Interactive 3D Visualization of Natural and Cultural Assets

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ABSTRACT

The realistic visualization of 3D models from natural and cultural assets have become a fundamental aspect in digital preservation, as well as in the development of innovative scientific applications, creation of interactive virtual museums and others. Most of the projects related to cultural heritage focus on the digitalization process and techniques to generate 3D models for visualization. However, important issues regarding the remote visualization of these models through the Internet have not received such attention. In this work we discuss these issues and propose a novel interactive web-based tool for realistic visualization of 3D models. By including features for a high level of interactivity and usability the proposed tool is an effective multiplatform solution for 3D visualization to support educational and scientific activities as well as to make the remote access to natural and cultural assets collections more efficient and attractive.

Categories and Subject Descriptors

I.3.8 [**Computer Graphics**]: Applications; D.2.2 [**Software**]: Design Tools and Techniques; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism; J.5 [**Computer Applications**]: Arts and Humanities

General Terms

Design, Experimentation, Management

Keywords

Digital Preservation, Interactive Visualization, 3D Modeling

1. INTRODUCTION

Digital preservation allows future generations to understand and contextualize their history and culture [11]. The need to ensure that the cultural heritage of humanity be preserved digitally has motivated the development of new technologies, encouraged scientific projects and supported conservation and restoration activities, among others [12].

Systems for scanning and realistic visualization of three-dimensional (3D) models of cultural and natural assets have become an essential tool to support research activities, education, entertainment and culture. These systems enable assets to be accessed and exploited virtually in high level of detail, reducing the risk of irreversible damage caused by transportation or physical manipulation. Another advantage in using these systems is the possibility to investigate artifacts characteristics with enhanced security and reliability, e.g. detection of fragile areas, cracks, among others.

When digitally preserved, objects may be represented by 3D models which basically consist of a geometric surface covered by a texture map [6]. The geometric surface of objects may be obtained by different devices [2], from which 3D laser scanners are considered more accurate and appropriate. These scanners acquire range images from different views of the object which, once integrated, provide information about its geometry [15]. High resolution color cameras can complement the process of 3D modeling by generating realistic textures, preserving features such as color and reflectance of the object [1]. We should stress that recent projects related to digital preservation of artifacts [12, 7] have explored innovative techniques to create realistic 3D models. However, the visualization of 3D models has not yet received the attention it deserves.

In order to ensure a high degree of interactivity with the user, the visualization systems of 3D models need to provide fast and practical access, with usability features adequate to as many people as possible and, more importantly, effectively perform its functions. Accordingly, as a 3D model of an object is interactively viewed by the user and different views (i.e. images) are being shown successively in the system, it is essential for this system to provide a realistic interaction with the object.

The frames per second (fps) rate can be a measure to evaluate this efficiency because the higher the rate, the smoother and more natural is the feeling of moving the object during visualization and therefore more realistic is the user interaction with the object. In [3] tests were made with a 3D visualization application and the authors noted the need for at least 6 fps to enable the navigation in virtual worlds and 20 fps or more for appropriate interactivity. However, the ideal rate depends on each application. It is important though that there is a real-time response for each user action.

High response time for user actions, complex interfaces and difficulties to carry out operations on 3D models, e.g.

zoom in and zoom out, are the main limitations of some of the existing tools for 3D visualization. In order to minimize such limitations, this paper presents a tool for realistic visualization of 3D models that meets the desired requirements.

This paper is organized as follows. Section 2 discusses the main projects related to digital preservation of artifacts and their visualization systems, highlighting their main features. Section 3 presents the tool designed for visualization of 3D models, including comparative results with other approaches. Section 4 presents a web system for our 3D Virtual Museum that uses the developed 3D viewing tool, followed by final remarks in Section 5.

2. PROJECTS AND TECHNOLOGIES FOR 3D VISUALIZATION OF NATURAL AND CULTURAL ASSETS

In most digital preservation projects, each team develops their own system for visualization of 3D models [10, 8, 4]. Visualization systems can integrate different applications, servers, databases and other computational tools to allow 3D visualization. 3D visualization tools, also called 3D viewers, may allow visualization via web, but only a few have such feature. 3D viewers can be stand-alone or plugins for web browsers.

