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On the Digital Reconstruction and Interactive Presentation of Heritage Sites through Time

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Abstract

Virtual time travel from existing remains of a heritage site to its previous states and original condition is an educational and interesting experience and can provide better understanding of history. However, digitally reconstructing non-existing objects is a challenge. The interaction and navigation within virtual 4D worlds (adding time to 3D worlds) is also problematical due to the time dimension. In this paper we developed an approach to modelling of heritage sites that has undergone changes over the years. The method creates independent models from different types of data, such as frescos and paintings, drawings, old photos, historic descriptions, and digitization of remains, then assembles and integrates these models for an interactive presentation. Several research issues had to be addressed: (1) Modelling from frescos and drawings with incorrect perspective, (2) modelling from paintings and old photos including fine geometric details from shading (3) colouring models from old photos and drawings to match the colours of existing elements, (4) the seamless and accurate integration of models created independently from different sets of data, and (5) the creation of intuitive interactive presentation that combines all the models and other useful information. We provide contributions to these issues, including our own advanced model viewer, and apply them to modelling of: destroyed Haida house of Chief Weah (Masset, Canada), the demolished and partially relocated Rideau Chapel (Ottawa, Canada), and the Stenico castle (Trentino, Italy) which undergone many changes over several centuries. Each of these diverse examples illustrates different approach for reconstructing heritage sites that changed through time.

1. Introduction

Reconstructing a historical site as it once was or as it evolved over time is one of the most important goals of virtual heritage. The remains of the site, or the site in its present state, either at its original location or where it is currently residing, can be digitized in 3D using digital cameras or laser scanners. Non-existing parts or changed elements have to be reconstructed from any available records such as paintings, old photos, sketches/drawings, written accounts, expert information, and data from similar more complete remains of objects from the same time period. One can anticipate two scenarios:

1- The site/object has changed, damaged, or destroyed.
2- Parts or the entire site have been removed and scattered at various locations such as museums.

Both have modelling and visualisation challenges and require novel presentation to create a virtual site as it has originally been or during other time periods and as it is now, considering that both experts and non-experts are to use the system. The interactivity with models of sites that changed over time adheres to no standard approach and remains a difficult task since there is no simple way to interact with the time dimension [SR02]. Many attempts have been made, however the outcome is usually only a pre-rendered movie, which bypasses the interactivity problems. We address some of the presentation issues, along with the reconstruction of destroyed parts from various records. Specifically, the objectives of this paper are:

1- Modelling of remaining parts and objects at their current location using imaging and laser scanning.
2- Modelling of destroyed parts from any available sources such as old photos, paintings, sketches, plans, and descriptions in historical documents.
3- Assembling and integrating the models to create the site as it originally was and at different periods in its history. Different hypotheses may also be given if there is uncertainty.

4- Designing and implementing interactive presentation with space-time interface to navigate through these models and link with other multimedia components and information related to the history of the site.

Visualising the effect of natural lighting at different day/night time and seasons, and artificial lighting such as candles, is also desirable. The time dimension may not follow a logical linear rule since it is usually compressed and will undoubtedly have missing periods. The remainder of the paper is organised as follows. The next section discusses relevant previous work in modelling and visualising historic sites at various eras, and then elements of our approach are detailed in the third section. Three vastly-different case studies are presented in section 4 followed by concluding remarks.

2. Previous Work

There is a large body of work in each of the issues we focus on. An exhaustive review is beyond the scope of this paper, thus only representative work is given to illustrate the different concepts. We divide the review into projects and modelling and presentation techniques.

2.1. Example of projects

The exhibition Virtual Time Travel in Istanbul [FPM02] comprises the virtual reconstruction of the Hagia Sophia, currently used as a museum. It has been a church and a mosque during different periods in history. This work shows the progression and changes to the architectural and decoration during those periods. The Deep Map system [MZ00] generates personal guided walks for tourists through a city. It takes into account personal interests of the tourist when generating the tour. A 3D reconstruction of the Heidelberg city is part of Deep Map, where destroyed parts can be interactively re-built by the user using a collection of architectural elements (windows, roofs, etc.) that have been used in past centuries. Into the Breath of Sorabol [PKK03] is a virtual event that transformed Kyongju City in Korea into the ancient Silla Kingdom of 1,300 years ago. Interactivity and high-resolution immersive imagery offered seven experiences to the theatre's audiences, including a visit to the Royal Yellow Dragon Temple, 553 AD, and its nine-story wooden pagoda which was destroyed by Genghis Khan and currently only the foundation stones remain. [STY*03] modelled the Parthenon with its carved decorations, most of which are currently in museums, to create a complete virtual reconstruction of the structure in its original and present state. Arrigo VII mausoleum and the partially damaged cathedral in Pisa were reconstructed by scanning the remaining and dispersed pieces [BBC*04]. Lost parts were completed by CAD tools. [SCM04] recreated the now-relocated Kalabasha temple in Egypt, placed it back in its original location and orientation, and illuminated it as it may have appeared some 2000 years ago.

