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Virtual Reality and Cultural Heritage on the Web

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Abstract

The paper presents various issues dealing with presentation of cultural heritage objects in a virtual space. While the reconstruction techniques are mentioned just briefly, the attention is paid to the visualization approaches for wide audience, i.e. techniques targeted to the web. Due to the diversity of network connections and performance of computers used by ordinary users, the efficient representation of virtual objects plays an important role. Web-based presentation of three-dimensional scenes requires specific user interfaces. Those issues are discussed and accompanied by examples and practical experience from the design and implementation of the EU project Virtual Heart of Central Europe.

Keywords: Virtual reality, Cultural Heritage, Web-based visualization, User interface

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1. Introduction

Wide availability of the Internet fits well into purposes of many cultural institutions like museums, cultural and historical archives, libraries, and universities. If such institutions aim to collect, preserve, and finally to show various exhibits from the real world to public or professional audience, the web is a way to deliver a digital (virtual) representation of almost any kind of exhibit to any interested user.

The web technology itself was initially considered as a platform for efficient work with documents, i.e. (hyper)text and images. This traditional way is still convenient for the presentation of cultural heritage objects like paintings, engravings, canvases, and other artworks with a two-dimensional essence. In contrary, a web support for presentation of spatial (3D) objects, scenes, and environments is not so well established and widely accepted by ordinary users. Methods and data formats for digital representation of 3D data are much more complicated and heterogeneous comparing with 2D images. A general observation is that most providers (institutions) are afraid of using advanced technologies like the virtual reality (VR). They point out to a number of difficulties when creating virtual models of the real world objects – lack of algorithms for automatic reconstruction of large objects (e.g. exteriors and interiors of historical buildings), processing of huge amount of data resulting from scanning exhibits, optimization of geometrical and texture properties of highly detailed 3D objects, finding a balance between visual quality and amount of data transferred through the web, requirements to computer performance on client side, etc.

In this paper we discuss various techniques that have a potential to overcome issues dealing with modeling, optimization, and final presentation of cultural heritage objects using virtual reality paradigms. Section 2 introduces general approaches suitable for web presentation of cultural heritage objects. Brief overview of digital reconstruction techniques is given in Section 3. Specific features of web-based rendering are presented in Section 4, while user interface issues are discussed in Section 5. Section 6 describes practical results of the Virtual Heart of Central Europe project. Section 7 concludes the paper and shows directions for further development in the field.

2. Culture Heritage and the Web

Already existing web presentation techniques can be classified by the nature of examined objects and the methods used for their visualization:

Image: Static images of standalone 2D/3D objects.

Movie: Images/videos of 2D/3D objects placed in a 3D environment.

Model: Visual examinations of individual 3D virtual models.

Scene: Navigation in 3D scenes consisted of many objects.

These categories are further discussed in details.

2.1 Photograph based techniques

The first category is typically represented by web collections of 2D exhibits like paintings or a set of photographs of 3D objects. Such collections are often called *virtual galleries*. This does not correspond with the term *virtual reality*, but highlights the difference between real and digital world. Digital images are always of lower quality than the original art pieces, of different size, and other features. Virtual galleries made from images are the most frequently used technique for the web presentations (see e.g. Virtual Museum of Canada [WWWcan]).

The next category is suitable for museums that arrange objects in thematic expositions and want to show a relationship among individual exhibits. In such a case, a photo of an exhibition hall captures not only the exhibit itself but also a space in its vicinity.

Photographs can be organized in a sequence reminding of a *virtual tour* through the museum. A video recorded in a real exhibition is another kind of this category. The bottleneck when using video is a big size of data transferred through the web.

Figure 1. Panoramic image from the Louvre Museum. Perspective distortions are only small imperfections that are paid for a possibility to smoothly turn a user's view.

The most advanced technique based on photographs is known as *panoramic images* (see Fig. 1). A set of neighboring snapshots is digitally processed and mapped on an inner side of a cylindrical surface. A special browser/player displays a view from the center of the cylinder in an initial direction. Then it allows turning the view left and right or even zooming. Panoramic images can be covered by sensitive areas containing hyperlinks to other images or web pages. Several implementations are available - the most widely used one is based on the Apple QuickTime VR technology [WWWqui]. A representative web site utilizing panoramic images is the Louvre museum [WWWlou]. Although the technique of panoramic images can be applied to a single 3D object as well (corresponding images are mapped on a sphere surface from outer side in such a case), cylindrical panoramic backgrounds are more favorable. They can be produced using standard camera and a tripod. Panoramic objects require additional equipments like a rotary table.

