

*Thomas van Reimersdahl – Peter Melms – Henner von Hesberg*

## 3D Visualization Limitations of Historical Spaces: Requirements, Practices and Technical Visions

*Abstract:* This paper focuses on the limitations of 3D reconstructions and their visualization with recent software applications. Taking several cultural heritage research projects as examples (the cryptoporticus, the theatre of the Villa Domitian in Castel Gandolfo and the “Musensaal” in the Faustina baths in Milet), we discuss how archaeological requirements and current technical practices affect the limitations of 3D reconstruction and visualization approaches. In response, some technical visions will be introduced to illustrate some possibilities for overcoming several of these limitations.

### *Introduction*

Three-dimensional reconstruction projects of fragmentary buildings aim at mapping available fragments to a whole 3D model whereby unavailable parts are supplemented based on archaeological expertise. The main goal of such reconstructions is to generate a complete and sound 3D representation, enabling further studies. An additional benefit is that these reconstructions can be employed in public presentations. In the second section, we introduce three of our reconstruction projects. The subsequent sections reflect on the lessons we have learned through these projects. Demonstrations of our visualization software COVISE (Collaborative Visualization and Simulation Environment), which is freely available for scientific research projects, as well as discussions about technical feasibility led to a listing of typical requirements, which is presented in the third section. After a short theoretical introduction to the reconstruction process in the fourth section, the problems that were identified to be faced by each reconstruction project are presented in the fifth section. In the sixth section, technical limitations are focused on, and the maximum standards of quality that 3D reconstructions can currently achieve are discussed. As a result of our perennial research projects, we suggest a system of classification for 3D visualization applications in the seventh section which reflects the increasing demands on 3D visualizations as they respond to growing possibilities. These categories lead to some possibilities that we envisage for future projects, presented in the conclusion of the last section.

### *Reconstruction Projects*

In this section we introduce the archaeological background of our ongoing reconstruction projects: the cryptoporticus and the theatre of the Villa Domitian in Castel Gandolfo (HESBERG 1980; HESBERG 1981a; HESBERG 2006) as well as the “Musensaal” of the Faustina baths in Milet (GERKAN / KRISCHEN 1928). The lessons learned from their respective 3D reconstructions form the basis of the discussions in the subsequent sections.

#### **Cryptoporticus of the Villa Domitian in Castel Gandolfo**

The villa of the Roman Emperor Domitian, who reigned from 81–96 A.D., was situated between the places nowadays known as Albano and Castel Gandolfo at the edge of a crater, in the interior surrounding of the Albanian Lake. Among the emperor’s country estates this villa was the most important one, sometimes even serving as his residence. Its most important installations were scattered over terraces of the ridge of the crater, the area of which extended from the shore of the lake in the east to the Via Appia in the west, with a basal surface of at least 2500 × 1200 m<sup>2</sup>. This is where the emperor arranged games for the population of Rome and where he received the senate as well as foreign legations. After Hadrian’s villa near Tivoli, Domitian’s is the greatest among the villas of the Roman emperors. During the reign of Domitian, power became increasingly concentrated in the person of the emperor. This was externally expressed in his self-representation in public and private monuments. The villa clearly dis-



Fig. 1. 3D reconstruction results of the cryptoporticus.

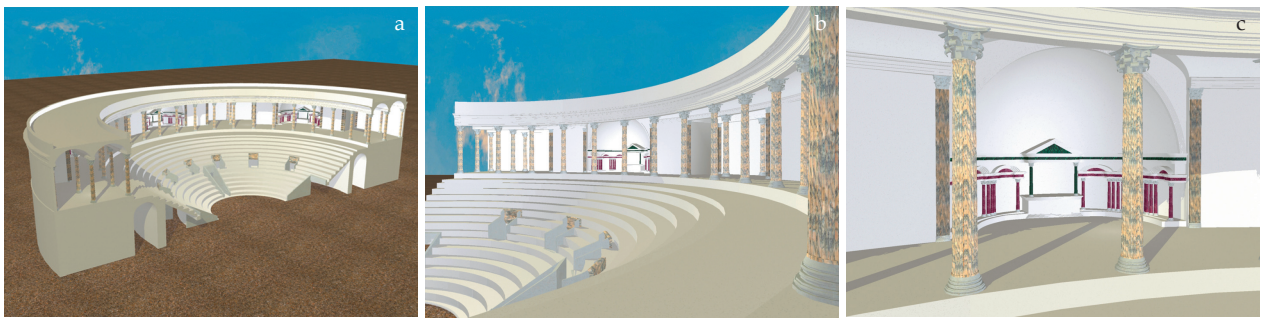


Fig. 2. 3D reconstruction results of the theatre.

plays this, with its severe composition, the peculiarity of several buildings as well as in its equipment.