2.2. Modelling techniques from various records

[CRZ00 & ElH01] developed 3D modelling techniques from single images such as old photos and paintings. [SC03] used antique maps to create 3D model and visualise the historical town Kawagoe, Japan. [TYK*04] also used old maps to reconstruct the city of Kyoto over various time periods. [RKN01] used old drawing and experts' accounts to model the historical building Huys Hengelo, Netherlands, which has been demolished and a factory was built on its foundation. [SG00] relied on various descriptions in historical records to reconstruct the Hawara Labyrinth, Egypt, and give the user different possible alternatives of what it may have looked like at 1800 BC. The city of Bologna, Italy, has also been modelled as of today and as it was through different historical periods [Boc04]. Modelling of non-existent buildings was based on historical archives, and archaeological excavations. [BP01] reconstructed da Vinci's ideal city from his sketches and physical models of his machines located at the National Science Museum in Milan. [GRZ04] reconstructed the now destroyed Bamiyan Buddha, Afghanistan, with Photogrammetry using available photos including old high quality ones and tourist photos from the Internet.

2.3. Presentation / rendering techniques

Many of the results of modelling sites at different times are shown in movies where interaction is not possible. Here we focus on approaches that allow user interactivity. There is no standard approach to interact with 4D models, but there are several alternatives that have been proposed, including:

- QuickTime VR object movie [VPW*04]: interactive access to 2D images by rotating the object with horizontal cursor movement and evolving the object through time with vertical cursor movement.
- XML/X3D [HFP06, MGSI01, and Gra02].
- VRML and Java/JavaScript implementation of dynamic virtual environments, particularly with VRML *TimeSensor* node [KHDZ05].
- Combination of techniques such as XML, Java, and panoramas –QTVR [PDH*04].

Approaches to create virtual museums have been summarized by [Bar00 & SLS*05]. They range from Web sites and CD-ROMS to extension of the physical museum with augmented reality or immersive VR. Visualising various types of information attached to the 3D model including uncertainties of the construction hypothesis was studied by [DB03]. Including non-photo realistic or artistic rendering in parts of the presentation to enhance the experience has been advocated [RD03]. 3D game technology has also been suggested [Cha03& LV04]. A VR presentation at the archaeological site of Ename, Belgium [PCKS00] included a 3D model of a destroyed abbey superimposed over a real-time video of the remaining foundation. An accompanying multimedia presentation offered additional information about the site and its past inhabitants. [RKN01] constructed destroyed historical buildings and handled missing parts with conflicting descriptions by giving the user different alternatives using Java and VRML interface that allows switching some parts on and off. [SFR01] developed a set of tools and techniques for visualising and interacting with historical data such as a time lens for viewing arbitrary event times and a time-space exploration tool for simultaneous viewing more than one event time and location of interest. [LS03] used augmented reality technology to overlay real models with 3D virtual models and multimedia contents inside a showcase at a museum. The visitor can interact with the exhibit and see the object throughout its history. [ZCG05] created an interactive graphical user interface with a time slider, along with a time window controlling the start and end of the period, to allow the user to visualise how the site appeared during that period. Through transparency and animation the uncertainty of the construction is integrated in the visualisation. Our approach, presented in 3.3, uses the same idea but adds several other options.

3. Modelling and rendering procedure

The steps we apply for modelling and visualisation of a heritage site through time are as follows (figure 1):

- Collecting material and documents from different time periods and investigating the validity of each (is it a true representation or an artist's conception?)
- Creating 3D models from the documents using modelling from painting and old photos and CAD modelling from drawings and other information.
- Creating 3D models of existing parts with imaging and laser scanning techniques.
- Assembling all 3D models and other data; linking components to each other, correcting scale, filling gaps, and creating smooth transitions.
- Creating an interactive presentation and high quality pre-rendered animations with all models and data.
- Light modelling with different light types at various daytimes and seasons.

