Communication of Digital Cultural Heritage in Public Spaces by the Example of Roman Cologne

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Abstract. The communication of cultural heritage in public spaces such as museums or exhibitions, gain more and more importance during the last years. The possibilities of interactive 3D applications open a new degree of freedom beyond the mere presentation of static visualizations, such as pre-produced video or image data. A user is now able to directly interact with 3D virtual environments that enable the depiction and exploration of digital cultural heritage artifacts in real-time. However, such technology requires concepts and strategies for guiding a user throughout these scenarios, since varying levels of experiences within interactive media can be assumed. This paper presents a concept as well as implementation for communication of digital cultural heritage in public spaces, by example of the project Roman Cologne. It describes the results achieved by an interdisciplinary team of archaeologists, designers, and computer graphics engineers with the aim to virtually reconstruct an interactive high-detail 3D city model of Roman Cologne.

Keywords: High-detail 3D Models, Virtual Reality, Real-Time 3D Visualization, Museum, Roman Cologne.

1 Introduction

With the beginning of the digital revolution in the second half of the 20th century, a new era heralded for all information-related activities, redefining how information is retrieved in economic, social and technological systems today. The communication of cultural heritage is one of these areas that experienced a continuous growth during this time, where it leveraged from the digitalization for a long-ranging preservation and efficient communication of context-sensitive information.

With major interest, the reconstruction of archaeological excavation sites emerged as a powerful tool to communicate archaeological features and cultural knowledge, not only to experts, but also to broad audiences of exhibitions or museums. A continuation of this trend for these public spaces involves digitized cultural heritage, in order to enable people an immersive exploration [13] of "collections for inspiration,

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learning and enjoyment". With the ongoing advancements on the field of virtual reality over the last decades [22], the coupling with digital cultural heritage has evolved as a promising application for an effective and immersive communication of this context-sensitive information. Here, the visualization with interactive 3D applications opens a new degree of freedom beyond the mere presentation of static visualizations. They allow a user to directly interact with 3D virtual environments and enable the depiction and exploration of digital cultural heritage artifacts in real-time.

However, these scenarios mostly induce highly complex and massive data, as being true to the original is one of the ultimate goals. Consequently, visualization concepts and strategies are required that do not only permit an effective communication of these context-sensitive information, but also guide a user throughout these scenarios, since varying levels of experiences within interactive media can be assumed. Therefore, visualization techniques are required on both, technical level in order to allow a real-time visualization of the reconstructions, and conceptual level for allowing users to interactively explore the environment and perceive this information intuitively.

Fig. 1. Exhibition of Roman Cologne at the Roman-German Museum in Cologne. This project is used as feasibility study for the general concepts described in this work.

In this paper we present general concepts and implementations of visualization techniques for interactive 3D reconstructions of digital cultural heritage in public spaces, by example of the project Roman Cologne (Fig. 1). It describes the results achieved by an interdisciplinary team of archaeologists, designers, and computer graphics engineers with the aim to virtually reconstruct an interactive high-detail 3D city model of Roman Cologne. It can be read as a guideline for similar future projects, e.g., to setup a collaborative content creation process, select appropriate data exchange formats, or to apply the presented visualization and optimization techniques to other domains of virtual archaeology [20].

To summarize, this paper makes the following contributions to the scientific community:

1. We propose a concept for the communication of digital cultural heritage in public spaces, such as museums or exhibitions. This basically comprises the identification and justification of different visual presentation modes.
2. We further present the research results for a prototypical application and implementation of a client-server model for information communication and human computer interaction in public spaces.
3. We furthermore present the application of these concepts to the project Roman Cologne that is currently and successfully presented as a permanent exhibition in the Roman-German Museum in Cologne.

The remainder of this paper is structured as follows: Section 2 reviews related work of the field virtual reality and digital cultural heritage. Section 3 presents the concept of three presentation modes suitable for communicating digital cultural heritage in public spaces using 3D virtual environments. Section 4 describes a client-server model and concepts for guided navigation and interaction. Section 5 explains the implementation of the previously described concept. Section 6 evaluates and discusses the preliminary results of the research project Roman Cologne and presents ideas for future work. Section 7 concludes this paper.