Stand-alone viewers are available as applications and must be downloaded and installed on the user computer, while viewers for web browsers generally require only the installation of plugins that can be done from the web browser. Most of the projects that allow visualization on web use plugins for web browsers. A challenge for these 3D viewers for web is to provide an intuitive interface, offering a high level of interactivity even when a large amount of data is shown.

The Virtual Reality Modeling Language (VRML) describes interactive 3D objects and 3D environments in a text format file. It is used by most web pages to describe 3D models [17]. A VRML viewer is required for a VRML 3D model to be viewed, usually a plugin for a web browser, e.g. Octaga Player (`www.octaga.com`), Cosmo Player (`ovrt.nist.gov/cosmo`) and Cortona3D (`www.cortona3d.com`).

Existing VRML viewers have several running inconsistencies and may be dependent of the web browser and operating system [14]. Choosing the appropriate VRML viewer for a particular application may be based on previous research, e.g. [18] presents a comparison regarding 3D content visual quality and the performance of different VRML viewers.

In some cases, a particular VRML viewer can be recommended, e.g. Cortona3D [4, 16], but the user is the one to decide which viewer to install. Moreover, the correct functioning of VRML plugins in web browsers depends on the configuration of each computer. Although VRML language is found to be efficient for the geometric modeling of 3D environments, not having a default viewer is a limitation. In the experiments performed in this paper, several problems with VRML viewers were found, including: different behaviors in the visualization of 3D models when computers with different hardware configuration or operating system were used; sudden inoperability of the system without error messages; intermittent delay in visualization, even with simple 3D models; high memory and processing consumption.

For several applications is important that the visualization be the most realistic possible, which requires 3D models with high resolution, resulting in more complex VRML files. VRML viewers lose performance when increasing the complexity of 3D models, negatively influencing the fps rate during their interactive visualization. Another VRML viewer drawback is that the user interface for 3D visualization has not yet been standardized. Even VRML viewers that meet the ISO standard differ both in the number of control options and the location of these options on the screen [17].

Although the interface is not standardized, VRML viewers always offer an interface to the user. This way, developers only need to be concerned with the 3D content to be displayed. For users, not having a standard interface results in difficulties in interacting with 3D models, since it is necessary to adapt to each VRML viewer interface (Figure 1).

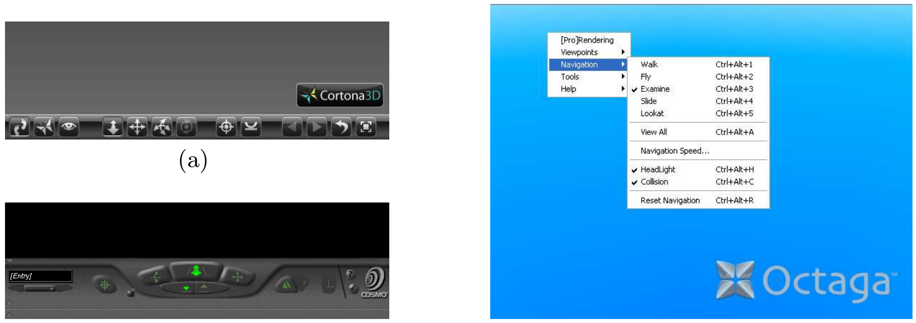
In "The Great Buddha Project" [7], a pioneering work of preservation and restoration of ancient assets of Japanese culture, several studies regarding digital preservation were performed, contributing to the development of this subject. This project created 3D models of Great Buddha statues, e.g. Asuka, Nara and Kamakura Buddha, and parts of the Bayon Temple in Cambodia. However, this work does not provide any means for visualization of the digitally preserved 3D models through the web, which would be interesting to promote educational activities and research.

Okamoto et al. [13] present a system for visualization of 3D models with large amounts of data. Users can perform real-time navigation and access 3D models information, as well as associate information to specific regions in the model by selecting its regions. This system was used to assist the restoration of the Bayon Temple, enabling researchers to store and manage information about the assets. It is important to say that the authors highlight that they intended to extend the developed system for use on the web (in its future work section), which meets the objectives mentioned earlier in this paper.

Sculptures made by Michelangelo were digitized in "The Digital Michelangelo Project" [12]. In this project the authors also discuss some problems which may occur in the digital availability of these works, e.g. unauthorized distribution of 3D models. Another difficulty is the physical reconstruction of objects, which can be made from the geometry and images of 3D models. In order to avoid these issues, security techniques are used in the visualization system proposed in the project, such as storing high poly 3D models on the server only.

