Simultaneous implementation of heterogeneous data for 3-D reconstitution of the UNESCO world heritage in danger: Arg-e-Bam

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This paper describes an implementation of diverse data resources in a three-dimensional CG reconstruction of damaged buildings of the Citadel of Bam, a UESCO world-heritage in-danger site. Because of the destruction of buildings in the 2003 earthquake, the necessity of modeling from interior and exterior spaces, and the unreliability of 2-D maps, the key process was simultaneous usage of heterogeneous data such as 2-D maps, photos, movies, text, drawings, etc., for systematic and semantic 3-D modeling. As the first achievement the paper concludes by the 3D reconstruction of buildings along the two main axes of the citadel.

1. Introduction

The Citadel of Bam (Arg-e-Bam), a UNESCO world heritage in danger[1], is an earthen architectural site that was demolished during an earthquake in 2003. This ancient and huge mud brick citadel once flourished through the production and trade of valuable cotton and silk cloth (its products could be found for centuries all along the Silk Road [1, 2]). Most of the buildings dating from 200 B.C. to 1900 A.D. were damaged in the earthquake (Figs. 1 and 2). As part of the digital archive of the heritage along the Silk Road (the Digital Silk Road project), we started a three-dimensional reconstitution of the Citadel of Bam and its buildings after this disaster.

Fig 1, 2: Citadel of Bam before and after the quake of 2003

We began the process of reconstitution by developing 3-D models of case studies at the site. We used state-of-the art tools to create 3-D CG models from 2-D maps showing interiors and exteriors of the buildings. Due to lack of precise 2-D maps, the 3-D models were developed through simultaneous usage of heterogeneous data including 2-D maps, photos, movies, and 3-D cartography maps. This paper discusses these heterogeneous data resources and the techniques which were implemented to provide a precise and systematic 3-D simulation of the original buildings. Section 2 and 3 introduce the first phase and initial input data, section 4 discusses the intermediate process of simultaneous implementation of heterogeneous data for 3-D modeling, and section 5 presents the final 3-D models of the first phase..

2. The first phase of 3D modeling

The Citadel of Bam covers approximately 200000 m^2. It is surrounded by a defensive wall and consists of six residential districts, around 20 public buildings a separate governor's district, and defensive facilities. In order to start 3-D modeling, we specified two major north-south and east-west axes inside the citadel. The north-south axis starts from the main gate and continues through a linear bazaar to the second gate. It ascends the hill to the upper-most building of the citadel. The major public buildings are situated along this axis. The east-west axis starts from the public square of the citadel (the square served a religious function) and passes through residential districts and houses of nobles. The major religious buildings are situated along this path. We selected ten buildings along these two axes for the first modeling phase because they represented the major types within the city (Fig. 3).

There are three stages to building a 3-D model of a building: modeling, viewing, and rendering. Modeling is the major job, and it entails making the 3-D geometry of the building components in a way that accurately represents the form of the real object; a 3-D modeling software environment such as AutoCAD®[2] and 3D studio MAX®[1] is used to create

[1] Bam and its Cultural Landscape
http://whc.unesco.org/en/list/1208

[2] AutoCAD is a suite of Computer Aided Design (CAD) software products for 2- and 3-D design and drafting, developed and sold by Autodesk, Inc. (from

the model from basic two-dimensional data on the buildings [3, 4]. The 3-D modeling starts by acquiring the preliminary 2-D maps from building surveys that include plans, sections, facades, details, etc.

Other methods of 3-D modeling include 3-D laser scanning[2] of the target building or modeling from photogrammetry data [5, 6].