2 Related Work

Subsequently, we briefly summarize related work that evolved in the areas of virtual reality and communication of digital cultural heritage in the past.

2.1 Virtual Reality for Digital Cultural Heritage

Numerous projects have been proposed that involve the modeling and rendering of digital cultural heritage in 3D virtual environments. Examples are the virtualization of the great inscription of Gortyna (Crete, Greece) for 3D documentation and structural studies [30], a reconstruction of ancient fresco paintings for a revival of life in ancient Pompeii [24], the reconstruction of Peranakans and their culture [26] and the reconstruction of 19th century Koblenz (Germany) as a case study for a 4D navigable movie [15].

However, only few projects have been presented so far that facilitate users to freely roam inside these virtual worlds, i.e. exploring digital cultural heritage in real-time and being fully navigable. In [9] the project Virtual Reality Notre Dame (VRND) is presented that builds on a gaming-based 3D engine for facilitating a virtual tour guide at real-time rates. With respect to the VRND project, [23] describe methodologies how to use widely available standard programming languages and APIs to not base on proprietary commercial 3D game engines, but still achieving visually compelling results. In [21] 3D real-time virtual simulations of the populated ancient sites of Aspendos and Pompeii have been proposed, that facilitate from virtual reality and simulated dynamic virtual humans for an immersive experience.

Beneath the mere reconstruction of virtual heritage in these environments, other research dealt with rendering techniques for enhancing the immersion aspect and increasing realism. In [12] light scattering is modeled including participating media for enhancing the perception of sites by the example of the ancient Egyptian temple of Kalabsha. Goncalves et al. make use of high dynamic range (HDR) imagery in order to enhance viewing experiences and depicting environments towards a predictive ancient lighting [10]. Furthermore, crowd simulation has been done to enhance realism regarding the population of these environments. In [28], a rule behavior system is used to model such specific and complex behavior.

2.2 Communication in Public Spaces

The reconstruction of archaeological excavation sites, used in combination with an interactive visualization in 3D virtual environments, emerged as a powerful tool to communicate archaeological features and cultural knowledge, not only to experts, but also to broad audiences of exhibitions or museums. Here, virtual reality offers new communication channels, whose use statically increased in these environments over the last years.

In 1994, a first application using virtual reality for heritage has been presented, that allowed the audience to interactively explore a 3D reconstruction of Dudley Castle (England) [4] on a regular screen. More sophisticated installations made use of the CAVE system [8], where the illusion of immersion is sustained by the projection of visuals on display screens of a cube and the audience positioned in the middle. Examples are the Dunhuang caves [18] and a reconstruction of an ancient greek temple in Messene [7]. A third installation possibility is panoramic screens of cylindrical shape, e.g. used in the Virtual Sculpture Museum of Pietrasanta (Italy) [6].

One of the most challenging issues when using these systems in public spaces is, however, the installation of interaction devices that are on the one hand intuitive and consistent, and on the other hand allow visitors to explore application-specific content they should experience without restrictions. A variety of evaluations of interaction devices for these environments exist, from regular 2D (mouse) and 3D (spacemouse) input devices [25, 16] to tactual explorations [2] and visionary interaction techniques like brain-computer interfaces [17].

3 Presentation Modes

This section describes the different presentation modes provided for the effective communication of 3D digital cultural heritage in interactive 3D virtual environments. Fig. 2 exemplifies the visualization of the following three modes: the *reconstruction*, *comparison*, and *findings* mode.

3.1 Reconstruction Mode

The visualization of possible virtual reconstructions or artifacts can be considered as main purpose for a system that communicates digital cultural heritage. It forms the basis for the remaining two presentation modes. Such reconstruction visualization is