Apart from the more general interest in the ruins, our work was determined first of all by what we might learn about the emperor's intention by evaluating the structure of the installation, the importance of the villa for Domitian and the function he assigned to it among his different residences. The consideration should now concentrate rather on the reconstruction of two buildings: the theatre and the cryptoporticus, and their use during the reign of the emperor.

In this ensemble the cryptoporticus formed a sort of spinal column and at the same time, due to its size, represented the most impressive instance of this type of structure. Measuring more than 338 m in length, 7.5 m in width and 10.5 m in height, it was the greatest known hall of its kind in antiquity (Fig. 1). Below the central terrace, starting from a zone offering more access to the public, which could be entered from streets from the Via Appia, it led to the private residential part of the villa.

The use of photogrammetrical and geodetical registration allowed the whole arrangement to be widely reconstructed. Regarding the equipment, two phases may be discerned. In the first one the walls were painted, in the second one they were covered with marble plates.

There are many questions connected with the reconstruction of the cryptoporticus, for instance how it appeared from the different parts of the building. The long route to the place of the emperor through the corridor should be analyzed in its different parts. The quality of light combined with the effects of painted walls or a polished marble surface are of high importance, as are the inclusion or exclusion of the gardens outside the building and other effects.

Whenever one imagines the cryptoporticus in function, one notices the conspicuous guiding line of the light, falling from the side windows in the northern section to the upper ones in the southern part. The light is reflected in the shiny marbled walls. Such staging is conceivable only in the context of the representation of the emperor; such a pedestal as a section of the staircase could have had no other meaning. To the visitor the emperor and his entourage must have appeared as if in a sort of window when the sun was in the south.

#### Theatre of the Villa Domitian in Castel Gandolfo

As was the norm for all Roman theatres, the theatre in the Villa was composed of two parts, the stage and the spectators' round (Fig. 2). The spectators' round was situated directly beside the steeply ascending terrain. It was possible to assemble the remaining

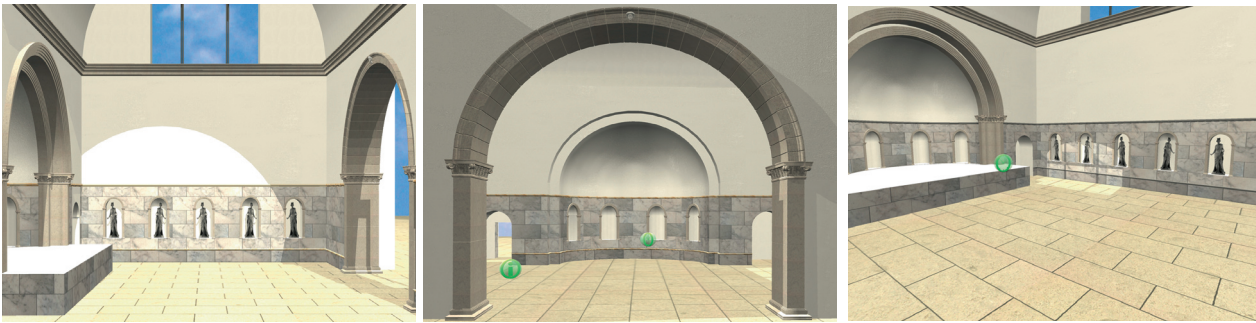


Fig. 3. 3D reconstruction results of the “Musensaal”.

parts of the decoration, insofar as they were fitting in their size and their characteristics, and to combine them with the rests of the construction. The spectators’ round was crowned by a porticus, and the system of draining pipes may be interpreted as fountain jets. One has to imagine a fountain before every other column.