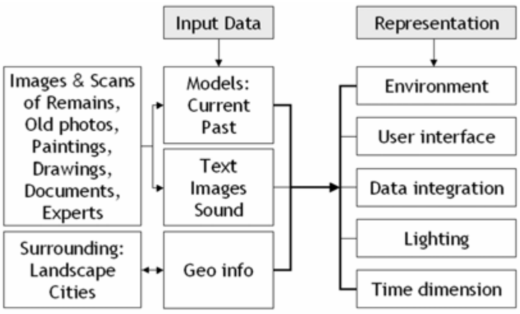

Figure 1: *Data input and representation.*

In the first step, the types of record available vary with each historical period. As far back as medieval time (1200's) one may find surveyors record such as control or markers and their measured locations. In Italy for example those records are called "Libri terminorum". Historic maps are also available for some cities. Pre-Renaissance paintings had incorrect perspective, which means they cannot be directly used for reconstruction. Beginning with the Renaissance, frescos, paintings, and other drawings with correct perspectives were becoming available in addition to accurate line and pictorial maps. In the mid 1800's grey-scale photographs were available and less than a century later colour photographs appeared. Since old visual records cover only portions of the scene, we need to complete the model based on available text descriptions and expert advice and hypothesis using CAD tools. Digital imaging and laser scanning have been widely used, by late the twentieth century, to model existing parts. Details of our approach for 3D modelling are given in [EBP*04]. We will describe some of the procedures next.

3.1. Modelling from medieval frescos/paintings

This procedure is summarised in figure 2.

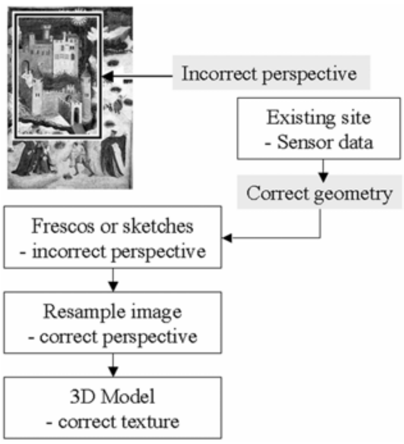

Figure 2: *Modelling from old frescos.*

The method requires that part of the object or site still exists, for example its foundation or archaeological remains. We use measurements from those remains to resample the painting or fresco to create an image with correct perspective and use this to reconstruct the site. If the site has completely disappeared, then there is no reliable procedure and we have to rely on CAD tools to create the model using the fresco mainly as a guide.

3.2. Renaissance paintings and old photos

We use a flexible approach for 3D construction from single images [ElH01]. The approach applies several constraints: coordinate constraints, surface constraints, and topological constraints in two steps: a calibration step and a reconstruction step. The solution is based on the Photogrammetric collinearity equations. Each point p extracted from an image i has two image coordinates, x_p and y_p and contributes two equations:

$$x_p = F_x(f_o, x_o, y_o, X_p, Y_p, Z_p, X_i, Y_i, Z_i, pitch_i, yaw_i, roll_i);$$
$$y_p = F_y(f_o, x_o, y_o, X_p, Y_p, Z_p, X_i, Y_i, Z_i, pitch_i, yaw_i, roll_i) \quad (1)$$

The parameters are three internal camera parameters (focal length fo, and principal point x_o, y_o), six external camera parameters (X_i, Y_i, Z_i, $pitch_i$, yaw_i, $roll_i$), and 3D object coordinates of point p (X_p, Y_p, Z_p). The camera parameters are the same for all points measured in the same image but each point adds three unknown XYZ coordinates. The image coordinates x_p, y_p may also include lens distortion parameters. We solve first for all camera parameters using the constraints: points with same X coordinate, Y coordinate, or Z coordinate, one point with zero coordinates to define the origin of the object coordinate system, and one point with a zero Y and Z to define the orientation. A distance is assigned between two points to define the scale. When sufficient constraint equations are formed together with equations (1), solution of all camera parameters is possible. In the reconstruction step, more constraints are added: shapes such as planes, cylinders, and quadrics, and topological relationships like symmetry and surfaces being parallel or perpendicular. This results in a basic model. A differential shape from shading approach is then used to add fine details to this model. Details of our approach can be found in [ElH06] and it is only summarised her. The process is applied to a work image: a version of the original with some pre-processing such as noise removal filtering and editing of unwanted shades and elements. We first create and triangulate a dense grid of points on the surface of the basic model, then modify the coordinates of these points based on their shading. The amount of modification is obtained from a curve describing the relationship between the grey-levels and the depth difference from the basic model. The curve intersects the grey-level axis at the average intensity value of the points actually falling on the basic model. By adjusting this curve the results can be instantly evaluated and readjusted if necessary. We now have a triangulated grid of points whose coordinates are altered from the initial basic model to account for fine details.