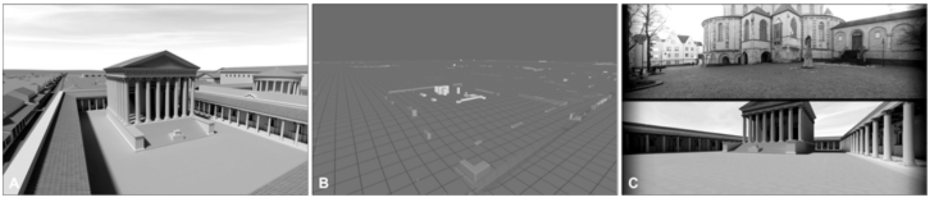

Fig. 2. Presentation modes for the communication of digital cultural heritage by the example of Roman Cologne at a single hot spot: (A) reconstruction mode, (B) findings mode, and (C) comparison mode that uses 360° horizontal panoramic views of the ancient and today's Cologne

the result of numerous projects that deal with interactive 3D virtual environments. Fig. 2(A) shows such visualization by the example of Roman Cologne [19]. Basically, there are two possibilities for the images synthesis of this visualization mode: photo-realism vs. abstract visualization. For example, in the case of Roman Cologne people often wish to have more realism in texturing and lighting, but archaeologist concerns that this would imply a "finished" reconstruction to the user. We choose an abstract, non-photorealistic, and simple coloring schema to communicate that the visualized reconstruction is only one out of many realities.

3.2 Comparison Mode

Based on the reconstruction mode, the comparison mode enables the comparison and dissemination of structural changes over time, i.e., between the reconstruction and today's state. We further observed, that this mode enable visitors with a local background a certain degree of entertainment.

There are several computer graphical approaches and rendering techniques of different implementation complexity to enable the image synthesis for such modes, e.g.

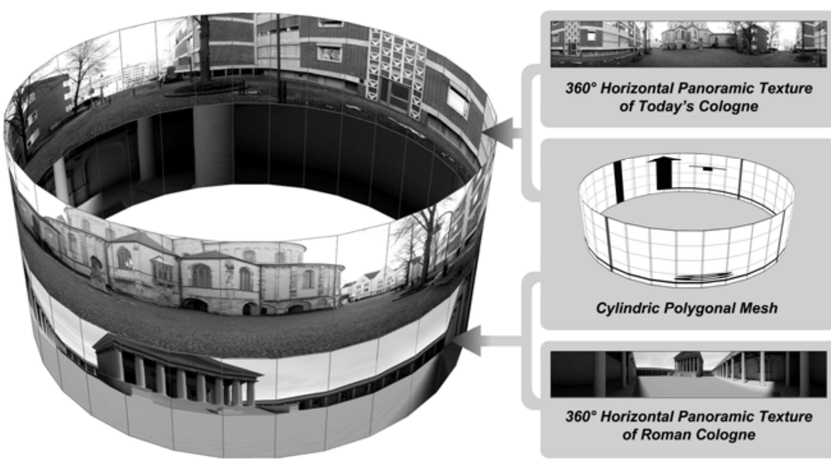

Fig. 3. Components for rendering the comparison mode of Roman Cologne

3D magic lenses [3] can be used to combine different geometries within a single view. Another possibility constitutes the usage of multiple viewports that contain images or screenshots using the same or similar camera configuration.

For the visualization framework of Roman Cologne, we apply a simple image-based approach that allows the side-by-side comparison of locations between the modern Cologne and the ancient version (Fig. 2 (C)). Instead of planar images, we create 360° horizontal panoramic images which are mapped onto two cylinders, each rendered using a virtual camera with an orthographic projection (Fig. 5). To navigate within this setup, the user can rotate both panoramic cameras at the same time.

3.3 Findings Mode

The purpose of this mode is the communication of the findings at their respective locations, which lay the basis for the actual reconstructions. Our goal was to enable a user to understand the relation between artifact and proposed 3D reconstructions performed by archaeologists and designers. As an example, Fig. 3 shows screenshots for the reconstruction mode of the Dionysus villa within Roman Cologne. Approaches for the communication of finding information embedded in reconstruction visualizations have to deal with the following challenges:

1. Multiple findings for a single reconstruction require interaction concepts and rendering techniques for the selection and highlighting of an instance or a group of finding objects.
2. The approaches require a concept that enables the communication of different reconstructions that can be derived from a set of findings.
3. It is necessary to handle different graphical representations for a finding object: 2D photographs, hand-drawn or digital images, as well as 3D polygonal meshes or point clouds, which are obtained from laser scanning.
4. Textual descriptions likely the medium that conveys and communicates the most context information. However, the depiction of text is limited by the available screen space and rendering quality.