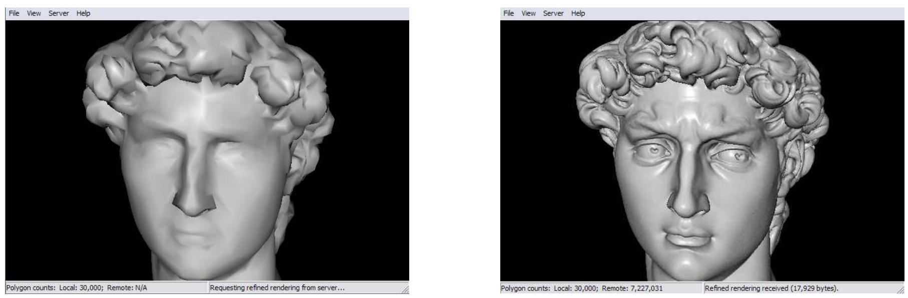
In addition, this project has developed a stand-alone 3D viewing tool [10] that allows users to interact with low poly 3D models. This viewing tool enables the user to view details of the assets through remote rendering by using a client-server architecture. In remote rendering, images are obtained from high poly 3D models rendered on a server, which are sent over the Internet to be viewed in the user's computer (client), as shown in Figure 2. However, there is no available version for the visualization in web browsers, which would make access more appropriate and practical for users.

In [8], examples of the Czech Republic cultural heritage are presented in a virtual environment. 3D models of buildings, monuments and other objects were created in order to preserve the culture of the age and provide information for those interested in history and related issues. In the virtual reconstruction process, VRML models are available for visualization on the web through VRML viewers. The authors point out the disadvantages of available virtual reality



(a) (b) (c)

Figure 1: Examples of VRML viewer interfaces: (a) Cortona3D, (b) Cosmo Player and (c) Octaga Player.



(a) (b)

Figure 2: Example of visualization using the system proposed in "The Digital Michelangelo Project": (a) low poly 3D model rendered locally on the client's computer and (b) image of the high poly 3D model rendered on the server and transmitted to the client through the Internet.

viewers, e.g. the need to install plugins and difficulties for beginner users in using these tools.

The Inuit 3D is a project of the Canadian Museum of Civilization [4] that allows the visualization of 3D models of artworks through 3D virtual scenarios composed by buildings representing a museum and its surroundings. The virtual museum of this project requires a VRML viewer to view 3D models in a web browser. The authors discuss the need to use other technologies for 3D visualization in order to avoid the need to install plugins and shorten transfer time of VRML files through the Internet.

In the Project "Augmented Representation of Cultural Objects (ARCO)" [16], the team developed a technology to create and manage virtual museum exhibitions for use on the web. Users can view and interact with 3D models of cultural objects that are displayed with VRML viewers, as well as use augmented reality. A study on the usability of the system [9] showed that some users had problems with system navigation and considered the interface to be very complex, requiring more detailed instructions for its use.

As described in this section, most digital preservation projects are geared towards the generation of 3D models and techniques to increase their realism. The 3D visualization task does not receive the attention it deserves, given the fact that projects tend to seek a quick solution, e.g. the use of VRML viewers. The realistic visualization is hence impaired due to the limitations of this technology. The following section presents an alternative to this problem: an effective tool for realistic 3D asset visualization which provides a high degree of interactivity and a simple and intuitive interface as one of its main features.

2.1 IMAGO Plugin

The IMAGO Plugin is a 3D viewing tool which was developed because existing technologies for visualization of realistic 3D models present usability and interactivity limitations. It enables realistic 3D models of objects to be viewed in a web browser efficiently, providing a high degree of interactivity.

The viewer interface allows interactivity with 3D models through simple and intuitive mouse or keyboard actions and can be customized depending on the audience. The rendering of 3D models, both low and high poly, is performed by maintaining a good rate of frames per second, providing a quick and realistic view.

The developed viewing tool enables museums to safely and easily present their artworks for 3D visualization in their websites as advertisement and even to make visits to museums more attractive. Artists can also submit their art in their personal websites by using the same tool, allowing the audience to interact with objects through the visualization of their 3D models. Moreover, researchers may use 3D visualization to enrich their studies and teachers may use it for educational activities.