2.2 Spatial Models

While the first two classes of web presentations make use of photo and video technologies, next two approaches are based on fully 3D representations. The visual exploration of individual *virtual object* is a useful method allowing rotation of an object around a pivot point to see it from all sides, and using a zoom to see details. Internal representation of the virtual object is typically a mesh of triangles covered by textures. A special browser/viewer installed in a web browser is necessary even if the model is defined using the VRML International standard [ISOvrm]. An example of the web site with a collection of several 3D exhibits is the Inuit exhibition [WWWinu] in the Canadian Museum of Civilization (see Fig. 2). Majority of web sites uses VRML language to describe 3D models, but other technologies derived from VRML also exist, e.g. MetaStream technology by Viewpoint [WWWvie].

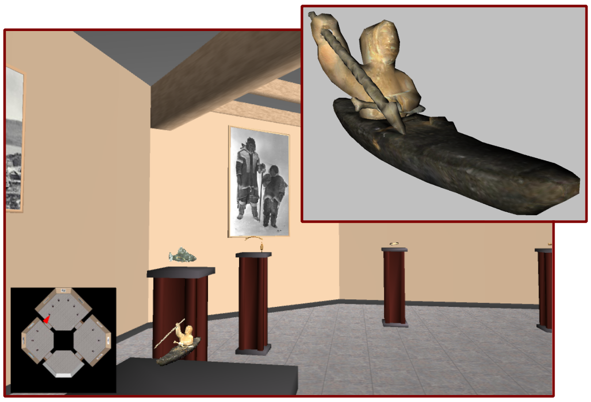

Figure 2. While the main hall in the Inuit exhibition is three-dimensional, exhibits are represented by 2D images with hyperlinks. When the image is activated, a new window with bigger 3D model is opened. Example shows an image of a hunter in kayak (left bottom corner) and a corresponding VRML model.

Another example of the power of computer graphics and especially virtual reality deals with *interaction* with virtual objects. This is particularly useful when old-time technical devices have to be presented together with their functionality. Thanks to VR principles, such a virtual machine can react on user's requests and change transparency of selected parts, show cross-sections, start animated show, or allow direct manipulation similar to a work in a real world (see Fig. 3).

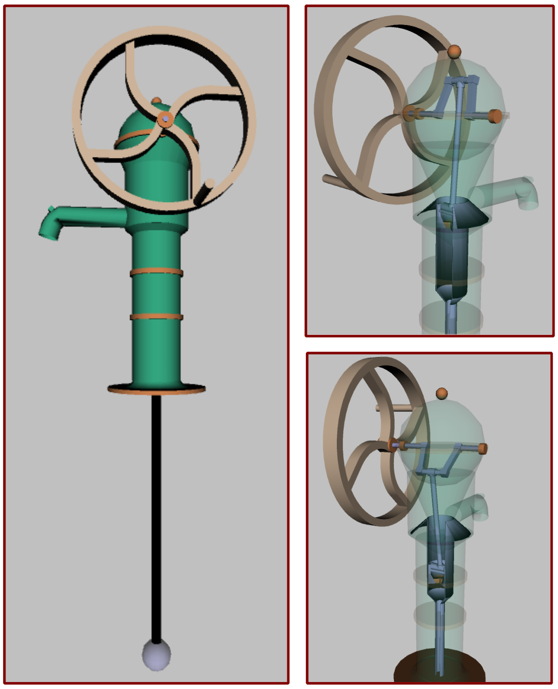

Figure 3. Functional and interactive virtual model of a hand pump shows internal parts using transparency and presents basic principles when users rotate a wheel. Under preparation for the National Technical Museum in Prague.

A very special technique that has been originally developed for cultural heritage conservation is a *point-based representation* of spatial objects in the Digital Michelangelo project [Lev00]. A high precision laser scanner scans a real object. Gigabytes of point samples are not immediately converted into a triangular mesh as usually, but are stored in a pyramid of point records consisting of coordinates, normal vector, color, and possibly other characteristics like reflectance per sample. Extremely high precision is good for archive purposes but not for interactive web presentation. To allow web users to examine such an object, a point-based renderer is necessary. One such a viewer is based on a client / server architecture [WWWsca]. Users locally manipulate with a low-resolution 3D mesh. When they stop the manipulation, a high quality image is immediately requested from the server. When received, the static image overlaps the view until new interaction starts (see Fig. 4).