In contrast of the geometric models of the reconstructions, the finding geometry has no textures assigned. Instead, we are using non-photorealistic lighting [11] in combination with unsharp masking the depth buffer [29] in order to support shape and depth perception. In addition thereto, a grid is displayed that approximates the underlying terrain (Fig. 3 (A)). It eases the perception which finding object was originally located above or below the ancient terrain. To distinguish between selected and unselected objects, simple color highlighting is used.

Fig. 4 (B) and (C) shows different reconstructions for a single set of findings. These different versions can be mutually blended with the rendering of the highlighted findings. Here, the user can control the blending factor as well as the blending speed. We experimented with an automatic decrease of the blending values over time, but believe that this rather distracts the user. With respect to the textual descriptions of findings, we choose not to embed these within the 3D visualization [19] but depict them on an additional viewport. This functionality is described in the next section.

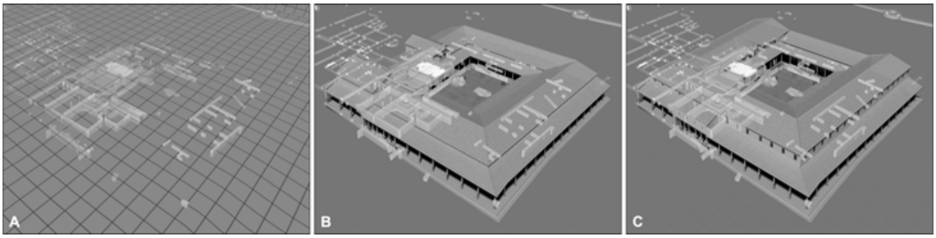

Fig. 4. Finding mode of the visualization of Roman Cologne: (A) depiction and highlighting of different findings at a hot spot, (B) blend-in of a reconstruction based on Fremersdorf, and (C) the reconstruction of Precht. They differ, e.g., with respect to the number of floors.

4 Exhibition Concept

This Section describes the application of the proposed presentation concept by the example of Roman Cologne. The permanent exhibition is located at the Roman Germanic Museum in Cologne and is a constituent part. The main requirements comprised the interactive exploration as well as guided interaction of the virtual 3D reconstruction.

4.1 Conceptual Overview

Fig. 5 shows a conceptual architectural overview of the presented client-server system. The basic museum setup is shown in Fig. 1. It mainly consists of the following two components:

Server: The server performs real-time image synthesis of the 3D content or scene, which is then projected on a vertical surface. Depending on the scene complexity, this can be computational costly and thus requires corresponding rendering hardware.

Client: The client offers the user control over the servers viewing configuration (e.g., the presentation modes) via a touch-based user interface and a 3D mouse. It displays additional information about the scene projected and is adapted to the presentation modes respectively (Fig. 6).

The separation between server-side rendering/visualization and client-side interaction/visualization has two major advantages for systems that provide interactive installations within public places:

1. The two viewports of the server and client provides more physical space to display various types of information that can be presented with an optimal screen real-estate.
2. It enables guided interaction and navigation with the 3D virtual environment using 2D touch events and an additional 3D mouse to control the virtual camera and server state.

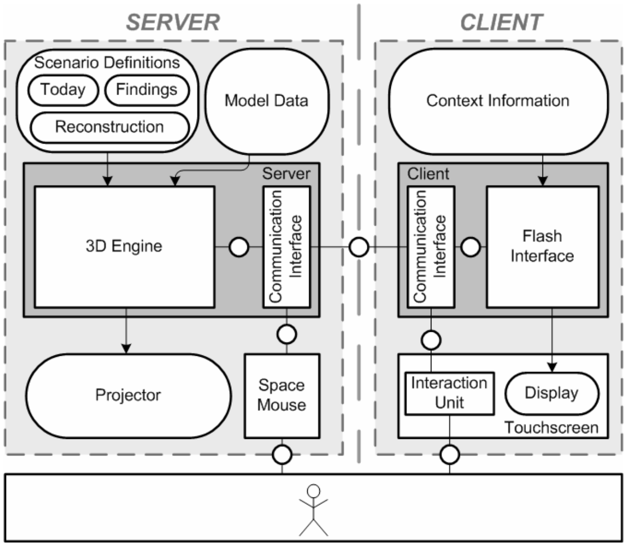

Fig. 5. Conceptual overview of the proposed client-server system

4.2 Concepts for Interaction and Navigation

This Section focuses on the user interface of the client (Fig. 6) and the control of server's virtual camera. As a basic functionality, the touch interface enables the switching between the three proposed presentation modes (Fig. 6 (d)).