The IMAGO Plugin is available in a website (`www.imago.ufpr.br/plugin/en_index.html`) and is compatible with the Firefox web browsers family, such as Mozilla Firefox, Iceweasel, and Netscape, among others, on Linux and Windows. Installation on both platforms may be done automatically

```
#Menus
View:Left,Right,Up,Down,Zoom In,Zoom Out,Reset Camera
Options:Wireframe,Texture,Specular Light,Reset Options
#Events
Left:left_event:mouse_device,keyboard_device
Right:right_event:mouse_device,keyboard_device
Up:up_event:mouse_device,keyboard_device
Down:down_event:mouse_device,keyboard_device
Reset Camera:resetcamera_event:mouse_device,keyboard_device
Zoom In:zoomin_event:mouse_device,keyboard_device
Zoom Out:zoomout_event:mouse_device,keyboard_device
Wireframe:wireframe_event:mouse_device,keyboard_device
Texture:texture_event:mouse_device,keyboard_device
Specular Light:specular_event:mouse_device,keyboard_device
Reset Options:resetoptions_event:mouse_device,keyboard_device
#Model
model=1
```

Figure 3: Example of the configuration file.

with installation programs. As in all 3D graphics applications, the IMAGO Plugin requires a 3D accelerated graphics card.

2.2 3D Viewing Tool Architecture

The IMAGO Plugin accepts a zip file as input, which is a compression format widely disseminated in the web. The zip file should contain a configuration file and can contain a 3D model file and a texture file. This zip file must be specified in the plugin call of the HTML file and must be located in a web server application. The plugin call uses the EMBED tag and uses some parameters such as the name of the 3D model, location of the zip file into web server, width and height of the plugin interface, among others.

The 3D model file is represented in text format and specifies the information about the object: the 3D coordinates (X, Y, Z) of each vertex of the model, the normal vectors of each vertex, the group of faces, represented by 3 vertices each, color information for each vertex or uv coordinates for 3D models with texture, and the color properties of the scanned object. It may be attached in the zip file entry, along with the texture image file with an extension of texture ".tga" (i.e. TARGA File Format).

The configuration file enables 3D model information, display interface and events related to the interface and the 3D model itself to be simply specified. As shown in Figure 3, it has three mandatory sections: Menus, Events and Model.

Menus are set in the interface configuration, which can contain text with any western character, allowing its use by different groups of users. However, the menu is just one option of the system, but it is rarely used in practical terms. Menus are defined in the configuration file after the tag "# Menu" and each line below it contains the label of the main menu followed by the labels of the options.

In the events configuration, the labels of the options described above are associated with pre-defined events available in the plugin (all pre-defined events are shown in Figure 3). The events can be triggered by the mouse, keyboard or other compatible input devices, for example, a virtual reality glove. The choice of devices and independence of language in written texts of the menus provide more flexibility to the interface and are adjustable to the needs of the application.

The events are set after the tag "# Events" and each line contains a label of an option set in the menus, followed by a pre-defined event and their corresponding devices. For example, the option labeled as "Wireframe" can be associated

```
#Model
model=2
ip=200.1.1.1
port=9000
```

Figure 4: Example of the Model section in the configuration file that indicates that the 3D model will be obtained by a server in the specified IP address and port.

with the event pre-defined as "wireframe_event", enabling or disabling the display of the triangles mesh of the 3D model.

The plugin can receive the 3D model through the input zip file or obtain it through a server of 3D models over the web. In order for the model to be obtained through the zip file, the line "model = 1" is included after the tag "#Model". To get the 3D model through a server, an example of a server is available in the IMAGO Plugin website, containing the necessary commands to perform communication with the viewer. Therefore programmers can create their own 3D models server using other languages and other resources. The configuration that indicates that the 3D models are obtained by the server (Figure 4) includes, after the tag "#Model", the line "model = 2" and adds the IP address of the web server and port number to be used for communication with the client application.

2.2.1 Running the 3D Viewing Tool

The plugin checks if the input has the required and necessary files according to the configuration chosen. The configuration file is mandatory and if the model is obtained through the zip file, the 3D model file should be included in the zip file. If the 3D model uses texture, regardless of how it is obtained, the texture should be included in the zip file. According to the chosen configuration, the menus are set to be displayed on the screen and the events are associated with the defined menu options and devices. The configuration allows you to choose:

- menus, mouse events to use menus and move the 3D model, and use of keyboard shortcut keys;
- menus and mouse events only to use menus and move the 3D model;
- no menus, mouse events to move the 3D model, and use of keyboard shortcut keys;
- no menus and mouse events just to move the 3D model.