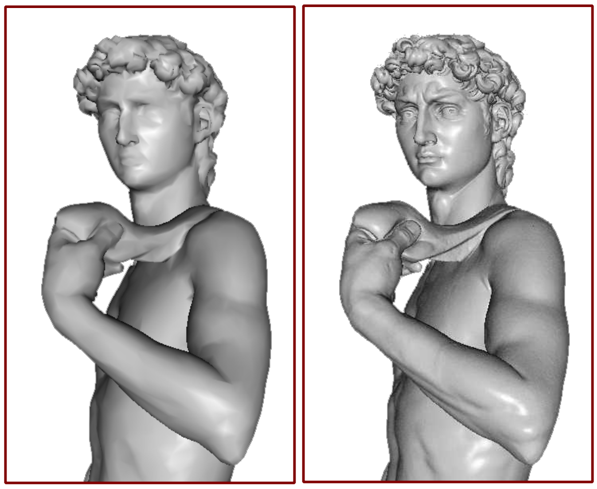

Figure 4. The Digital Michelangelo Project. A client interactively manipulates with the statue of David using simplified polygonal model (left). A high quality image is rendered on the specialized server on request (right).

2.3 Virtual Environment

The virtual reality technology offers not only an exploration of a single exhibit but of many virtual objects arranged into a *virtual scene*. The main difference from the previous approach is that users virtually enter the virtual space - they get a feeling of being a part of the *virtual environment*. To improve such a feeling, various navigation paradigms are applied. Users can walk or fly in a 3D space instead of staying at one place and looking around as in the case of panoramic images. Usually several predefined view positions are offered to users to help them with relatively difficult spatial navigation.

Being a part of a 3D space is naturally useful for presentation of interiors. It is even more convenient for visualization of exteriors where visitors meet historical buildings and generally any architectural objects placed in a space. Since the presentation system usually keeps relationships between proportions of buildings

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and basic parameters of a human user (height, view angle, speed of walking), it is easy to understand spatial properties of the presented object(s) and get astonished by a beauty and majesty of ancient constructions.

Virtual scenes consisting of many buildings typically require more geometrical and image data than a single object. That is why web presentations usually offer only limited virtual environment surrounding not more than couple of thousands square meters and/or tens of buildings. The example is a model of Wells Cathedral and its vicinity developed under the VirtuAl project [WWWvir].

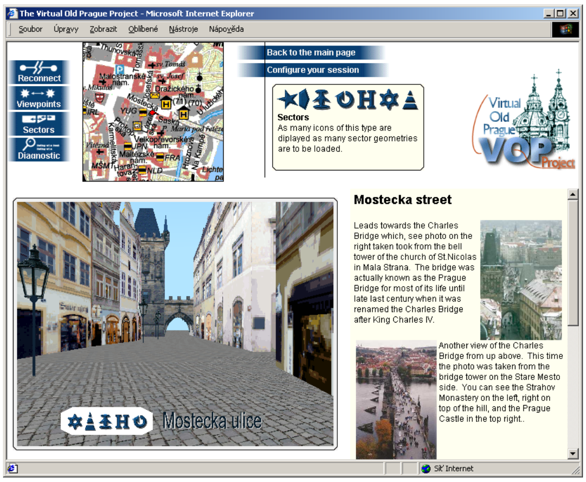

Figure 5. Web application Virtual Old Prague consists of several components – 3D scene window (left bottom), HTML document (right), and 2D navigation map synchronized with user's movement in a virtual space (top left).

Large historical and cultural areas are still rare on the web. The pioneering attempt is the Virtual Old Prague project [WWWvop] that is based on progressive downloading city parts in correspondence to current user's position in a virtual space (see Fig. 5). As user walks through the city, new streets, buildings and other objects are requested from the web server in advance. They continuously extend partial city model in a client memory. On the contrary, already visited city parts that became invisible are temporarily removed from the memory. This method keeps the complexity of displayed scene almost constant thus it allows scalable visualization of theoretically infinite virtual space [Zar01].