The avoidance of "getting lost situations" [5] in 3D virtual environments is the major goal of the proposed interaction and navigation metaphors. This comprises a trade-off between navigation aids or constraints and the total freedom to interact with the system. The orientation of the user is enabled by an overview map (Fig. 6 (e)) that contains a camera glyph indicating the position and orientation of the virtual camera within the 3D scene. This map alters slightly in each presentation mode: an aerial screen shot of the complete reconstruction visualization (Fig. 6 (1)(e)), a combined abstract map of the ancient and modern Cologne (Fig. 6 (2)(e)), and an aerial image of today's Cologne (Fig. 6 (3)(e)). The 3D virtual camera and the camera glyph are synchronized (Section 5.3).

To ease the access to specific locations in the 3D virtual reconstruction, the touch interface presents a number of hot spots (Fig. 6 (b)), which can be selected from a scroll menu at the bottom. After selecting a hot spot the server's virtual camera automatically approaches it by using automatic camera control, which is an important feature for interaction within 3D virtual environments. It is applied for moving the 3D virtual camera between hot spots and between different findings in the scene. Instead of explicitly modeling more than 100 camera paths we decided to derive these paths automatically.

Given the start and target camera settings, and the path duration, our system creates the camera path in the following manner: 1) to avoid possible collisions with buildings, the camera positions are interpolated on a parabolic path; 2) the viewing directions of

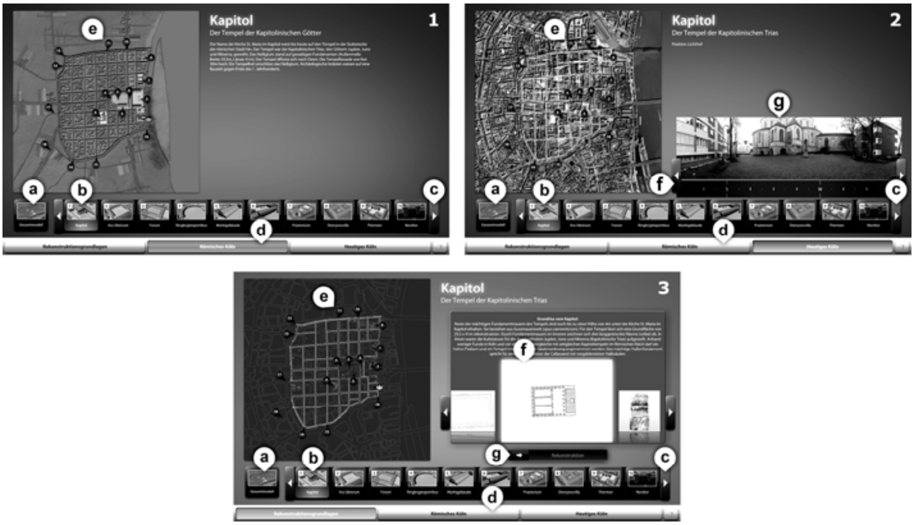

Fig. 6. Structure and organization of the client-side user inferface for the reconstruction mode (1), the findings mode (2), and the comparision mode (3) by the example of Roman Cologne

the virtual camera are interpolated linearly; 3) non-linear speed is used, which results in a slow path start and end.

With respect to the interaction possibilities, we distinguish between two basic types of hot spots: 1) an overview hot spot (Fig. 6 (a)) and local hot spots (Fig. 6 (b)). The local one allows user interaction using an orbital camera model only, while the global hot spot enables free navigation of six degrees-of-freedom via a 3D mouse. If in comparison mode, the 3D mouse can be used to rotate the panorama. In addition thereto, the user can control the rotation via a slider (Fig. 6(3) (f)) on the touch interface. If switching to the findings mode, the user faces a flow-menu from which he/her can select an active finding (Fig. 6 (2)(f)). Successively, the server moves the camera closer the findings and highlights it. A slider (Fig. 6 (2)(g)) can be used to blend-in the available reconstructions for the respective hot spot. To avoid collisions between the virtual camera and the scene objects, designers created an explicit collision model for the complete scene. In contrast to derived bounding approximations, this gives maximum control to the physics designer (Section 5.4).