The plugin uses the OpenGL graphics library for rendering 3D models and menus, and the Windows version uses an API of the operating system itself to render the menus, keeping the same visual standard in Linux and Windows versions. We used Vertex Buffer Array (VBO) of OpenGL to optimize the rendering of 3D models. If the computer not have support, the Triangle Strips technique [5] is used.

2.2.2 3D Viewing Tool Interface

The intuitive and simple interface of the IMAGO Plugin makes viewing more enjoyable for users, as it does not require effort to interact with the 3D models, making it attractive for educational activities. Basic operations such as rotating, moving, zooming in and zooming out the 3D model

Table 1: Comparison of the IMAGO Plugin with VRML viewers

3D model	Number of faces	IMAGO Plugin (VBO)	IMAGO Plugin (T. Strips)	Octaga Player 2.3.0.7	Cosmo Player 2.1.1
Alamito	342.520	75.0 fps	43.0 fps	12.06 fps	16.0 fps
Carybé	714.696	51.0 fps	22.6 fps	5.97 fps	9.0 fps
Owl	593.584	60.0 fps	26.0 fps	7.31 fps	10.7 fps
Prophet	1.409.939	28.5 fps	11.8 fps	3.12 fps	4.6 fps
Protocyon	873.746	43.0 fps	18.7 fps	5.0 fps	7.4 fps
Stenzel	666.900	54.0 fps	25.0 fps	6.49 fps	9.6 fps
Vase	792.809	47.0 fps	20.3 fps	5.48 fps	8.1 fps
Vitor	1.210.630	32.5 fps	13.7 fps	3.66 fps	5.3 fps

Table 2: Example of 3D models rendering with different levels of detail

Saint Francis	File size	Number of faces	fps
High quality	13.113 Kb	306.716	86.0
Medium quality	3.102 Kb	75.540	175.0
Low quality	830 Kb	21.336	220.0

are made in a practical way, using the mouse and/or using the menu and keyboard. Other important operations such as showing the 3D model in wireframe format, with or without texture, increasing or decreasing the specular lighting effect on the 3D model and moving the origin of the light source (Figure 5) are also available in this viewer and can be used through the menus or shortcut keys.

2.2.3 *Performance*

3D model files are very highly compressed in the zip formats, thus considerably reducing the file size and consequently reducing transmission time to user's computer. In order to perform the experiments in this section, we used a computer with the following specifications: Windows XP Service Pack 2 operating system, Intel Core 2 Duo processor 6300 1.86Ghz, 1 GB RAM and NVIDIA GeForce 7300SE graphics card.

Table 1 shows the comparison between the rendering performed by the IMAGO Plugin using VBO and Triangle Strips with two widely used VRML viewers: Octaga Player and Cosmo Player. The results show that even high poly 3D models (e.g. Prophet) are rendered with good fps. Moreover, it is clear that the fps rate is still acceptable with the variation in the 3D models poly resolution. Low poly 3D models have high fps rate as 3D models of high poly have a rate sufficient to provide good interactivity. Table 2 shows the comparisons between the 3D models.

2.2.4 *Remote Rendering*

Using the remote rendering technique is an alternative to improving the realistic visualization of cultural and natural assets, as it allows for the observation of more details of the objects. This technique also ensures the safety of 3D models because the high poly 3D models can be preserved on a server while only low poly 3D models are available to users.

As in [10], the user receives a low poly 3D model for manipulation when choosing a particular 3D model for visualization. When an angle of the 3D model is chosen for the visualization of a given detail, a high poly 3D model image of it is sent to the user and overlapped on the 3D model. This technique is currently being integrated into the IMAGO Plugin and will allow users of limited hardware computers to view 3D models with a high degree of interactivity.

3. 3D VIRTUAL MUSEUM

In order to validate and disseminate the results obtained in this work, the group developed a 3D Virtual Museum (`www.imago.ufpr.br/Museu/en_index.html`). It has a 3D model visualization system that can be accessed from a web browser using the IMAGO Plugin. The objects displayed in the 3D Virtual Museum were obtained with a 3D laser scanner (Minolta Vivid 910) and its 3D reconstruction was performed using the pipeline we developed for digital preservation of natural and cultural heritage [15]. To increase the realism in the visualization of 3D models, we used the method to generate high quality textures [1] acquired with the Canon EOS 5D digital camera.