Virtual reality offers more than a copy of a real world. It allows simulation of conditions that are either dangerous or unfeasible at present time. A paper by Pope and Chalmers [Pop00] describes a study where virtual model of a cave has been illuminated in the same way as many centuries ago. Ancient illumination produced by old materials (oil, candles) was simulated instead of using modern, i.e. electrical illumination facilities. Archeology can take advantage of such techniques to present atmosphere during ancient ceremonies and other events. Although results of this study are not available on-line, there are no technological obstacles to publish it on the web. A use of virtual reality for archeological purposes becomes popular. A list of ancient sites reconstructed and presented in 3D includes Pompeii in Greece, Sagalossos in Turkey (3D MURALE project), Turku in Finland, and many others.

Web-based presentation offers a very exciting possibility to museums and other cultural institutions. *Multi-user* virtual environment allows communication among users and experts. People can meet online in a virtual space, express their opinions, ask questions to real/virtual curators, and learn details on objects demonstrated by experts. This kind of communication is widely used in chat-based applications. It can be easily extended to 3D space [Zar02a]. The approach is directly applicable to many kinds of social interaction [Ada01].

3. Data Acquisition and 3D Reconstruction

The previous section demonstrated how useful role the 3D models/scenes visualization plays in a cultural heritage presentation. Before we start to make 3D models of real objects, we have to answer the following basic questions:

1. How to represent 3D models?
2. How to create/reconstruct 3D models?

The first question deals with data structures, file formats, media. The range of answers is unfortunately too wide. Each of the three main concepts (panoramic images, polygonal models, point-based representations) has pros and cons. File formats for each concept are diversified. A conversion between formats is not always simple and tends to loose precisions and application-related metadata.

In the following text we concentrate on boundary (polygonal) representations of 3D objects. A practical approach is to have a model in a flexible format like 3ds (by 3DStudio Max), obj (by Alias/Wavefront), or any other editable format. Then the data for the web presentation are exported and further optimized. The VRML is the most widely accepted as the final format in general.

The second question posed at the beginning of this section is probably the most important issue on the way from the real to a virtual world. A lot of approaches have been investigated and the research of automated reconstruction still continues. To get geometrical and image information about real 3D objects, various techniques and devices can be applied - laser range finders [Coo99], aerial (long-range) or ground (close-range) photographs [Col98], conventional or panoramic cameras, calibrated [Zac02] or uncalibrated cameras [Koc00], combination with GPS/GIS information [Kun03], etc.

A common problem of a 3D reconstruction is the big amount of resulting data (triangles, vertices, textures). The example in Fig. 6 shows a front face of reconstructed building. The mesh displayed as a wire frame on the right was generated from a set of calibrated images. Textured and rendered model is on the left.

Fully automated and general methods are still not available. Most techniques require limited user input in the initial reconstruction phase, but more interactive work for further conversion of large data into structures directly usable for rendering. A promising approach seems to be a knowledge-based architecture reconstruction, where typical elements like a window, a balcony, or an arc can be efficiently found and marked [Zla02].

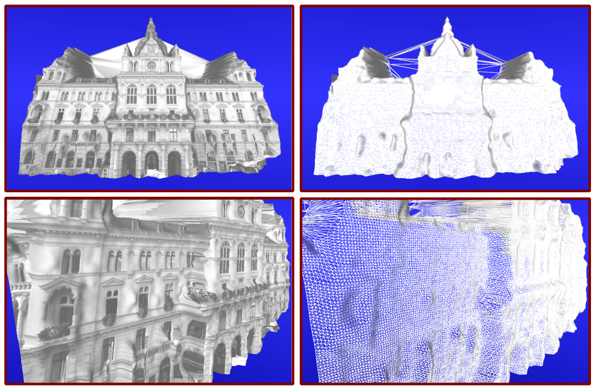

Figure 6. Image based reconstruction produces high density meshes. It is hard to classify construction elements (windows, doors) or even to join facades of the same house seamlessly. Example taken from the reconstruction of Graz City Hall, Austria. The model digitized by the VRVis research center consists of 56 thousands polygons.

Due to the lack of directly applicable reconstruction techniques, manual 3D modeling from scratch plays an important role. The most laborious work is to use a general modeling software like 3DStudio Max, where a photo is placed to a background and the corresponding (textured) model is created by a user from geometrical elements in foreground. In the case of architecture, a few special programs help to create a 3D model interactively using several photographs [Tay96][WWWpho].

