visit offers the possibility of experiencing the museum and the history of the building from a real person's point of view and interaction

scheme. For this purpose, the controlling positions have been replaced by the possibility of free movement by the user. To bridge long distances in the virtual object, a teleportation function is available for the navigation of the user (Figure 20 left). The users' hands can interact with various components of the virtual world to control the building's presentation. The object selection and menu operation are enabled via a "laser beam", which is controlled by the motion controller (Figure 20 centre). The highlight of the virtual museum visit is the animation of the architectural building history, which is vividly represented by the HTC Vive glasses directly in front of the visitor's eyes on the basis of the 3D models (Figure 18 right and Figure 20 right). Different historically-confirmed construction phases are visibly demonstrated in 3D and changes are illustrated by transition animations.
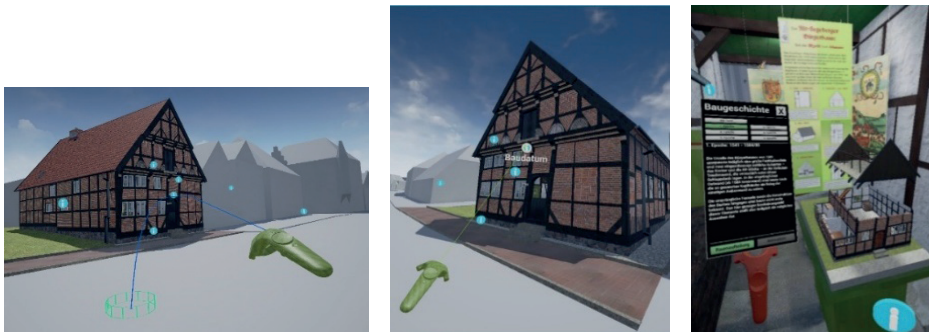

Figure 20. The virtual museum Old-Segeberg Town House in the Virtual Reality System HTC Vive as an intense experience: navigation in the virtual museum using the developed teleportation function (left), menu navigation with green motion controller by "laser beam" (centre) and second red controller for the information menu (right).

5. Conclusions and Outlook

This contribution has presented the virtual 3D reconstruction of the destroyed cultural heritage monument Siegesburg including the Kalkberg in Segeberg, and of the preserved monument Old-Segeberg town house, today the oldest building in Bad Segeberg and probably in the state Schleswig-Holstein, Germany. Using isometric maps such as the one from Braun-Hogenberg, historic sources and expert knowledge, the castle and the appertaining Kalkberg were successfully reconstructed in 3D for the generation of video sequences in Lumion 3D, representing a half-timbered architecture from Central Germany (Figure 15), while a second video generated with 3ds Max represents the castle in the northern European Brick Gothic (Figure 16). These video sequences symbolise the virtual

return of the Siegesburg, while the physical return was already realised using the physical castle model in the museum exhibition. Furthermore, a stereoscopic 3D video has also been generated using Lumion 3D.

In the second part of this project, the VR visualisation of the Old-Segeberg Town House has been presented. Therefore, the exterior and the interior of the historic building including the six construction phases were modelled in CAD using data from photogrammetry and terrestrial laser scanning. Using the textured 3D models of the building and its interior, a Virtual Museum was successfully developed and implemented for the museum Old-Segeberg Town House with two options: a) interactive software application for windows-based computer systems and b) virtual reality application for the VR system HTC Vive. Many visitors and participants have tried and tested the VM by using both a windows-based computer system and the VR system HTC Vive. The Old-Segeberg Town House can look back on 475 years of architectural development, identified and explained in the form of animations, which are the highlights of the virtual museum. The developed computer program contains 13 guided viewpoints distributed at important positions in the museum and 52 info menus with detailed information for visiting the virtual museum. The program has a size of 500 MByte and is executable as a standalone program on Windows operating systems. It is developed in the game engine Unreal, which offers not only complex visualisations of 3D objects, but also provides every programming tool necessary for creating extensive interactions between the user and the environment. It is planned to make this program accessible for visitors using a PC-terminal in the museum. It allows, in addition to the current exhibition, a multimedia interaction with the history of the city and the building. Thus, based on this building, it makes an important educational contribution for the urban development of Bad Segeberg and about 500 years of housing tradition in Schleswig-Holstein. Developed entirely in 3D, the VM is unique in this form in Germany as an informative component of a museum.