In order for the 3D Virtual Museum collections to be made available on the web and the 3D models geometry and their copyrights to be preserved, the system access is recorded and restricted according to the user access level. Common users have limited access and may view low poly 3D models. Researchers may request less restricted access in order to view the 3D models in higher resolution and thus observe the object in more detail.

The system uses a client-server architecture, where the client is the plugin viewer and the server contains high poly and low poly 3D models stored in a database. The client requests the server the 3D model chosen by the user in the 3D Virtual Museum website, which sends the 3D model for viewing if the user authentication on the server is confirmed. The system provides support for remote rendering, which is being aggregated to the IMAGO Plugin.

4. CONCLUSION

The creation of an innovative tool for visualization of realistic 3D models of natural and cultural assets, such as the IMAGO Plugin, contributes significantly to digital preservation activities. The tool allows for the modernization and expansion of applications in the areas of education, entertainment and culture, as well as it assists research activities by remotely accessing digitized collections.

The visual quality of 3D models, as well as the easiness to use and the high degree of interactivity offered by the developed tool, are crucial for the success of applications. Thus, projects involving digital preservation activities, virtual museums, among others, can use this tool as an appropriate, reliable and safe solution to make their studies.

For developers who use a 3D viewer, choosing the interface, storage and handling operations options of 3D models allows their application to be configured according to their goals. For example, in applications that require the security of the 3D models, there is the option of using a 3D models server which can control the accesses and can easily upgrade the database without making changes in the application.

As future work, we intend to develop a plugin version in Java using OpenGL in order to make the 3D viewing tool portable to any operating system and any web browser that supports Java. Furthermore, integration with a remote rendering system will provide greater accessibility to the system. Finally, the menu should be replaced by icons, as a way to reduce its limitation to a particular set of characters. The authors would like to thank CAPES and CNPq for funding.

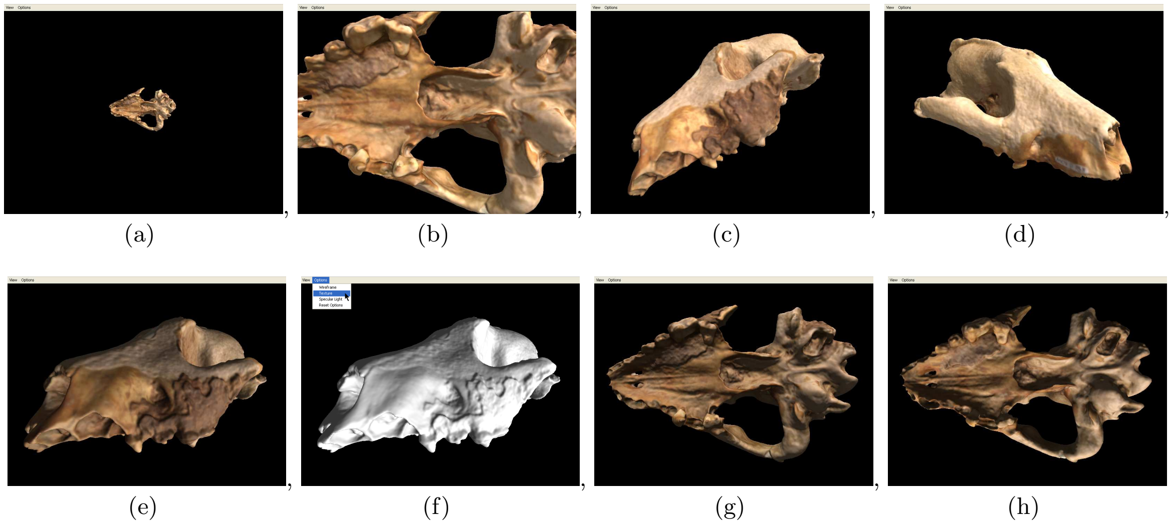


Figure 5: Examples of 3D model visualization of a Protocyon fossil. The Protocyon is an animal that inhabited caves during the Pleistocene (period between 1.816.000 and 11.500 years ago). Fossil belongs to the UFPR Museum of Natural Sciences. Actions: (a) zoom out, (b) zoom in, (c) and (d) move the 3D model, (e) 3D model with texture, (f) 3D model without texture, (g) and (h) move the light on 3D model.