The interior of the porticus is decorated with fountains. The combination of these with other architectural elements having corresponding curvature leads to the porticus.

The stage also may be reconstructed to a great extent in its original form. First of all there is the *pulpitum* belonging to the stage, with its architecture consisting of a dense row of small columns. The significance of a theatre in a private context usually refers to the organization of games (*ludi*) recorded for the Albanum as *Juvenalia* and *Quinquatrus* in reverence to *Minerva*.

The theatre presents a lot of different questions about perceiving architecture, for instance about the use of water and its aesthetic effects in connection with architecture, the use of veils and other installations on the scene with its curtain, the soundings and the lines in which visitors were guided to their places. For all these questions – how to see architecture at work, how to visualize movements in certain spaces which could be easily changed from one moment to the other – our project seeks answers. In this way the understanding of a residence as a place where the interaction between the emperor and his people is clearly regularized by the ceremonial, by which its performance obtains a determinative effect, should be possible.

#### “Musensaal” of the Faustina baths in Milet

The “Musensaal” (Hall of Muses, see Fig. 3) belongs to the Faustina baths in Milet and is located on the

western coast of Anatolia, nowadays the Aydin Province of Turkey. The building complex of the Faustina baths extends about 2 ha and lies in the centre of the antique city, enclosed by the stadium in the west and the southern market in the east, between the northern and the southern part of the city.

According to an inscription found at the entrance of the “Musensaal”, the Faustina baths were donated by Faustina minor, the second wife of the emperor Marcus Aurelius. The Reference to Faustina minor allows the building to be dated to the 2<sup>nd</sup> century AD.

In addition to the actual public bath, the Faustina baths also includes a *Palaestra* and a *Stadium* attached to the south-western corner of the *Palaestra*. The “Musensaal” delineates the northern end of the *Ambulacrum*. The eastern and western walls contain several niches in which statues of muses were placed, which explains the name of the room.

#### *Archaeological Requirements*

Reconstruction projects in archaeology mostly deal with incomplete remains and use archaeological expertise to complete the remains towards a whole virtual model for at least one construction time, enabling them to address scientific questions. With the possibility of perceiving the reconstructed models on a life-size scale, fully immersed in a Virtual Reality environment, the need for realism increases because each detail becomes clearly visible. The demand for realism has controversial aspects – the higher the degrees of simulated realism, the higher the costs for the implementation. Thus each project has to balance how much realism can be achieved within its budget. The best solution is a 3D model which has an appearance that is as photorealistic as possible with regard to the textures used as well



as the reproduction of the architectural details and the underlying materials. Such a model provides an intense impression of the ambience of the original structure, thus allowing a deeper understanding of the visual interaction between architectural elements and – for instance – lighting. On the other hand, a too realistic appearance suggests a degree of certainty, which sometimes cannot be justified sufficiently, regarding the data and material the reconstruction is based upon. Thus, while the textures used should reflect the appearance of the original materials (e.g. the type of marble) the overall model should retain the appearance of an abstract representation. But of course without the scientific elaboration of archaeologically sound reconstructions and without the visualization of the results, scientific discussion could not be initiated and therefore could not lead to further improvements.

The interactive exploration of the reconstructions is the main means by which historical spaces are perceived in a natural way and even in a scientific, explorative way. While common navigational techniques are the main basis for interactive exploration in architectural visualization applications, other methods allowing different reconstruction versions to be selected are also required. One major way that models contribute to scientific research is by allowing the visualization of changes over time. Therefore, the different reconstructed construction phases have to be interactively selectable without leaving and restarting the application. An additional simple-to-use interface element should allow a construction phase to be selected and the corresponding parts to be dynamically reloaded into the current scene. Also, different reconstruction approaches must be selectable in order to make it clear that there may be multiple equivalent interpretations and reconstruction approaches, each justifiable on the basis of the same findings.

The differentiation between facts and assumptions is also one major requirement of reconstruction projects. The visualization should provide visual clues to distinguish between confirmed archaeological facts and additional assumptions or interpretations. One common technique is to draw the unconfirmed parts with an abstract texture.

### *Reconstruction Workflow*

In this section the common practises of the 3D reconstruction workflow are introduced. This workflow includes several processes that have to be ex-

ecuted stepwise and involves the reconstructions of geometry and texture.