The current follow-up project "Segeberg 1600" is concerned with the historically correct reconstruction of the complete urban and rural area of the two villages Segeberg and Gieschenhagen in the year 1600 (Figure 21). Some of the modelled objects of the Siegesburg will be reused as revised and improved versions for this project, especially concerning textures in the Brick Gothic and details. The idea behind this project is the implementation of the entire 3D data of the village Segeberg in a game engine for a virtual reality application using the Virtual Reality System HTC Vive as it is already realised for the museum Old-Segeberg Town House (Kersten et al., 2017).

The 2D version of the history of the Siegesburg and the village is shown regularly in the exhibition of the museum Old-Segeberg town house. The combination of the physical model, the video and the interactive VR visualisation helps the visitors to visualise the situation of Segeberg and especially the castle

more than 400 years ago. Since the castle and the complete urban environment have changed drastically since then, very little is known about parts of the history of Segeberg—to the point that many people are not even aware that there once was a castle on top of the Kalkberg. This project helps to increase the historical awareness of the local community and the tourists interested in such historic events. This 3D reconstruction of these cultural heritage monuments also demonstrates the potential in the documentation, visualisation and preservation of current or already destroyed cultural heritage objects.

A realised VR application using the HTC Vive is a very immersive experience. It provides the opportunity to walk through a virtual reality environment such as the museum of the Old-Segeberg Town House or the virtual villages of Segeberg and Gieschenhagen in the past, to collect all of the provided information and to see all of the different animations, which explain the topics more than in a physical exhibition, e.g., in serious games.
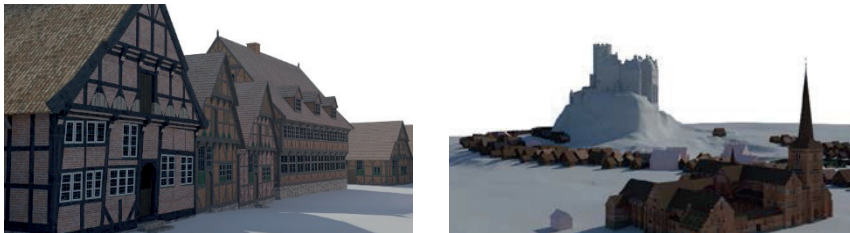

Figure 21. Textured 3D building models of the villages Segeberg and Gieschenhagen, Germany, in the Early Modern Age at 1600: Old-Segeberg Town House and town hall (first and forth building, left) and an overview of already modelled buildings for the VR project "Segeberg 1600" (right) with the St. Mary's church and the monastery in the front and the Siegesburg in the background.

References

1. Bauer, T. Museen und Internet. *Museol. Online* **2001**, *3*, 112–161.
2. Deggim, S. Visualisierung der historischen Siegesburg in Bad Segeberg. Unpublished project report, Master study program Geomatics; HafenCity University, Hamburg, Germany, 2015; p. 36.
3. Deggim, S. Entwicklung Eines Virtuellen Museums für ein Historisches Gebäude am Beispiel des Alt-Segeberger Bürger-Hauses. Unpublished Master thesis, Master study program Geomatics, HafenCity University, Hamburg, Germany, 2016; p. 82.

4.   Deggim, S.; Kersten, T.; Lindstaedt, M.; Hinrichsen, N. The Return of the Siegesburg - 3D-Reconstruction of a Disappeared and Forgotten Monument. In *3D Virtual Reconstruction and Visualization of Complex Architectures*, Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences Conference, Nafplio, Greece, 1–3 March 2017; D. Aguilera, A. Georgopoulos, T. Kersten, F. Remondino, E. Stathopoulou, Eds.; Vol. XLII-2/W3; ISPRS: Nafplio, Greece, 2017, pp. 209–215.