5. REFERENCES

[1] B. T. Andrade, O. R. P. Bellon, L. Silva, and A. Vrubel. Enhancing color texture quality of 3D models for digital preservation of indigenous ceramic artworks. *Proc. IEEE Int'l Conf. Computer Vision, Workshop on eHeritage and Digital Art Preservation*, 2009.

[2] P. J. Besl. Active, optical range imaging sensors. *Machine Vision and Applications*, 1(2):127–152, 1988.

[3] G. C. Burdea and P. Coiffet. *Virtual Reality Technology*. Wiley-IEEE, 2003.

[4] F. Corcoran, J. Demaine, L.-G. Dicaire, M. Picard, and J. Taylor. Inuit 3D: An interactive virtual 3D web exhibition. In *Proc. Museums and the Web*, pages 163–169, 2002.

[5] F. Evans, S. Skiena, and A. Varshney. Optimizing triangle strips for fast rendering. In *Proc. IEEE Conf. on Visualization*, pages 319–326, 1996.

[6] T. Hawkins, J. Cohen, and P. Debevec. A photometric approach to digitizing cultural artifacts. In *Proc. Conf. Virtual Reality, Archeology, and Cultural Heritage*, pages 333–342, 2001.

[7] K. Ikeuchi, T. Oishi, J. Takamatsu, R. Sagawa, A. Nakazawa, R. Kurazume, K. Nishino, M. Kamakura, and Y. Okamoto. The great buddha project: Digitally archiving, restoring, and analyzing cultural heritage objects. *Int'l Journal of Computer Vision*, 75(1):189–208, 2007.

[8] Z. Jiri and S. Pavel. Cultural heritage presentation in virtual environment: Czech experience. In *Proc. 14th Int'l Workshop on Database and Expert Systems Applications*, pages 92–96, 2003.

[9] A. Karoulis, S. Sylaiou, and M. White. Combinatory usability evaluation of an educational virtual museum interface. In *Proc. 6th IEEE Int'l Conf. Advanced Learning Technologies*, pages 352–354, 2006.

[10] D. Koller, M. Turitzin, M. Levoy, M. Tarini, G. Croccia, P. Cignoni, and R. Scopigno. Protected interactive 3D graphics via remote rendering. *ACM Trans. Graph.*, 23(3):695–703, 2004.

[11] K.-H. Lee, O. Slattery, R. Lu, X. Tang, and V. Mccrary. The state of the art and practice in digital preservation. *Journal of Research of the National Institute of Standards and Technology*, 107(1):93–106, 2002.

[12] M. Levoy, K. Pulli, B. Curless, S. Rusinkiewicz, D. Koller, L. Pereira, M. Ginzton, S. Anderson, J. Davis, J. Ginsberg, J. Shade, and D. Fulk. The Digital Michelangelo Project: 3D Scanning of Large Statues. In *Proc. ACM SIGGRAPH*, pages 131–144, 2000.

[13] Y. Okamoto, T. Oishi, and K. Ikeuchi. *Digitally Archiving Cultural Objects*, chapter Editing, Retrieval, and Display System of Archeological Information on Large 3D Geometric Models, pages 441–455. Springer, 2008.

[14] R. M. Rohrer and E. Swing. Web-based information visualization. *IEEE Computer Graphics and Applications*, 17(4):52–59, 1997.

[15] A. Vrubel, O. R. Bellon, and L. Silva. A 3D reconstruction pipeline for digital preservation. *Computer Vision and Pattern Recognition, IEEE Computer Society Conference on*, 0:2687–2694, 2009.

[16] R. Wojciechowski, K. Walczak, M. White, and W. Cellary. Building virtual and augmented reality museum exhibitions. In *Proc. 9th Int'l Conf. 3D Web Technology*, pages 135–144, 2004.

[17] J. Zara. Virtual reality and cultural heritage on the web. In *Proc. 7th Int'l Conf. Computer Graphics and Artificial Intelligence*, pages 101–112, 2004.

[18] J. Zara and J. Krivanek. Graphics performance benchmarking based on VRML browsers. In *Proc. Virtual Reality Int'l Conf.*, pages 111–120, 2001.