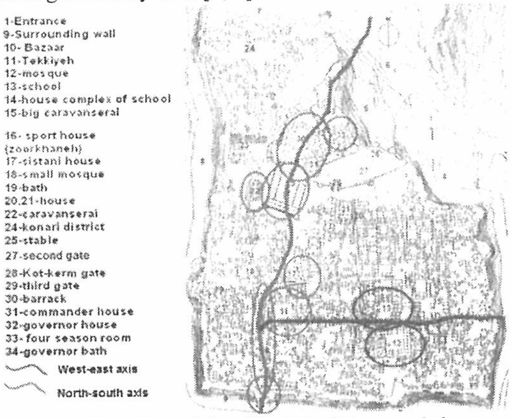

Fig. 3: Site plan of the Citadel of Bam and the ten 1st phase case studies that lie along north-south and west-east main axes

As our target site is huge and its buildings are mostly destroyed, we could not use laser scanning or photogrammetry for 3-D modeling. Moreover, our goal was to create a precise 3-D model of the interiors and exteriors of the buildings. Therefore, we chose manual modeling from 2-D maps by using state-of-the-art tools like Max®.

3. Initial step: modeling from 2-D maps

Maps or 2-D drawings of the buildings in horizontal (plan) and vertical (facade, sections) plan were made before the earthquake. These were provided by ICHTO,[3] and they included ground floor plans, ground floor plans, first floor plans, a site plan, facades, sections, and perspectives.

Normally to make a complete survey of a building, one needs complete maps of the building levels (from underground to the roof), complete sections, the outside and inside elevations (the elevations of each space, each room, etc.) and all dimensions and heights on scales from 1:100 to 1:1 [7]. Unfortunately, due to very limited resources for such a map survey and due to the complexity and huge scale of the site, we had to deal with several shortcomings of these maps:

The dimensions of the plans of different levels were incompatible (as shown in Fig. 4 for the entrance).

There were errors in superimposing the plan or the facades or sections.

The details of the facades were not precise, especially the form of the arches.

The elevation and sections of all the facades of the buildings were missing.

There were few facades or sections of interior spaces.

The unreliability of the maps led us to investigate heterogeneous data sources that could be helpful in making 3-D models of the selected cases. These data were used to overcome the problems of the 2-D maps.

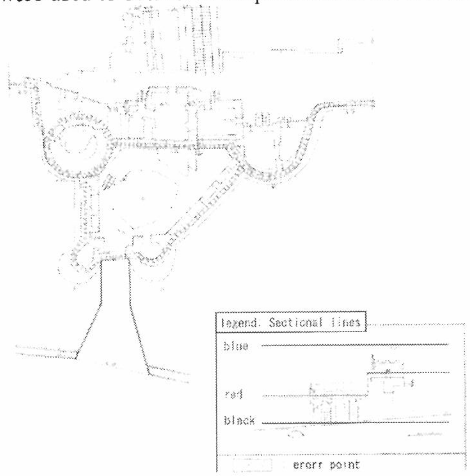

Fig 4: Analysis of map of the main entrance and errors in the coincidence of the plans of different levels

4. Intermediate process

Modification with 3-D cartography map

Cartography is defined as the study and making of maps from spatial information[4]. The 3-D cartography map used as a reference for our research was

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http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=2704278 [1November2007]

[1] 3D Studio Max (sometimes called 3ds Max or just MAX) is a 3-Dimensional vector graphics and animation program, written by Autodesk Media & Entertainment (from http://usa.autodesk.com/adsk/servlet/index?id=5659302&siteID=123112 [1November2007])

[2] Laser Scanning is the process of shining a structured laser line over the surface of an object captured by a CCD camera sensor to record accurate dense 3D points in space. (from http://www.dirdim.com/serv_laserscanning.htm [1November2007])

[3] Iranian Cultural Heritage and Tourism Organization

[4] http://www.gtasa.asn.au/glossary/gloss_c.htm [1November2007]

reconstituted from an aerial photo of the Citadel of Bam taken in 1994. This photogrammetric material was provided under the Irano-French 3-D Cartographic Agreement [1] on Bam (IFCA) and Iranian National Cartographic Centre (NCC). The 3-D cartography map provides a wire-frame 3-D model of the whole citadel as an AutoCAD® file. Its major information includes the plan and the heights and shapes of the vaults and domes of the roofs. We superimposed the 2-D map on the 3-D cartography to find the errors in the dimensions. The plan was then modified as presented in Fig. 5, which shows a model of the caravanserai (The model and figure was provided by F. Chopin from EVCAU[2]).

