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Digital preservation of historical buildings using virtual reality technologies

Research Article

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Abstract: 3D model creation and visualization is often used in digital preservation of looks and structure of historical buildings. Virtual reality (VR) technologies facilitate this 3D model creation and visualization. 3D scanner can be used for acceleration of the data collection and model creation. 3D displays can be used to improve visual perception and 3D printing can be used for physical model creation. In this paper is presented the way for preservation of historical buildings using virtual reality technologies. Example of preservation procedure, which consists from 3D scanning, 3D model creation, optimization and visualization, is shown on the historical building of The State Theatre of Košice.

Keywords: virtual reality technologies • 3D scanning • 3D modeling • 3D visualization • preservation of historical buildings

1. Introduction

Preservation of looks of historical buildings is an important part of cultural heritage preservation. In the past, there were for historical building preservation blueprints, sketches or paintings used. Today, technologies allow us to create 3D models of historical buildings that can be used for preservation. Under the said phrase it is commonly understood that these are steps of various structural modifications, which then contribute to the preservation of the historical building.
Application of virtual reality technologies helps to the preservation of looks of the historical buildings. Preservation of design documentation of the building is not a suitable technology of preservation. However, for the most historic buildings it is considered important to preserve all the information on construction plans and process of construction of buildings in the past. Of course, this point of view implies the possibility to apply the technology of virtual reality as preservation of information about construction of buildings.

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The creation of a 3D model of a historical building needs a lot of effort. Everything begins with collecting of information and analysis (preparing phase). When the data are prepared, the 3D model creation begins (modeling phase). A check of model for errors follows after 3D digital model creation (verification phase). The visualization of the final model is the last step. This process is depicted in Fig. 1 [2, 3].

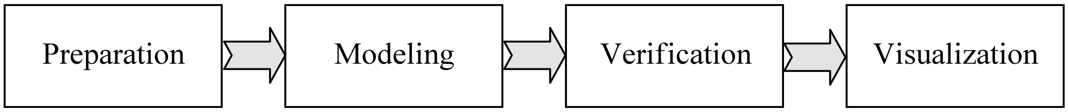

Figure 1. Modeling and visualization process.

Modeling and visualization phase can be improved by using virtual reality technologies. Modeling phase can be improved with 3D scanning and visualization phase with 3D displays and 3D printers.
In this paper the way for preservation of historical buildings using VR technologies is presented. Section 2 presents 3D scanning problem area. In section 3, the scanning process of The State Theatre of Košice is described. Section 4 shows verification procedures used during visualization preparation. Section 5 presents VR technologies that can be used for visualization. Section 6 summarizes information presented in the paper.

2. 3D model acquisition process

The 3D model acquisition process (Fig. 2) consists of two main stages which are [4, 5]:

- 3D scanning,
- data processing.

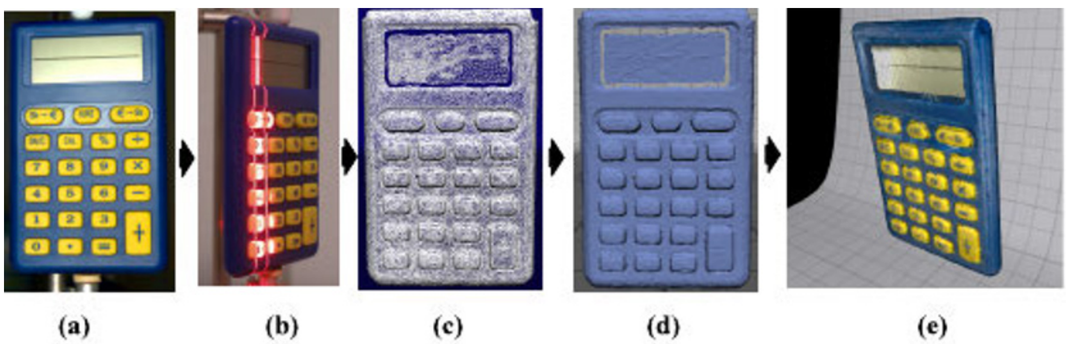

Figure 2. 3D model acquisition process: (a) original object, (b) scanning process, (c) scanned object (point cloud), (d) model without texture, (e) visualized final textured object.