4.3 Presentation Setup

We divide the presentation setup into two parts: A client and a server. These two computers communicate with each other via a LAN (Fig. 1). The client is connected with a touch screen by inputech (1920x1080px) based on Nextwindow technology and runs a Core2Duo 3 GHz with 2 GByte RAM and a ATI Radeon 4650 (1 GByte RAM). It is used for both, the display of context-specific information as well as terminal for controlling the server. The server runs a Core i5 750 2.66 GHz with 4 GByte RAM and a NVidia GTX 285 (2 GByte RAM) and is connected with a beamer (1280x800 pixels) for displaying the 3D reconstruction on a vertical surface in front of the terminal.

5 Implementation

This Section briefly describes the implementation of the previously described concepts, with the main focus on the server-side image synthesis, content management, and messaging. The client was implemented on Adobe® Flash® using object-oriented action script.

5.1 Real-Time Image Synthesis

The server-side image synthesis can be performed in real-time using modern consumer graphics hardware [1]. Since the optimized geometric model (Table 1) fits into the video memory, we use in-core rendering techniques instead of out-of-core rendering techniques. The complete process of mesh optimization is described in [20]. We use a custom scene graph, shader programs [14] and a compositing pipeline for rendering. Therefore, each presentation mode represents a specific scene graph configuration. At loading time the geometric models are loaded and the scene graph is constructed. The client commands (Section 5.3) triggers the respective reconfiguration of the scene graph.

5.2 Content Management and Content Creation

Since we have a separate data basis for 2D content of the client visualization and 3D content of the server, special care is required for the synchronization between these two. For the communication between client and server (Section 5.3), we use unique global textual identifiers for modes, hot spots, and findings that are mapped by the client and server individually to the respective local content repositories.

In addition to the content creation pipeline described in [20], the geometric representations of the finding meshes are explicitly modeled or triangulated point clouds derived from laser scan data of the original findings. We choose a fixed aspect ratio (16:10) for 2D content creation of the client to minimize sampling artifacts, which would be introduced by rescaling the content otherwise. Both, client and server use a XML data-based file format that allows for easy maintenance and extension. This approach is also suited for a possible data-base binding later on.

The images required for the comparison mode can be obtained by photographs and application screen shoots. In the case of Roman Cologne, we use panoramic images with 360 degrees horizontal field-of-view. After relevant positions are determined within the reconstruction, a photographer acquired real-world images, which are aligned and stitched using Adobe Photoshop®. Our visualization system can acquire panoramic images using a rendering technique described in [27].

5.3 Client-Server Communication

For the communication between the client and the server we implemented a simple text-based protocol that can be easily extended and maintained. The textual messages are exchanged via TCP/IP sockets, whereas the client controls state consistency and initiates hand-shakes and resynchronization. The following messages are exchanged:

Client-Side: The Adobe® Flash® interface performs the initial hand-shake, transmits mode-changes, hot spot changes, the rotation angle of the panorama, as well as the blend factor for the reconstruction and the active finding. It further issues the demo mode after a defined idle time span.

Server-Side: The rendering server confirms the execution of sent commands, and sends the position of the virtual camera at a fixed interval, as well as automatically breaks a demo mode on user interaction.

All interactive controls, such as sliders or the flow-menu element, are sampled at a user defined frequency in order to handle possible network latency and socket congestion correctly. In our implementation we achieve best result using a frequency of 70ms within LAN.

5.4 User Interaction and Collision Handling

A central component for implementing the user interaction is collision detection and handling. It is used to preserve the intrusion of the virtual camera into buildings and to compute intersection points required for the orbit navigation metaphor. For implementing collision handling we use the Bullet physics engine, which is an open source software project. To increase the performance of the collision detection, we decided to use explicitly modeled collision geometry consisting of 57,840 vertices and 95,409 faces (Fig. 7). This approach has the advantage of providing maximal control to design the collision bodies, but requires a complete update of the collision model if only parts of the graphical model changes.