The roof surfaces were modeled according to 3-D cartography map. Most of the original roof surfaces had vaulted shapes and curved forms made from mud brick and covered by coatings of mud and straw. To model this special kind of roof realistically, the wire-frame lines of the cartography map had to be modified; the surface was created by using the 'ploy editing modifier'. This is a common function of the tool for modeling curved surfaces like the skins or bodies of virtual characters in 3-D animations. As the surfaces of roofs in the Citadel of Bam had organic non-geometric shapes with soft edges, this technique is suited for recreating them as shown in model of Sistani house in Fig 6. (The model and figure was provided by Prof. A. Einifar of the University of Tehran).

The walls were modeled from the corrected 2-D plan by the 'Loft Modifier' function. The heights were extracted from the elevation and cartography map. Lack of information about the facades in these resources forced us to investigate another resource, i.e., photos.

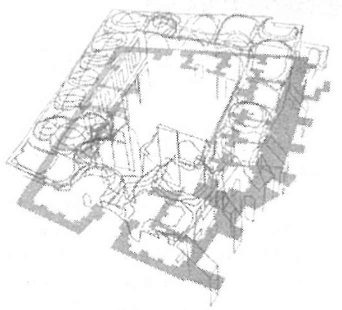


Fig. 5: Superimposition of 3-D cartography (green and red lines) and the plan (gray part)

[1] Pr. Chahriar Adle's project

[2] Espace Virtuel de Conception Architecturale et Urbaine (EVCAU), a laboratory of Ecole Nationale Supérieure d'Architecture de Paris-Val de Seine (ENSA PVS)

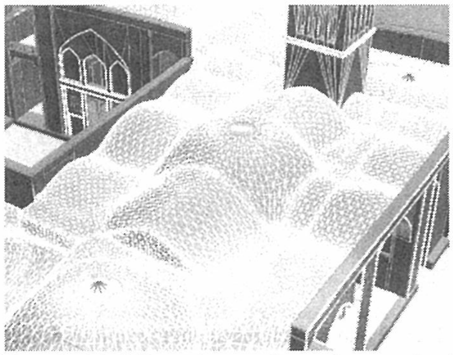


Fig. 6: Modeling the surface of a roof with polygons

Exploiting photos of facades and interior spaces

Photos taken of the Citadel of Bam were the major complementary resource for our 3-D modeling. The photo databases used in our research include photos taken by individuals, photos taken by ICHTO during the restoration process, and photos taken during special events and ceremonies.

Around 37 spots around the citadel were photographed before the earthquake. We were faced with several problems as follows:

The low resolution of some photos,

Too many photos from popular views (such as the one shown in Fig. 2) and very few images of private buildings or residential districts,

Lack of images of interior spaces, and

No data related to parameters of the cameras or no photos from calibrated cameras.

The demolished state of the buildings made the photo archiving process more complicated. We investigated different references to gather photos of citadel before the earthquake. Moreover, we still have a call open over the Internet for people or groups to help us by making their photo collections of Bam available for 3-D modeling[3].