4. Web-based Presentation Issues

Web presentations differ from standalone applications running locally on a computer in several features. First, data obtained from a server are delayed depending on Internet connection and *data sizes*. Second, web communication is stateless, i.e. server usually does not hold any state information about a client thus the user interaction has to be processed on a client side.

A limited size of data transferred from the server influences the visual quality of presented objects. Virtual scenes are always a simplification of the reality – this is especially true for web-based VR. A web presentation has to balance between a quality and a speed (both speed of rendering and speed of downloading data). The more efficient data representation and compression is used the better downloading speed is achieved together with better speed of rendering (number of frames per second).

As stated in previous section, 3D models are usually created in a modeling software and then transformed/simplified into a web-based format like VRML. This conversion is often not very well optimized, since people working with 3D modeling packages care about visual beauty and effects more than about efficient data storing. The following practice should be kept when the final model is targeted to the web:

- *Primitive objects* (cylinders, cones, etc.) described analytically, not by meshes.
- Repeatedly placed objects/details defined via *references*, not by copy-paste method. This applies to textures as well.
- All *textures downscaled* to resolution not bigger than 256 pixels in any direction (large textures consume too much memory in a graphics card when decompressed).
- Polygonal models exported with individual *normal vectors* in exceptional cases only. Default normal vectors should be used as much as possible.

One of the most efficient principles widely used in VR is known as *Level of detail* (LOD). A model is described by several representations, from the most detailed to extremely simple ones. A presentation system switches among these representations in correspondence with a distance between a user and the rendered object. Thanks to the LOD principle the overall scene complexity stays constant as well as rendering speed.

When preparing LOD representation(s), a nature of the model should be considered. Objects with curved shapes (like statues) are usually modeled using polygonal meshes. A number of mesh simplification algorithms exist. Many of them have been designed to transfer mesh data progressively [Hop96] [Gra03] thus allowing to display LOD smoothly starting from tens up to thousands of polygons.

When models are not described by meshes only, but of various geometrical objects and many textures, a higher-level approach is more suitable. A structure of LOD can be tuned to a specific kind of objects. One such approach designed for virtual buildings is introduced in [Zar02b]. Models of house facades are created using co called *Urban LOD* as seen in Fig. 7. This technique is based on the assumption that the most noticeable parts are windows, doors and/or particular decorations like paintings. Low-resolution images of these parts are transferred from a server earlier than detailed geometry of the rest of the house. As the façade consists of many windows with the same shape, their images are repeatedly mapped on a façade. It saves a time and a memory required for high quality image/texture of the whole façade that is downloaded later and displayed from a small distance.

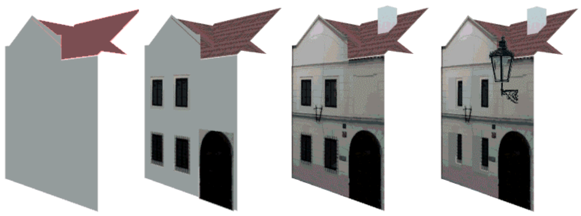

Figure 7. Urban LOD arranged into four discrete steps. The first three levels deal with a planar façade and several textures. The façade on the fourth image is three-dimensional.

Notice that not all presentation systems are able to display LODs progressively, but in discrete steps only (e.g. VRML).

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5. Navigation and User Interface

Navigation in a 3D virtual space is sometimes a nightmare for users accustomed to window based GUI where point-and-click is the major interaction technique. Moreover, web pages with hyperlinks are based on similar interaction techniques: click-and-go. To the contrary, virtual reality offers several navigation paradigms – walk, fly, examine. Each of them usually contains additional navigation elements like turn head, rotate object of interest, go ahead/back, pan, change camera optics, jump to another viewpoint, etc. A user interface for 3D is not yet standardized. Even VRML browsers complying ISO standard differ in a number of control elements and their arrangement on a screen. This fact increases skepticism of ordinary users.

To achieve platform independent behavior in VR applications, one has to create a user interface as an integral part of the virtual scene. One such interface is shown in Fig. 8. It has a function of so called *head-up display*, since it stays at the same position on a screen while user navigates through the virtual scene.