When several images of the same object or site exist, we developed a procedure to create a single consistent model from the images (figure 3). We start with the best image available and create a model as described above. From the resulting model, we now have the geometry that can be passed on to the other images. The model can then be completed from those images in a straight forward manner since all the 3D information has the same scale and coordinate system.

Since old photos are in greyscale, we need to colour them to match the colour of remaining elements. Some techniques are available to transfer the entire colour from a source to the target image by matching luminance and texture information between the images [WAM04]. We adapted a colour-matching tool that matches interactively selected adjacent textures from different images [EGP*03].

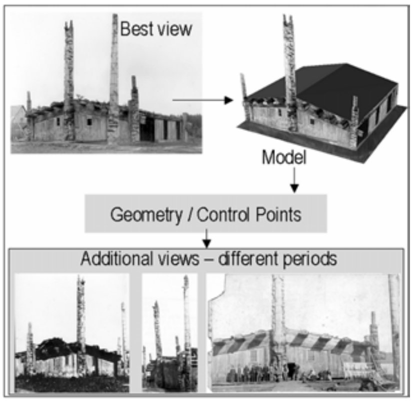

Figure 3: *Consistent modelling from many old photos.*

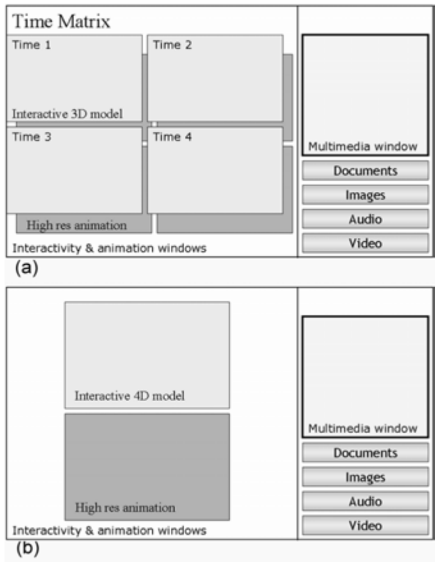

Figure 4: *Two presentation alternatives*

3.3. Presentation / rendering

After consulting our project partners, we opted for two desktop presentation paradigms (figure 4) that are configured according to the project requirements:

- Time Matrix (figure 4a): a different model for each time period that lets the user make the selection from a matrix of displayed windows, or
- A single X3D file that contains all the models from the different times (figure 4b). The manipulation or interaction will be applied to all the models so going from one model to another will be smooth. A time slider is used to select a period in history, and then

opacity or transparency is assigned to model parts based on what should be visible for this time period.

Other information is shown in a separate window and is linked to the model parts in the interactive window where clicking on an object and the desired button invokes the corresponding information. The presentation is prepared in XML with embedded multi-media (video, audio, images, and text). There are two model forms (figure 5): (1) pre-rendered animation with maximum resolution and realistic illumination; and (2) interactive model with resolution to allow real-time interaction. For a large site with more than one building or room, we use a map or floor plan for navigation.

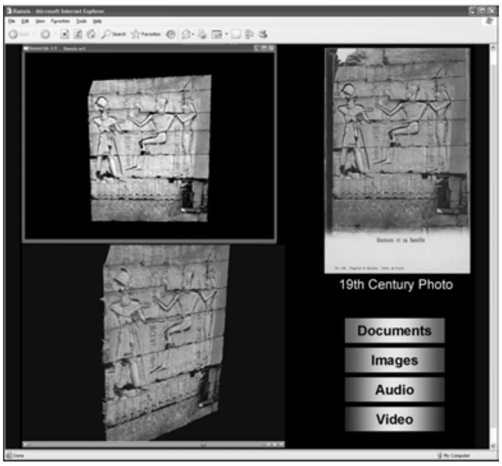

Figure 5: *Screenshot of a presentation.*

3.4. The "Demotride" viewer

To improve user interaction (navigation and object manipulation) with the models, we developed the Demotride viewer [D06], which works with content files based on the VRML and X3D international standards. More specifically, Demotride's support of time sensors allows animation of time and interaction with the 4D models. One feature that distinguishes Demotride from the other viewers is its ability to provide what we call controlled interaction, where the user is bound to respect the visualisation and interaction parameters specified by the content developer. For example, Demotride supports a unique feature that permits specifying the rotational speed of the viewpoint when navigating in the virtual scene. Another interesting feature of Demotride is the support of advanced travel techniques that allow, for example, direct looking at any specific point in the scene located around the user's current viewpoint. These travel techniques developed for virtual walkthrough go well beyond the standard techniques (e.g. rotate, walk, and fly) normally found in other viewers. Other features include support for sound and text and programmable keyboard interaction.