The geometrical reconstruction starts with drawings and plans, ideally from different points of view. At the very least, top-down drawings and drawings from one side have to be available. At best, there are detailed drawings available, showing each side of the particular object. Firstly, the foundation walls have to be reconstructed based on top-down drawings. Then follows the reconstruction of the room height, including the roof, window openings, doors or passages. To reconstruct the room height accurately one needs to have drawings showing at least one side-view. The third and final step covers the reconstruction of geometrical details such as columns, capitals, cornices and additional decoration and ornamentation, equally based on drawings from multiple points of view.

In the subsequent texture reconstruction, the resulting objects need to be textured to give them a more realistic appearance. This task is relatively easy to accomplish if the original materials (e.g. marble) are conserved. The textures can then be created based on photos of these materials, presuming that the conserved parts of the materials are of an appropriate size. In this case, tiling of the texture-image would be possible without too much visible repetition. But even if the original materials are conserved, they often are in such a bad or weathered condition that they could not be used to create textures from photos, as the reconstruction intends to show the materials in their primary condition and not in the condition the materials are in after several hundred years. However, in most cases the objects, which have to be reconstructed, are completely destroyed. In this case, the textures have to be created with image editing software, based on some assumptions. In this regard, even small findings could aid the specification of the original materials.

### *Reconstruction Problems*

Reconstruction projects always have to deal with a couple of common problems. In most cases modellers are not archaeologists. To get an archaeologically sound reconstruction it is important that modellers get acquainted with the demands, the requirements and the aims of archaeological reconstructions. The most important thing is that they follow them strictly without adding own interpretations. Only if modellers discuss each inconsistency with the ar-

archaeologists can the final model meet archaeological demands. Another common problem is that during the modelling process, a certain state or version of the reconstruction has to be specified as “the first choice” to be displayed, even if there are equivalent competing alternatives. Other identified problems concern the phases of geometry reconstruction and of texture reconstruction.

Most geometry reconstruction problems result from the underlying data of the raw material. Available plans and drawings are sometimes inconsistent, incomplete or even wrong. While archaeologists are traditionally used to working with 2D drawings and plans, it is often difficult to raise this data to the third dimension – in some cases, reconstructions which seem to work well in 2D, do not work in three dimensions. The next problem is a problem of scale and proportionality. This means the existing drawings use different scales and therefore demand large adjustments in scale and proportion before they can be used as references for modelling. These adjustments often entail problems with distortion. In some cases, there are no drawings at hand covering different points of view, so certain parts of the building (or object) can not be reconstructed precisely. Finally, the available drawings can be contradictory, i.e. drawings from different views show in fact different reconstruction approaches at the same time.

The main problem with texture reconstruction is the potential lack of conserved parts of the original material. In this case, no verifiable assertions can be made about the used materials. But even if some of the material is conserved, it often is in a rather bad or weathered condition, so it can not be used to represent the former condition and appearance of the object. Or, if parts of the materials are conserved, these parts are often too small and will result in visible repetitions, thus tiling of the texture images should be avoided. This problem often occurs with highly structured or grained materials, like marble. In all of these cases, textures for the three-dimensional reconstruction have to be created from scratch using image editing software, based on more or less reasonable assumptions.

### *Technical Limitations*

The limitations outlined in this section are all concerned with the gap between the requirements

posed by archaeologists and matters of technical feasibility. The limitations of technical feasibility are always determined by hardware functionality and hardware performance.

### **Accuracy vs. Real-Time Visualization**

One of the main requirements for a scientific 3D reconstruction is the demand for an accurate and detailed representation of the lost spaces. However even though it is obviously possible to include all the small details, the rising degree of detail unfortunately leads to high polygon counts for the whole reconstruction. The problem with this is that rendering speed is limited by the performance of current graphics hardware. The higher the polygon count of the 3D model, the slower the 3D model will be rendered in a real time visualization environment. To ensure an interactive display frame rate, it is therefore necessary to achieve a trade-off between the desired level of perfection and the possibilities of real-time rendering.