2.1. 3D scanning

In general, the result of a 3D scan is a set of points in space with corresponding 3D coordinates called point cloud (Fig. 2-c). To capture the whole object, a series of scans from various angles has to be made. There are several types of 3D scanners, which differ in the technology used for obtaining a point cloud. They can be divided into two main categories:

Contact scanners. Contact scanners require a physical contact with the object being scanned. Although they are usually very precise, they are also much slower (order of 10^3 Hz) than non-contact scanners (order of 10^5 Hz). A typical example of a contact 3D scanner is a coordinate measuring machine (CMM).

Non-contact scanners. Non-contact scanners use radiation to acquire required information about objects. They are of two basic types: passive and active. The main advantage of passive scanners is that they are cheap as they do not require so specialized hardware to operate. To scan objects, they only use existing radiation in its surroundings (usually visible light). In contrast, active scanners are equipped with their own radiation emitter (usually emitting laser light). While the latter are considerably more expensive, they are also much more accurate and able to scan over much bigger distances (up to few km).

2.2. Data processing

Data processing consists of several parts. First, the point cloud has to be meshed, i.e. the points have to be connected into a collection of triangles (called faces). The next step is to align the scans from various angles to create the whole object surface. The aligned scans then have to be merged into one continuous mesh, so that no overlapping parts occur. The merging process also involves filling the eventual "holes" (unscanned parts) in the model. Aligning and mesh creation step can be switched if it is required for data processing. Additionally, there is an optional step to simplify the mesh, which consists of reducing the number of triangles in order to save memory needed to visualize the final 3D model.

Figure 3. Leica ScanStation 2.

2.3. Used scanner

For scanning, the Leica Scanstation 2 3D scanner (Fig. 3) from Leica Geosystems was used. More details about this 3D scanner (e.g. scanning range, scanning rate or scanning angles) at manufacturer's webpage [9].
There are different types of scanners. The one used in the experiments is of type *time-of-flight*. That means it is an active scanner that uses laser light to probe the subject. It uses a time-of-flight laser rangefinder. The laser rangefinder finds the distance of a surface by timing the round-trip time of a pulse of light. A laser is used to emit a pulse of light and the amount of time before the reflected light is seen by a detector is timed.
Since the speed of light is known (c), the round-trip time determines the travel distance of the light, which is twice the distance between the scanner and the surface [9]. Let t be the round-trip time, then distance d is given by the following equation:

$$d = \frac{c \cdot t}{2}. \tag{1}$$

3. The scanning process of The State Theatre of Košice

3.1. 3D scanning

For scanning of any object it is important to find the right scanning positions to acquire the best 3D scans with the minimum number of scans. Optimal number of scans for buildings that has rectangular ground-plan (like the State Theatre of Košice) is eight. Four scanning positions are perpendicular to the walls (Fig. 4, positions: 1, 3, 5, 7) and another four scanning positions lie approximately on the diagonals of the building (Fig. 4, positions: 2, 4, 6, 8). Schematic view of scanning positions for the State Theatre of Košice are shown on Fig. 4. Height of scanner for all eight scanning positions was 1.8 m and distance to theatre is shown in Table 1.

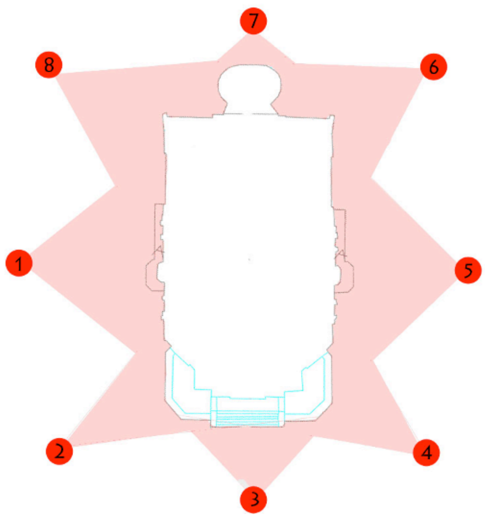

Figure 4. Schematic view of scanning positions.

The scanning process consisted of the following steps (each step except the first one was done in the Cyclone software):

- placing markers (Fig. 5) (these markers serve for scans aligning; to align two scans at least 3 markers are needed that are mutual for both scans),

Figure 5. Markers used for scans aligning.

- setting horizontal and vertical angle for scanning,
- creating a photography of scanned object (this photography serves as texture for scanned object),

- setting scanning resolution (for scanning the resolution 2 cm× 2 cm was used; this resolution was selected after resolution tests and offers good scan details with reasonable scanning time),
- 3D scanning,
- acquiring exact positions of markers.