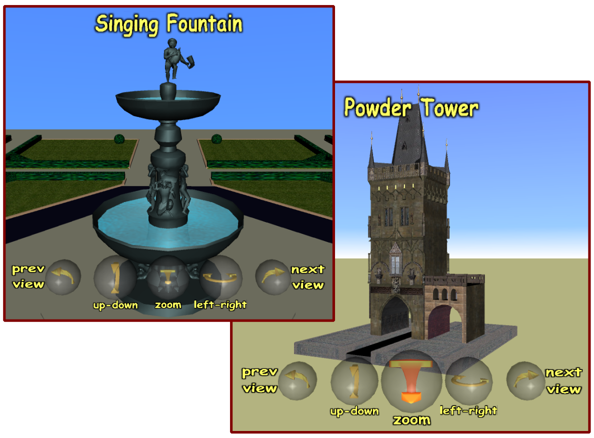

Figure 8. 3D control elements designed for navigation in a virtual space. The active button is scaled and highlighted. Examples from the Virtual Heart of Central Europe project – Singing Fountain and Powder Tower in Prague.

The user interface in the example consists of control buttons represented by semitransparent spheres with 3D icons and textual description. The outermost spheres allow choosing previous/next viewpoint. The other buttons manipulate with a 3D object of interest. This interface is suitable for exploration of one object rather than for a large virtual space, since it does not allow free walking/flying. An animated walk-through started by selecting a proper viewpoint is used instead.

Our experience is that such a simple GUI is acceptable for most users. Surprisingly we met curious situation when technically oriented students were not able to work with manipulation buttons in the middle, since they clicked on them instead of dragging.

Another strange point is a work with hyperlinks in VR. Users are not familiar with sensitive objects thus they do not click on 3D models even if objects have a shape of signposts. Additional highlighting is necessary in form of animated colors, bouncing arrows, or size changes of interactive objects.

Since users are familiar with 2D tourist map, they appreciate a presence of such a map even in a 3D environment (see small plan in a left bottom corner in Fig. 2 or the map in Fig. 5). Most maps show a current position of a user. Rarely, they serve as additional navigation element allowing immediate jump to any place displayed on the sensitive map.

To conclude this section, we should point out that large virtual space offers quite advanced possibilities like route planning. Instead of using predefined animated tours only, a presentation system can implement an algorithm that helps users to arrange/optimize a walk through a virtual city connecting selected places of interest. Subsequent navigation can be executed via animation of a specific viewpoint. Since this technique limits user's self-activity to simple watching a moving scene, another approach is to extend the scene by additional signs pointing to a proper direction or by a map with highlighted route. Users then freely walk through the space with an individual speed.

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6. Virtual Heart of Central Europe

The aim of the EU project Virtual Heart of Central Europe (VHCE) is to present historical architectural gems of four selected cities from different countries – Bratislava (SK), Graz (AT), Maribor (SI), and Prague (CZ). In particular, the project concentrates on vertical solitaires – Towers and Wells. The motivation is to digitally preserve more than twenty selected buildings, to reconstruct them virtually, to prepare appropriate digital storytelling, and to publish results on the web using rich hyper linked structures and multi-modal approach [Fer04].

The design and implementation of the project have brought several interesting problems to be solved. First, all reconstructions were performed by four independent groups in four European cities. Data are stored in national web servers while the main applications runs in another (common) server [WWWvhc]. This main server represents a portal to all objects and their presentations. A common presentation framework ensures a seamless integration of data coming from four distant sources. To achieve flexibility and a transparency of data management, all data components are described in XML notation. Possible new objects digitally reconstructed in a future can be added without a need to rebuild the whole presentation structure.

The second problem was the decision about technology to be used for presentation of spatial objects and scenes. We have decided not to limit users to a particular method but to offer them a variety of approaches. Thus every building is presented concurrently via hypertext, images, videos, panoramic images, and VRML scenes combined with sound effects and further information. To show these techniques to non-experienced users, several video sequences were prepared with the aim to remove users' mental barriers dealing with 3D space and navigation (see Fig. 9).