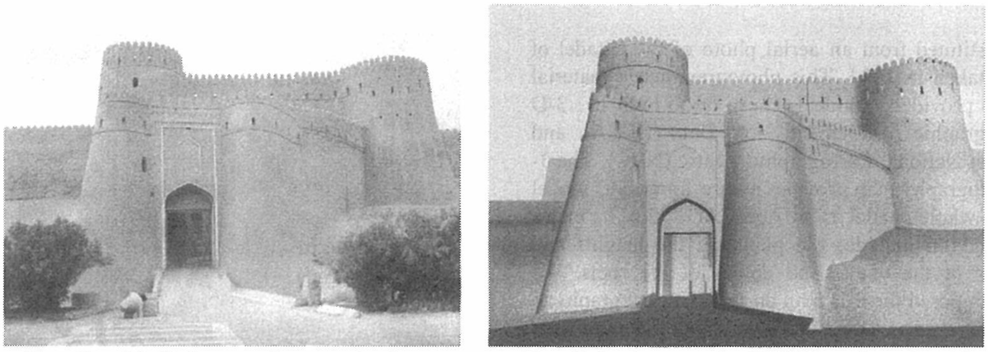
Some parts of the buildings still exist or could be photographed once debris was removed. We surveyed the main axes in the site to provide more image data.

Photos were used to complete the frontage of the interior or exterior spaces of the 3-D model. For this, we used the 'Camera Matching technique' of the tool to extract information about the dimensions from available photos as precisely as possible.

Camera matching technique

Photographs before the earthquake played an important role for modeling the elevations of the buildings.

[3] http://dsr.nii.ac.jp/bam/index.html.ja [1November2007]



Figs. 7 and 8: Reference photograph of camera matching (left, photo credit: ICHTO) and rendered image of the model from the same aspect as the reference photograph (right)

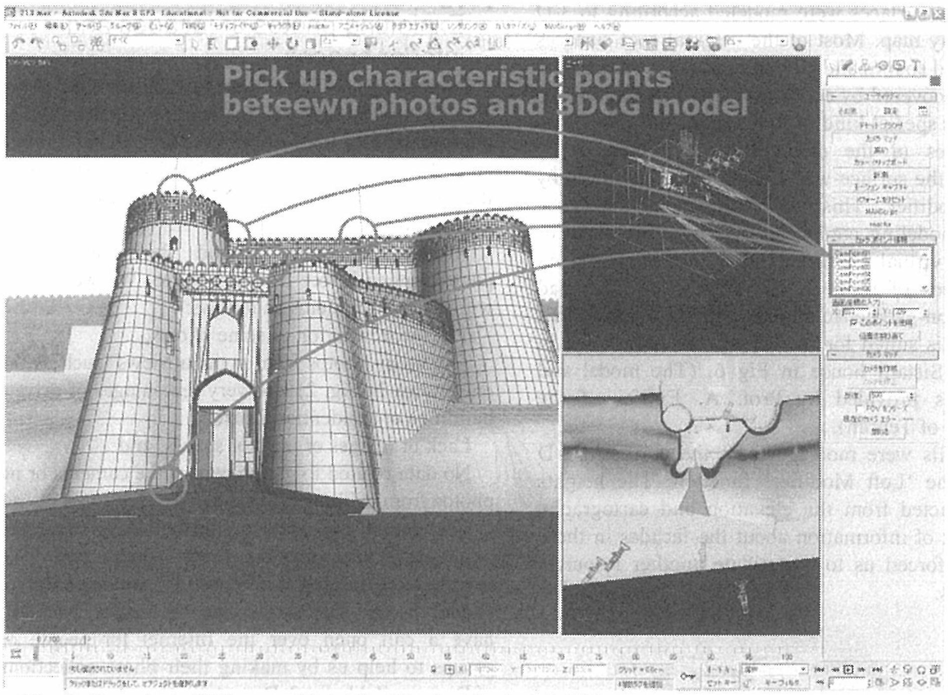
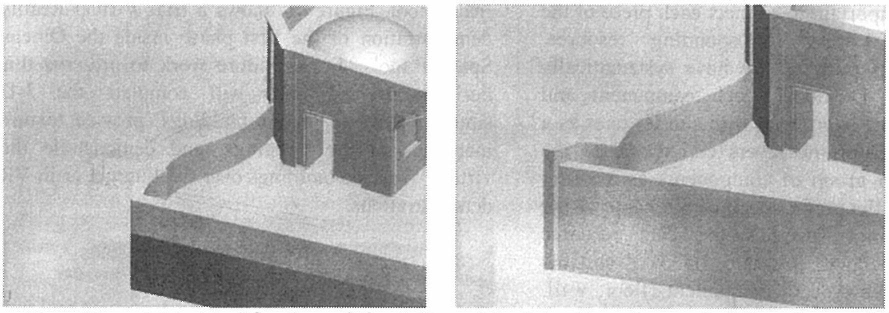