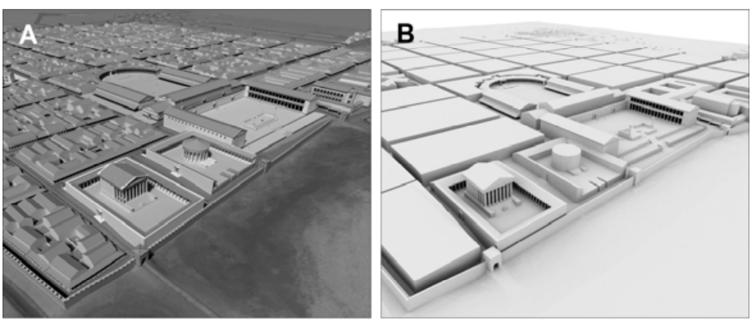

Fig. 7. Comparison between the geometry representation for visualization (A) and the collision handling (B)

6 Results and Discussions

This Section describes the results and evaluation of the proposed system. We start with a performance analysis and then describe preliminary observations with respect to the users. The performance of a 3D reconstruction is an important issue when a smooth and real-time experience for a user is aspired. The majority counts any application a real-time application, as soon as it renders more than 30 frames per second in average. Table 1 summarizes basic statistics for each of the three modes presented in Section 3.

Table 1. Statistics for the modes: reconstruction (Roman), comparison (Modern), and findings

Mode	Mesh	Vertices	Faces	Texel
Roman	372	15.465.030	21.132.616	1.307.049.984
Modern	**2**	136	128	12.987.912
Findings	64	327.842	291.988	4096

We measured the performance for the mode "Roman Cologne" on the setup described in Section 4.3. For the benchmark, we enabled view frustum, and backface culling, and disabled vertical synchronization. As basis for measuring, we used four different camera paths: Two paths that cover a bird's eye perspective and two paths that cover a pedestrian perspective. Table 2 summarizes the performance for different screen resolutions.

The results in Table 2 show that our system setup allows rates at real-time. We furthermore observe a higher frame rate of approximately 8% in pedestrian areas. A third observation allows classifying our implementation regarding a limiting factor. As the frame rate decreases with higher resolutions, the GPU can be seen as limiting device. As a summary, our application is fill-limited, showing an increase of 15% when using a resolution of 800x600 pixels instead of 1920x1200 pixels (Full HD).

The evaluation of the proposed system comprises two main steps: a test phase and a reviewing phase. During the test phase, the systems setup is tested thoroughly offline. This includes the tuning of sensitivity parameters of the input device and the physics engine. In the reviewing phase, the system is installed in the Roman-German Museum and is tested by staff and visitors. The results of that phase (one month) are then incorporated in the system. The preliminary observations during that phase basically yield positive response by the users, even if only a single user can interact with the system, while others are watching or waiting. We observed that the modern mode was very popular among most of the visitors.

Table 2. Performance evaluation for the mode “Roman Cologne” in frames-per-second (fps)

	Bird’s Eye View [fps]			Pedestrian View [fps]		
Resolution	Avg.	Min	Max	Avg.	Min	Max
1920 x 1200	65.2	46	72	70.0	61	77
1600 x 1200	68.9	57	75	73.0	64	79
1024 x 768	72.7	43	81	78.8	70	84
800 x 600	74,7	40	83	80.5	71	85

7 Conclusions and Future Work

This paper presents a concept and implementation for the interactive communication of digital cultural heritage in public spaces by the example of the research project Roman Cologne. The proposed concept makes use of a client-server architecture, consisting of a 3D real-time rendering server and 2D touch sensitive user-interface to enable guided user exploration of a 3D virtual environment and knowledge communication. We generalized the approach towards a visualization tool for digital cultural heritage. The systems turns out to be a success, thus, other cities are eager to install similar approaches.

In order to enhance the usability of our system, we incorporated an additional statistics module that collects user data with respect to selected hot spots and the amount of time spent within these. We hope to identify remaining possibilities for get-lost situations and to rank features based on the importance to the users. We further strive towards making the existing content interactively available via the world-wide-web by using the recently standardized web-perspective view service (WPVS). In this context, we furthermore plan to evolve the existing system into a framework, which then can be used by third parties. Therefore, a data-base binding as well as out-of-core rendering techniques in combination with level-of-detail approaches are required to enable the interactive image-synthesis of geometrically even more complex data sets.

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