Photography creation time, scanning angle and time of every scanning position are shown in the following table (Tab. 1). Textured point cloud scanned from position 5 is shown on Fig. 6.

Table 1. Scanning times and angles.

Scanning position	Distance [m]	Photo creation time	Horizontal angle	Vertical angle	Scanning time
1	17.0	2m 5s	100°	43°	9m 35s
2	23.5	2m 1s	62°	45°	5m 29s
3	25.1	1m 56s	78°	51°	8m 5s
4	24.5	1m 30s	50°	45°	4m 15s
5	17.5	2m 2s	105°	43°	10m 35s
6	15.0	1m 20s	42°	31°	3m 44s
7	26.4	1m 25s	68°	34°	5m 59s
8	30.0	1m 24s	35°	27°	4m 30s

Figure 6. Point cloud with texture (scanned from position 5).

3.2. Data processing

Data processing was divided into following parts:

- aligning point clouds and mesh creation,
- mesh simplifying.

3.2.1. Aligning point clouds and mesh creation

For point clouds aligning, Cyclone was used (Fig. 7 shows part of Cyclone that serves for aligning). Point clouds can be aligned manually or automatically. For manual aligning it is necessary to pick at least 3 points that are mutual for both aligned point clouds.

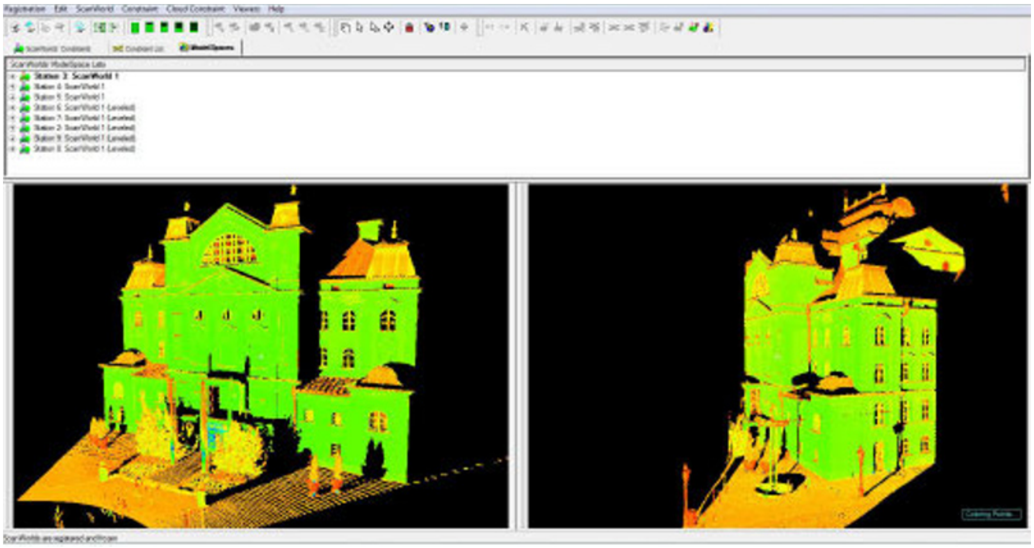

Figure 7. Aligning point clouds using Cyclone from positions 7 and 8.

Automatic aligning is similar to manual (also at least 3 point are necessary) but points are taken automatically from coordinates taken by scanning markers. For point clouds aligning of The State Theatre of Košice, the automatic aligning method was used.

Fig. 8 shows final point cloud created from all eight point clouds. Final step of this part was mesh creation from point clouds using Cyclone.

Figure 8. Final point cloud of The State Theatre of Košice after merging.

3.2.2. Mesh simplifying

For mesh simplifying, the 3D modeling application 3ds Max [7] was used. Simplifying consisted from two parts:

- deleting meshes that did not belong to theatre building (for example parts of surrounding buildings that were acquired together with the theatre building – Fig. 9),

Figure 9. Final point cloud of The State Theatre of Košice after merging.

- simplifying theatre mesh using 3ds Max *Optimize* function. For the *Optimize* function the default setting was used, only the parameter *Face thresh* was set to 6.0. This setting was selected after tests and offers good ratio between mesh details and vertices/faces number.

By deleting meshes that did not belong to the theatre and by using the *Optimize* function a reduction to 3 715 977 vertices (63.3%) and 5 814 551 faces (56.5%) was achieved. Table 2 shows vertices and faces count before and after simplifying.