One instrument to diminish this impact is to include “levels of detail” in the reconstruction. To utilize this technology, multiple models have to be build for every single object in different levels of detail. These different models can be switched, according to the distance between viewer and object. For instance, if the viewer is far away from a column, the details of the capital are not visible and therefore there is no need to render them. If the viewer comes closer to the column, the displayed model will be switched to one on a higher level of detail. If the viewer zooms in very closely, a high resolution version of the capital will be displayed, so the user is able to examine every detail of the column.

### **Photorealism vs. Real-Time Rendering Capabilities**

Despite the fact that the photorealistic presentation of reconstructed buildings is controversial in some cases, there are scenarios where such a presentation is reasonable. But what makes a 3D model look photorealistic?

One of the key answers to this question is lighting. To evoke a natural impression it is essential to include techniques like physically correct dynamic lighting and shadows as well as physically correct reflections on shiny surfaces, although the optical impression is predominantly rather subtle and therefore not noticeable until these effects are miss-

ing. The problem here is that these techniques, in spite of their relatively small optical impact, are computationally very intensive.

A highly detailed, dynamically lighted and physically correct 3D model with several millions of polygons still pushes current hardware to its limits, i.e. it can not be rendered with adequate interactive frame rates.

### *Categories of 3D Model Visualization Applications*

From our point of view, three levels of 3D visualization applications can be identified in the field of archaeology: pure 3D, interactive 3D and integrated interactive 3D. Pure 3D visualizations applications aim at producing animations or videos of high quality. The human-computer-interaction is limited to navigational tasks, only allowing simple walk-throughs. There are numerous examples of visualizations in this category, for instance the Temple of Zeus in Athens (GAIATZES et al. 2000). In interactive 3D visualization applications, the geometric complexity of the models is reduced to permit rendering in real-time. Typical interaction tasks include the selection of alternative sub-models, for instance a submodel from a distinct construction period (HEINE / BRASSE / WULF 2006; JABLONKA 2004). Another typical interaction task is the direct manipulation of selected textures and material properties in order to study the variations within them.

Most current 3D visualization applications can be assigned to these two categories. We predict that in coming years the interactive 3D visualization applications will mature to integrated 3D visualization applications. In such applications several information systems, such as roombook databases, 3D model archives, geographic information systems, and digital libraries, are connected to the visualization application, allowing detailed contextual knowledge to be requested and presented on demand in the 3D environment. Some reconstruction projects already connect a 3D model with a database (HEINE / BRASSE / WULF 2006) or with GIS-like features, like TroiaVR (JABLONKA 2004). But such reconstructions still lack detail and operate only on an abstract level, or restrict users to pre-defined interactions. Improving this approach will result in a new and powerful instrument for scientific analysis enabling the stored information to be correlated in a more intuitive way.

### *Conclusions*

With integrated interactive 3D visualization applications (third level applications) several new possibilities can be envisaged. For instance, an authoring system for didactic knowledge representation could be added. Such a system could provide a toolbox assisting the creation of guided tours for use in education and in museums. New guided tours could be created by the interactive selection of several intermediate stages by requesting the roombook database or other available databases. These intermediate stages could be directly linked with 3D models and with some further contextual information explaining the content. And finally, the transitions between the stages have to be added, thereby completing the guided tour experience for the target users.

A second possibility concerns the major role archaeologists can play in the process of 3D reconstruction, again from a technical point of view. With mobile devices like tablet PCs archaeologists could immediately create digital documentation without using handwritten documents at all, thus skipping the time-consuming process of handwriting recognition. They could also contribute to or even practice the 3D-scanning on-site by themselves. These practises would significantly reduce the time needed to get the right and most promising details for future research. If they also uploaded the generated documents to a project server for sharing purposes with other project members and experts, it would be possible to start the scientific research off-site and even to collaborate close to the campaigns with computer supported collaborative workspace (CSCW) methods.

3D reconstructed cultural heritage objects are brought alive through visualization hardware, visualization software and human-computer interfaces. CPU processing power and transistor density double every 18 months on average. This trend is called Moore's law, and follows from empirical observations which have been taken for about 40 years and appear to be continuing (MOORE 1965). Moreover, computer graphics performance increases by even more than a factor of two every year. As a result of these rapid improvements, we certainly should invest our time and efforts in reconstructing the objects as accurately as possible without thinking about the hardware limitations we are currently confronted with.