4. Representative Examples

In each of the flowing examples we will indicate the current status of the site, short history, and the available data and records that we made use of to reconstruct it. Modelling of existing parts is detailed in [EBP*04].

4.1. Chief Weah House

The house of Northern-Haida Chief Weah was located in Masset, BC, Canada (figure 6). The structure with its nine skilfully carved totem poles is historically significant and represents a way of life that no longer exists. Known as the "monster" house for its large size, it was built in 1810s and demolished, along with other Haida houses, in the 1880s. A modern house was then built on its foundation. Fortunately part of the foundation still remained in the 1970s under the existing house and some measurements were done then. Also there are written accounts from the 1880's, including some approximate measurements. Many photographs of the house interior and exterior are at the archives of several museums. One of the house totem poles was taken to the Museum of Civilization in Ottawa (figure 7c) where it is now on display. Some articles from inside the house, or similar houses, also survive in museums.

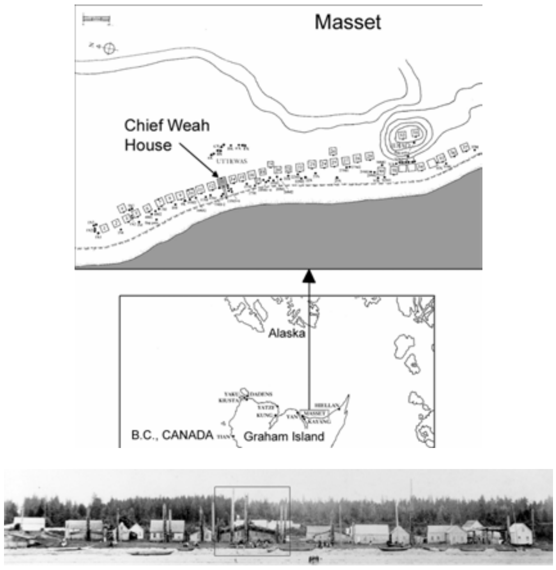

Figure 6: *Masset map and Chief Weah house location (also part of the presentation) and a 1880s photo.*

Totem poles should ideally be scanned to capture all their details. However, due to their size (from 5 to over 10 meters high) and shape, this would be an expensive time consuming exercise for this project. Thus, an image-based method had to be developed [ElH06]. In the first stage of this multi-stage approach, basic shapes are determined with an interactive approach while in the subsequent stages fine details are added automatically by dense stereo matching and shape from shading. The technique also takes advantage of the way totem poles are made: being symmetric and have a flat back. Data from various sources were compiled and used to provide constrains to calibrate the old photos and create the models with the technique described in section 3.2.

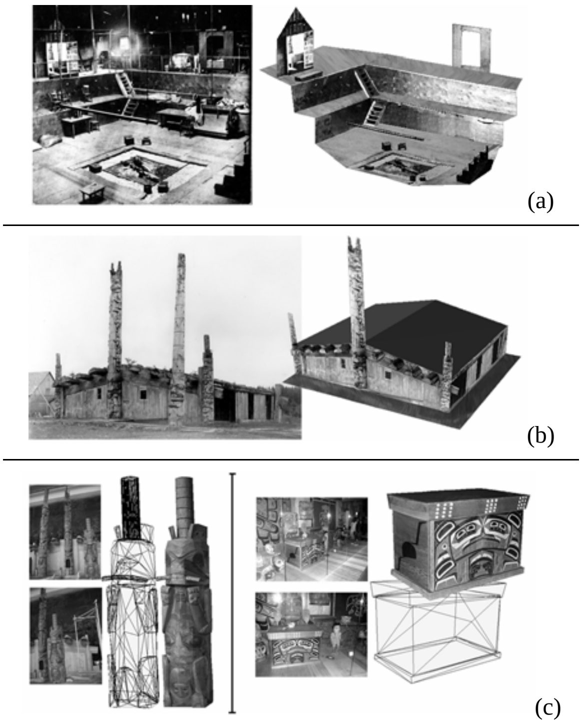

Figure 7: *Haida house models: (a) the inside from old photos, (b) outside, (c) existing totem pole and objects.*