5.   Fangi, G.; Wahbeh, W. The destroyed Minaret of the Umayyad Mosque of Aleppo, the Survey of the Original State. *Eur. Sci. J.* **2013**, *4*, 403–409.

6.   Gruen, A.; Remondino, F.; Zhang, L. Reconstruction of the great Buddha of Bamiyan, Afghanistan. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2002**, *34*, 363–368.

7.   Gütt, I. Smartphone-Applikationen im Museumsbereich. Bachelor Thesis, Studiengang Museumskunde, Fachbereich Gestaltung, HTW Berlin, Berlin, Germany, 2010; p. 74.

8.   Herzberg, A.-C. Visualisierung der Siegesburg von Bad Segeberg mit 3Ds Max Design. Unpublished project report, Master study program Geomatics, HafenCity University, Hamburg, Germany, 2015; p. 28.

9.   HTC Corporation. Vive PRE User Guide. Available online: http://www.htc.com/managed-assets/shared/desktop/vive/Vive_PRE_User_Guide.pdf (accessed on 31 May 2017).

10.   Ivarsson, E. Definition and Prospects of the Virtual Museum. Master Thesis, Uppsala University. Available online: http://www.elinivarsson.com/docs/virtual_museums.pdf (accessed on 31 May 2017).

11.   Jones, G.; Christal, M. The future of virtual museums: On-line, immersive 3-D environments. *Created Real. Group* **2002**, *4*, 1–12.

12.   Kersten, T.; Acevedo Pardo, C.; Lindstaedt, M. 3D Acquisition, Modelling and Visualization of north German Castles by Digital Architectural Photogrammetry. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2004**, *35*, 126–132.

13.   Kersten, T.; Lindstaedt, M. Virtual Architectural 3D Model of the Imperial Cathedral (Kaiserdom) of Königslutter, Germany through Terrestrial Laser Scanning. In *EuroMed 2012—International Conference on Cultural Heritage*; Lecture Notes in Computer Science (LNCS), Ioannides, M., Fritsch, D., Leissner, J., Davies, R., Remondino, F., Caffo, R., Eds.; Springer-Verlag: Berlin/Heidelberg, Germany, 2012; Volume 7616, pp. 201–210.

14.   Kersten, T.; Hinrichsen, N.; Lindstaedt, M.; Weber, C.; Schreyer, K.; Tschirschwitz, F. Architectural Historical 4D Documentation of the Old-Segeberg Town House by Photogrammetry, Terrestrial Laser Scanning and Historical Analysis. In *Cultural Heritage. Documentation, Preservation, and Protection*, Proceedings of the 5th International Conference, EuroMed Progress, Limassol, Cyprus, 3–8 November 2014; Ioannides, M., Magnenat-Thalmann, N., Fink, E., Zarnic, R., Yen, A.-Y., Quak, E., Eds.; Lecture Notes in Computer Science (LNCS) 8740; Springer International Publishing: Cham, Switzerland, 2014, pp. 35–47.

15. Kersten, T.; Tschirschwitz, F.; Deggim, S. Development of a Virtual Museum including a 4D Presentation of Building History in Virtual Reality. In *3D Virtual Reconstruction and Visualization of Complex Architectures*, Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences Conference, Nafplio, Greece, 1–3 March 2017; D. Aguilera, A. Georgopoulos, T. Kersten, F. Remondino, E. Stathopoulou, Eds.; Vol. XLII-2/W3; ISPRS: Nafplio, Greece, 2017, pp. 361–367.

16. Lawson, E. Game Engine Analysis, 2016. Available online: https://www.gamesparks.com/blog/game-engine-analysis/ (accessed on 12 January 2017).