The simplifying function deals with the problem of enormous huge number of vertices and faces. [1] defines it as the process of reducing the number of faces used in the surface while keeping the overall shape, volume and boundaries preserved as much as possible. It is the opposite of subdivision. The algorithm can simplify any oriented 2-manifold surface, with any number of connected components, using a method known as edge collapse. Roughly speaking, the method consists of iteratively replacing an edge with a single vertex, removing 2 triangles per collapse. Edges are collapsed according to a priority given by a user-supplied cost function, and the coordinates of the replacing vertex are determined by another user-supplied placement function. The algorithm terminates when a user-supplied stop predicate is met, such as reaching the desired number of edges. As it is given by the definition, there is a single algorithm reducing both the count of vertices and faces.

There are two basic types of methods of simplification[1]. Global error tracking methods produce highly accurate simplifications but take up a lot of additional space. Cost-driven methods, produce slightly less accurate simplifications but take up much less additional space, even none in some cases. The *Optimize* function tracks global error.

Table 2. Vertices and faces before/after simplifying.

Scanning position	Before simplifying		After simplifying	
	Vertices	Faces	Vertices	Faces
1	472 333	807 419	244 095	341 884
2	923 648	1 630 899	609 886	1 005 252
3	1 500 267	2 661 869	1 240 775	2 144 765
4	768 476	1 373 441	515 857	880 426
5	819 735	1 413 898	445 570	7664 532
6	270 690	460 492	128 263	179 461
7	429 621	730 319	204 790	271 490
8	680 920	1 208 556	326 741	326 741
Entire model	5 865 690	10 286 893	3 715 977	5 814 551

The selected method uses various parameters, but for the purpose of our simplification, only one of them was set to different value than the defaults given by the software (these default values are coming from the acceptance testing of the product).
The Face Thresh parameter [7] sets the threshold angle used to determine which faces are collapsed. Low values produce less optimization but better approximations of the original shape. Higher values improve optimization, but are more likely to result in faces that render poorly. Default value is 4.0, used value is 6.0.

4. Verification experiments for visualization preparation

The digital preservation procedure was prepared based on several experiments. These experiments consisted of almost the same steps as presented in this paper.
The aim of the experiments was to evaluate the scanning procedure and its planning phase, to collect suitable parameter values for data processing such mesh simplification and find limitations of the 3D visualization architectures that determine these processing parameters.
The scanning parameters were based on the scanner manual and empirically derived from the experience gained during the experiments, where the following objects were scanned:

- human faces (to check resolution and scanning time limits),
- the Institute of Computer Technology (ICT) building (a modern style building in the university campus),
- the classic style building at Park Komenského 3 (also in the campus),
- the St. Michael Chapel in Košice.

In the first iteration, all scanned data were processed using default values of the used data processing software. If the processing failed or lasted disproportionately long in comparison to the amount of data, the processing parameters were fine tuned. Failure in processing was evaluated as checking the alignment of the scans, completeness and continuity of the model. The initial level of detail was high, but this could change during later processing steps.
The created 3D models of the faces and later only buildings were used in visualization using the available technologies (these will be presented in the following section). The fidelity of the created virtual reality system was measured using subjective classification and objective values such as CPU load, memory and system swap usage, and processing speed based on frames-per-second property of visualization. If any of the available visualization systems was not capable to a speed of 24 frames-per-second, a new version of the original 3D model was created by entering a new iteration of scanned data processing.
These iterations could lead to two situations:

- the final 3D model remains unbroken after simplification meaning the level of detail is suitable for visualization, or

- the level of detail in the resulting 3D model is too low meaning the parameter fine tuning failed. In this case the model version was dropped and a new iteration was started with a different strategy of data processing parameter tuning.

The simplification procedures were used only for visualization preparation. The original 3D models that needed a simplification due to their very high level of detail were kept and preserved as originals.

5. Visualization using VR technologies

5.1. 3D displays

3D displays allow information presentation in three dimensions. There exist several technologies for 3D displaying and each technology has its advantages and disadvantages. There are several types of 3D displays that can be used for 3D visualization [6].
Our choise for the purpose of 3D visualization for this paper are a passive stereoscopic system and an autostereoscopic 3D display.