4.2. The Rideau Street Chapel

The chapel of the Convent of Our Lady of the Sacred Heart in Ottawa, better known as Rideau Street Chapel, was demolished by a developer in 1972. Luckily, its architecturally unique interior was dismantled and later reassembled inside the National Gallery of Canada where it is currently preserved (figure 8a). The chapel measured 32 m x 14.5 m x 8.5 m (H). This project objective is to digitise and model the existing interior and reconstruct the destroyed exterior from old images and drawings to create a complete virtual reconstruction of the chapel as it once was. We used: CAD modelling from existing engineering drawings, laser scanning with two different scanners, Photogrammetry, and modelling from old photos. The existing engineering drawings, which were based on surveying and Photogrammetry, created the overall model of the interior of the chapel (figure 8b). More details on the walls and ceiling were obtained by a time-of-flight scanner with 5 mm resolution (figure 8c), and finer details on sculpted surfaces were obtained by a close-range triangulation-based scanner with 0.5 mm resolution. The outside of the chapel was modelled from photographs taken before 1972 (figure 9). All models were integrated together and presented with the tools described in section 3.

Figure 8: *Current chapel interior: (a) overall view, (b) part of wire-frame model, (c) scanned data.*

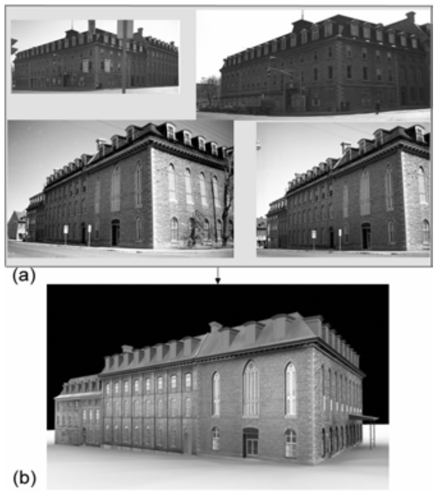

Figure 9: *Rideau Chapel: (a) old images, (b) the model.*

4.3. The Stenico Castle

The Stenico castle is one of the oldest and most important medieval castles in Northern Italy, and is an interesting mixture of styles of buildings added over several centuries. A view of the castle is depicted in the January panel of the "cycle of months" frescoes (figure 10a) in Aquila Tower at Buonconsiglio castle in Trento. The view shows a remarkable difference between the shape of the castle entrance in the 1350s and now. Outer walls and towers have been shortened or removed. We fully modelled the castle as it stands today from aerial and ground images and available floor plans. Using the model of the remains of the altered parts, we reconstructed them as they were from the 1350 fresco using the method outlined in figure 2. The buildings in the current model have also been constructed at different dates, thus the presentation uses transparency on such buildings depending on the time period being observed.

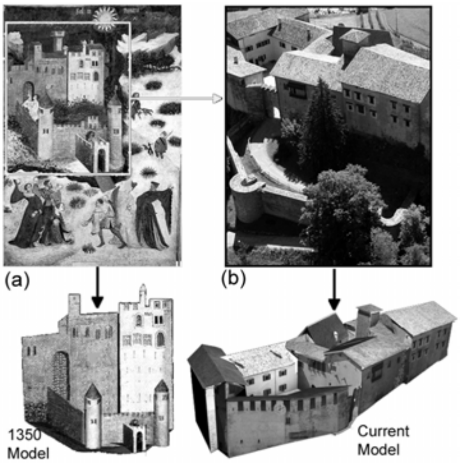

Figure 10: *Stenico Castle models: (a) from fresco, circa 1350, (b) currently from aerial and ground photos.*

5. Conclusions and future work

We have addressed several critical issues in the virtual reconstruction and interactive visualisation of heritage sites that have undergone changes over time or no longer or partially exist. Techniques to create models from frescos, paintings, and old photos were developed and applied to several different projects. Interactive presentation tools to handle 4D models in space and time and other information have been produced. Since we are still refining the procedure, future work includes comprehensive evaluation of the interactive presentation alternatives, at various configurations, by several groups of users. Both experienced and non-experienced users will be drawn upon. Further work involves designing and implementing an immersive system and comparing it to this desktop-based system.

6. Acknowledgements

Charles Hill, art curator of the National Gallery of Canada provided us with unlimited access to the Rideau chapel set up at the gallery. The Stenico castle modelling is funded by the "Provinicia Autonoma di Trento".

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