17. Meydenbauer, A. Ueber die Anwendung der Photographie zur Architektur- und Terrain-Aufnahme. *Zeitschrift für Bauwesen* **1867**, *17*, 61–70.

18. Mortara, M.; Catalano, C.E.; Bellotti, F.; Fiucci, G.; Houry-Panchetti, M.; Petridis, P. Learning cultural heritage by serious games. *J. Cult. Herit.* **2014**, *15*, 318–325.

19. O'Flanagan, J. Game Engine Analysis and Comparison, 2014. Available online: https://www.gamesparks.com/blog/game-engine-analysis-and-comparison/ (accessed on 11 January 2017).

20. Pescarin, S.; Pagano, A.; Wallergård, M.; Hupperetz, W.; Ray, C. Evaluating virtual museums: Archeovirtual case study. In *Archaeology in the Digital Era*, Proceedings of the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26–29 March 2012; Earl, E., Sly, T., Chrysanthi, A., Murrieta-Flores, P., Papadopoulos, C., Romanowska, I., Wheatley, D., Eds.; Amsterdam University Press: Amsterdam, The Netherlands, 2013; pp. 74–82.

21. Petridis, P.; White, M.; Mourkousis, N.; Liarokapis, F.; Sifniotis, M.; Basu, A.; Gatzidis, C. Exploring and interacting with virtual museums. In Proceedings of the 33rd Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Tomar, Portugal, March 2005; pp. 73–82.

22. Pujol, L.; Lorente, A. The Virtual Museum: a Quest for the Standard Definition. Archaeology in the Digital Era. In Proceedings of the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, UK, 26-29 March 2012; pp. 40–48.

23. Reimers, H.; Hinrichsen, N. Das Alt-Segeberger Bürgerhaus. Vom Stadtwohnhaus des 16. Jahrhunderts zum Stadtmuseum im 21. Jahrhundert. Lutherstadt Wittenberg, Torgau und der Hausbau im 16. Jahrhundert; Goer, M., Furrer, B., Klein, U., Stiewe, H. and Weidlich, A., Eds.; Jahrbuch für Hausforschung 62; Jonas Verlag: Marburg, Germany, 2015; pp. 341–355.

24. Reussner, E. Wissensvermittlung im Museum – ein überholtes Konzept? *Kultur und Management im Dialog* **2007**, *5*, 20–23.

25. Samida, S. Überlegungen zu Begriff und Funktion des „virtuellen Museums": Das archäologische Museum im Internet. *Museol. Online*, **2002**, *4*, 1–58.

26. Schweibenz, W. The "Virtual Museum": New Perspectives for Museums to Present Objects and Information Using the Internet as a Knowledge Base and Communication System. In *Knowledge Management und Kommunikationssysteme, Workflow Management, Multimedia, Knowledge Transfer*, Proceedings of the 6th International Symposium for Information Science (ISI 1998), Prague, 3–7 November 1998; Zimmermann, H.H.; Schramm, V., Eds.; UVK Verlagsgesellschaft mbH: Constance, Germany, 1998; 185–200.

27. Shaw, J. The Virtual Museum. In *Installation at Ars Electrónica*, ZKM, Karlsruhe: Linz, Austria, 1991.

28. Styliani, S.; Fotis, L.; Kostas, K.; Petros, P. Virtual museums, a survey and some issues for consideration. *J. Cult. Herit.* **2009**, *10*, 520–528.

29. V-MusT. What is a Virtual Museum? Virtual Museum Transnational Network, 2011. Available online: http://www.v-must.net/virtual-museums/what-virtual-museum (accessed on 13 January 2017).

30. Wahbeh, W.; Nebiker, S.; Fangi, G. Combining Public Domain and Professional Panoramic Imagery for the Accurate and Dense 3D Reconstruction of the Destroyed Bel Temple in Palmyra. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2016**, *III-5*, 81–88.

31. Wiedemann, A.; Hemmleb, M.; Albertz, J. Reconstruction of historical buildings based on images from the Meydenbauer archives. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2000**, *33*, 887–893.