5.1.1. Passive stereoscopic system

This system uses passive stereoscopic technology based on INFITEC technology (more details about INFITEC technology at [8]). The parts of this system (Fig. 10) are as follow:

- pair of projectors with INFITEC filters and glasses,
- special projection screen,
- mouse or "space mouse" for navigation in 3D scene,
- rendering cluster consisting from three PCs with cluster version of visualization software called SuperEngine.

Rendering cluster currently supports scenes rendering up to 5 million polygons. Rendering performance of this cluster can be extended by adding other computers to the cluster.

Figure 10. Parts of stereoscopic system: screen, glasses and projectors.

5.1.2. Autostereoscopic 3D display

The selected autostereoscopic 3D display is Philips WOWvx (Fig. 11). 3D image is created using the 2D-plus-depth method. More details about this 3D display and 2D-plus-depth method at manufacturer's webpage [10]. Fig. 11 shows 3D visualization of The State Theatre of Košice using Philips WOWvx.

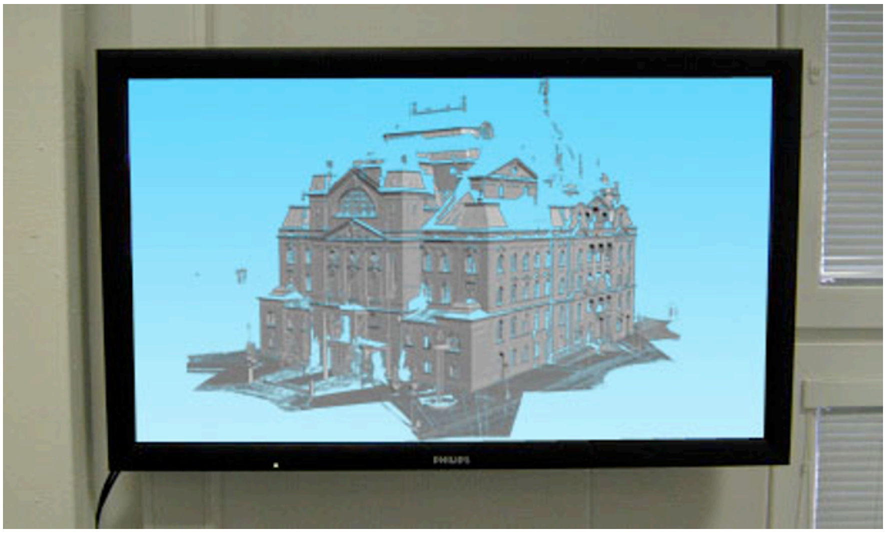

Figure 11. 3D visualization using Philips WOWvx.

5.2. 3D printers

3D printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material. 3D printers are generally faster, more affordable and easier to use than other manufacturing technologies. 3D printers offer developers the ability to print 3D models for visualization, testing or direct parts creation. The 3D printer used in this research is ZPrinter 450 (Fig. 12 left). More details about this 3D printer (e.g. maximum printing dimensions or printing resolution) at manufacturer's webpage [11]. Fig. 12 (right) shows 3D model of St. Michael Chapel which was printed with ZPrinter 450. Work on the printed model of The State Theatre of Košice is currently underway.

Figure 12. ZPrinter 450 (left) and printed model of St. Michael Chapel (right).

6. Conclusion

The aim of this paper was presentation of digital historical building modeling and visualization for cultural heritage preservation (i.e. digitization and presentation) using virtual reality technologies. Example of preservation procedure, which uses 3D scanning, 3D model creation, optimization and visualization, is explained on the historical building of

The State Theatre of Košice. For scanning the Leica ScanStation 2 3D scanner was used. Point clouds were aligned and meshed using Cyclone software. Final mesh (3D model) was simplified using 3ds Max. Final model consists of 3 715 977 vertices and 5 814 551 faces. For visualization purposes these VR technologies were presented:

- 3D displays - passive stereoscopic system with INFITEC technology and autostereoscopic 3D display Philips WOWvx,
- 3D printing - ZPrinter 450.

Presented information shows that VR technologies are very suitable for creation and visualization of 3D models used in preservation of historical buildings. Also VR technologies simplify 3D model creation and visualization process.
The simplification procedures were used only for visualization preparation. The original 3D models that needed a simplification due to their very high level of detail were kept and preserved as originals.
Future work will be focused on:

- implementation of other VR technologies into digital historical building preservation (e.g. augmented reality or head mounted displays),
- digital preservation of other historical buildings in Slovak Republic.

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