Fig. 9: Snapshot of "Camera Match" utility inside the MAX®

Rendering of the CG model from the same aspect as the photographs made it much easier to make comparative studies of the CG model (as shown in Figs. 7 and 8). We used the 'Camera Match' utility. The setting of the camera for the specific photograph was calculated for correspondence with the common characteristics of the photograph and CG model. After that, we reproduced the camera setting of the photograph within a scene of the CG model, and this enabled rendering from the same aspect as the original photograph (Fig. 9).

The camera matching process has a number of difficulties and is inaccurate. However, the CG model can be decorated and given features like holes in walls and accurate arches by comparing CG images at angles matching those of the actual images taken before the earthquake.



Figs. 10 and 11: Modification of the 3-D model of the Four Season building (in grey) by using the 3-D cartography map (red line). Before adjustment (left) and after adjustment (right)

Simultaneous adjustment of photo and 3-D cartography map

The generated model was superimposed on the 3-D cartography map again to look for errors. Since the model was based on an unreliable plan and used manual matching from photos, we collated it with cartography data and corrected it when necessary. We modified the model and the incompatibilities with cartography data by using the 'soft selection' function of the 'Polygon Edit Modifier' tool. Figures 10 and 11 show the modification of the parapet of the monumental reception room according to cartography map (red lines).

Complementary data

Due to lack of photographs on the interior spaces we looked for other modeling resources. During this task, we found ourselves becoming architectural detectives to discover the mysteries of buildings with complicated forms that had all but disappeared. Because of the missing views of the available documents the other complementary resources we used are as follows.

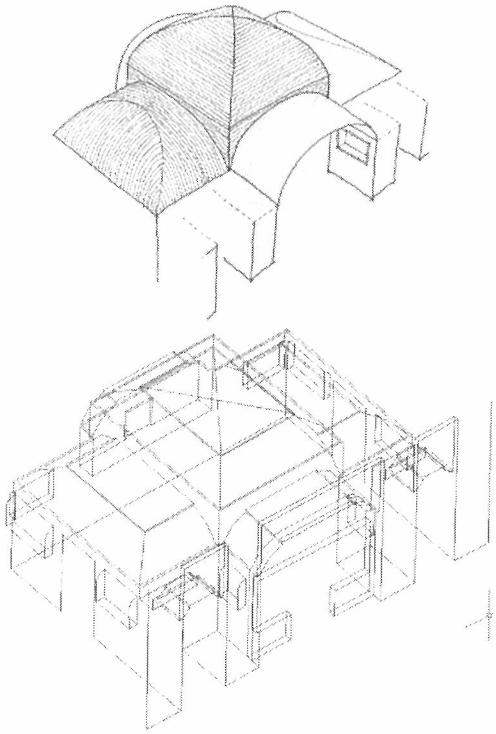
Movies

Other references for completing the 3-D models were movies taken by professionals[1] or amateurs of spaces for which no photos or maps were available.

Text and sketches

Text was used for disambiguating changes in shape made during the restoration periods before the earthquake, discovering the history of the citadel and the buildings inside it, and describing the spaces. These sources included annual reports of the restoration process, unpublished papers about history and architecture, papers submitted to the first and second congress of the history of Iran, Citadel of Bam (1374-78) [1, 2], and the Bam region report.

In some cases, sketches by experts who worked at the site before the earthquake and remembered the original shapes of the buildings were used for 3-D modeling. Sometimes they were the only available resource (as shown in Figs. 12 and 13).