In computer graphics, we are currently observing a movement from texture-mapped rendering to pixel graphics processing units (GPU) based rendering.

A GPU is a second processor dedicated to graphics which takes over graphics processing from the CPU. With its highly parallel architecture it can operate very efficiently at manipulating and displaying computer graphics. To use it, however, special programs have to be developed and loaded into the GPU. These programs will enable, for instance, simulating geometry with textured flat geometries and computing large area marble textures at run-time, avoiding visible repetitions.

### *Acknowledgements*

This work is part of the ongoing reconstruction projects in collaboration with the Archaeological Institute (Villa Domitian) and the Computer Science Chair Prof. Lang (Villa Domitian, "Musensaal") of the University of Cologne, the German Archaeological Institute (DAI) in Rome (Villa Domitian) and in Berlin ("Musensaal"), and the Collection of Classical Antiquities in Berlin ("Musensaal"). The "Musensaal" project was founded by the Gerda Henkel Stiftung. The authors wish to thank all the individuals that have contributed to the development of these projects.

### *References*

GAITATZES et al. 2000

A. G. GAITATZES / D. CHRISTOPOULOS / A. VOULGARI / M. ROUSSOU M., Hellenic cultural heritage through immersive virtual archaeology. In: H. THWAITES (ed.), Presenting next generation applications. Proceedings of the 6th International Conference on Virtual Systems and MultiMedia (Gifu 2000) 57–64.

GERKAN / KRISCHEN 1928

A. VON GERKAN / F. KRISCHEN, Thermen und Palaestren: Ergebnisse der Ausgrabungen und Untersuchungen seit dem Jahre 1899. Milet I 9 (Berlin 1928).

HEINE / BRASSE / WULF 2006

K. HEINE / C. BRASSE / U. WULF, WWW-based building information system for „Domus Severiana“ palace at palatine in Rome by OpenSource Software. In: M. IOANNIDES / D. ARNOLD / F. NICCOLUCCI / K. MANIA (eds.), VAST 2006. Joint Event of VAST / CIPA / EG WS G & CH / EuroMed, Nicosia, Cyprus, October 30 – November 4, 2006. Eurographics Symposium Proceedings (Aire-la-Ville 2006) 75–82.

HEINE / HENZE / RIEDEL 2005

K. HEINE / F. HENZE / A. RIEDEL, Raumbezogene Informationssysteme für Bauforschung und Archäologie. Forum der Forschung, Wissenschaftsmagazin der BTU Cottbus 18, 2005, 91–98.

HESBERG 1980

H. VON HESBERG, Zur Datierung des Theaters in der Domitiansvilla von Castel Gandolfo. Atti della Pontificia academia romana di archeologia. Rendiconti, 51/52, 1978–81, 305–324.

HESBERG 1981a

H. VON HESBERG, Neue Ausgrabungen in Castel Gandolfo (Artis 1981).

HESBERG 1981b

H. VON HESBERG, La Scaenae Frons del teatro nella villa di Domiziano a Castel Gandolfo. Archeologia Laziale 4, 1981, 176–180.

HESBERG 2006

H. VON HESBERG, Il potere dell'otium – La villa di Domiziano a Castel Gandolfo. Archeologia classica 57, 2006, 221–244.

JABLONKA 2004

P. JABLONKA, Virtuelle Archäologie, TroiaVR – Schlussbericht (Tübingen 2004).

MOORE 1965

G. E. MOORE, Cramming more components onto integrated circuits. Electronics 38, 1965, 114–117.

*Thomas van Reimersdahl*

*Peter Melms*

*University of Cologne*

*Chair of Computer Science Prof. U. Lang*

*Robert-Koch-Str. 10/52*

*50931 Köln-Lindenthal*

*Germany*

*[reimersdahl@uni-koeln.de](mailto:reimersdahl@uni-koeln.de)*

*Henner von Hesberg*

*German Archaeological Institute*

*Department Rome*

*Via Sardegna, 79*

*00187 Roma*

*Italy*

*[hesberg@rom.dainst.org](mailto:hesberg@rom.dainst.org)*