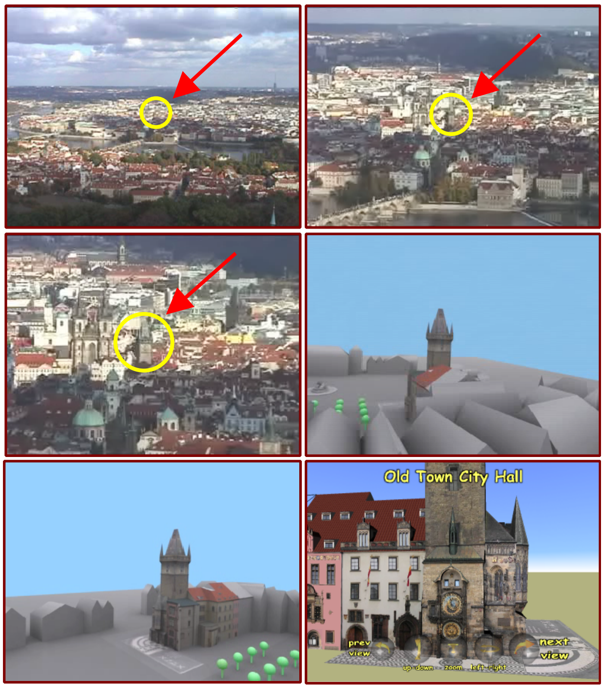

Figure 9. The VHCE project. Sequence of images from video mixed from recorded data and a synthetic scene rendering. A record of the Old Town City Hall in Prague is first zoomed, then blended with a 3D scene and finally presented as an interactive VRML model.

Since we consider the 3D virtual environment as the most impressive and informative for spatial data presentation, we have added many effects to standard geometrical and texture representation. The City Hall in Fig. 9 (right bottom image) allows starting animation of walking apostles on the tower together with a sound of clock. Top of the tower offers animated sightseeing over the neighboring area, etc. All those actions are performed inside a VRML browser window.

In specific historical areas, it was necessary to capture so called *genius loci*, i.e. to present object of interest together with its vicinity. We have incorporated panoramic image method into a pure 3D environment, as seen in Fig. 10. Although perspective distortions are still clearly visible, the overall feeling is better than in case of colored only background. Moreover, people, cars, and other object on photos increase the realism of the scene.

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Figure 10. The VHCE project: Plague Sign in Maribor. Virtual sculpture in the middle is surrounded by planar faces with background images mapped on. The scene was made by GeMMA Lab (http://rcum.uni-mb.si/~gemma), University of Maribor, Faculty of Electrical Engineering and Computer Science.

The project has been tuned to web environment, thus all media were carefully processed to achieve a small size of data transmitted to web clients (see Table 1). Most of 3D models (in compressed VRML format) are superior to movies in terms of size, image quality and other features like interactivity. On the other hand, VRML models tend to miss photo-realism and distant objects in background. Here panoramic images optimally complement pure 3D models. Size of movie is acceptable for high speed Internet connection only. Higher resolution movies will be of interest for off-line version of the project that is going to be published on DVD and/or CD.

Table 1. Typical data sizes for one virtual object in the VHCE project

Media type	Data size
Set of images (about 10 photos)	1 MB
Panoramic view	1-2 MB
Movie	5-10 MB
VRML model with textures	500 kB
Sound effects	400 kB

7. Conclusion

This paper presented an overview of techniques applicable for the preparation and presentation of cultural heritage objects and scenes on the web. It has been shown that the virtual reality principles can be directly utilized for this kind of visualization, especially when optimized in terms of data sizes. However the lack of automatic reconstruction methods followed by efficient post-processing slows down the progress in the area. Another yet not solved issue is a commonly accepted user interface for the navigation in a virtual space.

We conclude with a belief that the integration of the research in the area of computer vision, computer graphics, and human-computer interface will soon overcome existing imperfections and gaps. The web definitely has a potential to bring cultural heritage on the screen of any interested Internet users.

Acknowledgments

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[WWWinu] Inuit 3D Museum in Canadian Museum of Civilization Corporation.
http://www.civilization.ca/aborig/inuit3d/inuit3d.html

[WWWlou] Louvre Museum Official Website.
http://www.louvre.fr/

[WWWpho] PhotoModeler Photogrammetry Software.
http://www.photomodeler.com/

[WWWqui] QuickTime VR Authoring.
http://www.apple.com/quicktime/qtvr/

[WWWsca] ScanView: a system for remote visualization of scanned 3D models.
http://graphics.stanford.edu/software/scanview

[WWWvhc] Virtual Heart of Central Europe. Project home page.
http://www.sccg.sk/~projects/virtual-heart/

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http://www.viewpoint.com/

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