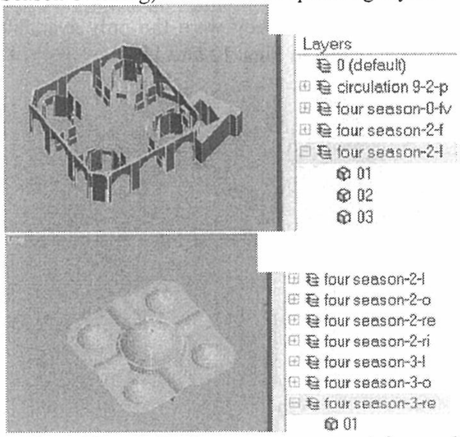
Figs. 12 and 13: Sketch of ceiling of a room inside the Sistani house: the only available data for modeling and the generated 3-D model

5. Systematic and semantic model

The different data resources used to model the citadel can produce 3-D models with different levels of accuracy. As the results of our research and its 3-D models are to be used as digital documentation of for eventual physical restoration of the destroyed

[1] The Bam citadel, directed by M. Zahedian, Bam; the eastern gate of Iran, directed by H. Emami; Bam, sustainable heritage, ICHTO, Bam, in the Silk Roads series by NHK.

buildings, it is important to connect each piece of the 3-D model with its corresponding resource. According to this purpose, we have systematically developed our 3-D model; each component and object in the model is grouped with similar ones as a layer. The names of the layers correspond to the metadata of each group of components as a string with three parts: the prefix specifies the name of the building; the infix specifies the data resource (heterogeneous data we introduced above); and the suffix specifies the type of component (floor, wall, ceiling, roof, door, window, etc.). We call this identification process *layer management*. Figures 14 and 15 shows the implementation of the layer management technique for systematic modeling of a case study of the monumental reception room (Four Season building) and the corresponding layers.



Figs. 14 and 15: Layer management for model of the Four Season building

5. Virtual reconstitution of the two main axes

Our collaboration between CG experts (an international team of modelers from Waseda University, University of Tehran and EVCAU) and historical architectural experts has completed the first phase of 3D modeling of buildings along the two main axes of the site. The simulated buildings are as similar as possible to the original ones. All the models are merged inside a basic topographic 3-D map of the site and are attached to their location by using the geographical features (longitude and latitude) provided inside the 3-D cartography map. They are provided as a single file that is imported as a VRML[1] file with coordinate information. The file can be viewed and interacted by using a virtual reality tool. Figure 16 shows a trial Virtual Reality demonstration of the first phase inside the Omega Space®[2] tool. In our future work to preserve this heritage digitally, we will complete the 3-D simulation of the major buildings, provide texture mappings of the buildings, and demonstrate the virtually revived buildings over the Internet or in VR demonstrations.

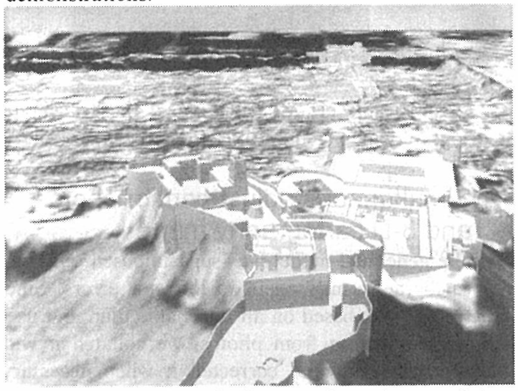


Fig. 16: Snapshot of VR scene from the top of the Citadel of Bam looking toward the city

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[7] Neufert Architect's Data Third Edition, Blackwell Science, Great Britain. Noton, N.H. 1982

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[1] VRML stands for Virtual Reality Modeling Language or Virtual Reality Markup Language. (from http://encyclopedia.thefreedictionary.com/VRML[1 November 2007])

[2] Omega Space is the first Japanese VR presentation software developed by Solidray Co., Ltd http://www.solidray.co.jp/ [1November2007]