A Virtual Connection between Past and Present: the Digital Revival of Cham’s Architecture (Vietnam)

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Abstract — The traditional approach for understanding an archaeological site, mainly focused on excavations and stratigraphic examination of findings through the archaeological analysis, is still the main way for hypothesizing its most probable interpretation. As demonstrated in several case studies 3D digital acquisition techniques may greatly help for applications such as site and findings documentation, digital stratigraphy, 3D GIS or virtual interaction between experts. In addition, an accurate geometrical representation in digital form may be used, once integrated by archaeological considerations, as a starting point for creating virtual reconstructions of the site, embedding the most probable hypotheses. However, this last step might be critical for a apparently trivial reason: with very few exceptions the archaeological skill for interpreting some ruins and the technological skill for 3D modeling the corresponding site reconstruction are owned by different individuals or group of scholars. The aim of this paper is to describe a widespread 3D documentation of a site and a possible reconstruction process step by step, starting from a laser scan survey and a set of historical documents, focusing on a reasonable multi-disciplinary concurrent interaction to reach the best virtual reconstruction solutions. This path may help both archaeologists to better focus their thoughts through a detailed visual representation, and the technological experts to avoid misleading details in the final virtual reconstruction. The case study regards a group of Cham temples located in the Mỹ Sơn site, an UNESCO archeological area in Vietnam.

Keywords - Cham Architecture, 3D Laser Scanner, Reality-based modeling, Digital Reconstruction, Virtual Archaeology

I. INTRODUCTION

In the last decade the use of 3D acquisition techniques in the archaeological field has allowed to improve the survey process, providing high resolution reality-based digital models, capable to be linked with different historical documentations, greatly improving the conventional bi-dimensional hand-made survey and improving the knowledge process of the archeologist. Another possible output, supported both by reality-based models and historical data, can lead to the progressive reconstruction of suggestive 3D digital models of not anymore existing architectures made lively through Computer Graphics. These can be useful for a careful interpretation of the existing ruins but sometimes they might also be capable to suggest new archaeological discoveries. A weak part of the latter process is represented by the risk of lack in scientific reliability of the reconstructed model, due to the actual disjunction between the modelers producing the final detailed output, and the archeologist owning the knowledge for creating the appropriate reconstructive hypotheses. The methodology here proposed is based on a first extensive 3D documentation of the site in its current state, followed by an iterative interaction between archaeologists and digital modelers, leading to a progressive refinement of the reconstructive hypotheses. The starting point of the method is the reality based model, that, together with ancient drawings and documents, is used for generating the first reconstructive step. This is annotated through archaeological considerations that has to be confronted with geometrical constraints, producing a reduction of the reconstructive hypotheses to a limited set, each one to be archaeologically evaluated. This geometry-archeology loop is iterated until the result become convincing by both points of view, integrating in the best way all the available starting data. This described methodology has been verified on the ruins of five temples in the Mỹ Sơn site, a wide archaeological area located in the central Vietnam. Created by the ancient Cham civilization active in Vietnam from 7th to 18th century, it has been listed as UNESCO World Heritage in 1999. Such activity has been conducted in the framework of the project “Ewec Archaeosites – archaeological sites in the east-west economic corridor”, an interdisciplinary research between Politecnico di Milano, Fondazione Lerici and ICM – Hanoi. Mỹ Sơn area contains a reasonably well preserved system of 78 Cham Temples, some of them destroyed by the nature in the last centuries. The integration of 3D surveyed data and historical documentation has allowed to support a gradual reconstruction of not existing architectures, developing their three-dimensional digital models step by step, from rough shapes to better refined ones. The 3D acquisition and modeling of a specific set of temples, indicated by the archaeologists as “G group”, is here presented and methodologically discussed.

II. HISTORICAL BACKGROUND

Hidden in the forest, surrounded by a circle of low mountains, wet by a network of streams and rivers, around 70 monuments were discovered in 1885 by a group of French soldiers surveying the Mỹ Sơn area. From that time, the
existence of a new culture came to the light: the Cham civilization.

Unknown until XIX century, the Cham culture played a significant political, economical and artistic role in the history of Southeast Asia. Since II century AD, probably due to the intensification of the commercial contacts with the Indian traders, with the growing of the population and with the necessity to face with a more complex system of administration, we assist to the emergence of different kingdoms, scattered in the Indochina peninsula, deeply influenced by the Indian social and religious model, both Buddhist and Hindu.

From the VII century onward, Cham evidences became more consistent. Organized as a sort of confederation of kingdoms, the Chams had to face with a continuous internal fights concerning the dynastic power. In addition attacks from the neighboring populations, as the Khmer from west and the powerful Viet from north, caused the decline of the kingdom in 1471. From that moment until 1832, their history is marked by lost wars for defending their identity, before the complete disappearance.

The most important religious complex of Cham culture was Mỹ Sơn. Located in the ancient kingdom of Amaravati (Quang Nam Province) Mỹ Sơn is situated 68 km south from Danang, and 40 km west from Hoi An, the ancient trading port of Faifo, nowadays well known touristic venue, recently nominated World Heritage by UNESCO.

During the conflict with the US, Mỹ Sơn became a partisan base. To prevent American incursions by land, all the possible accesses to the site were mined, as well as the slopes of the hills [1]. This was the reason why in August 1969, the site became a war target. A surgical B52 strike caused serious damages - and in some case the complete loss - of many monuments at that time still standing.

A. Site description

For its peculiar natural location the site was selected as religious centre since IV century and became a “memorial” of the noble achievement of the royal dynasty.

The introduction of brick masonry, the favorite construction material used by Champa, started around the end of seventh century and maintained until the end of Cham civilization, allowed to reach hazardous and elegant forms of architecture, jointly with a sophisticated way of building technology. The temple followed a quite similar model: square plan, with three distinctive elevated bodies: from the bottom, a platform, the sanctuary body and a high stepped roof. The external surface was often plastered to better protect the building, painted and decorated with bricks carvings. The stone was also used for decorative purposes (tympana, antefixes, lintels, door-jams, columns or pilasters). The quality of the bricks was excellent for the selection of clay, in order to support the typical Cham way to produce human figures or floral decorations directly carved on the temple walls.

The Cham builders used an organic mortar to stitch the bricks, resulted by a mixture of natural resins, able to obtain quite invisible joints between the bricks. By this technique, the masonry resulted “waterproofed”, avoiding in this way the infiltration of water and humidity, dangerous for the potentiality to produce, in time, a degradation of the structure.

B. Italian Archaeological Mission

In 1997, a trilateral agreement between UNESCO, the Vietnamese Ministry of Culture and the Lerici Foundation (Politecnico di Milano) was signed with the aims to resume archaeological researches in Mỹ Sơn, and to implement the management and conservation plan, in view of a possible inscription of the site, to UNESCO World Heritage.

In 2004 began the UNESCO project, financed by the Italian Ministry of Foreign Affairs, titled: “Safeguarding My Son World Heritage Site: Demonstration and Training in the Application of International World Heritage Standards of Conservation at Mỹ Sơn Group G Monuments”.

Group G is composed of 5 buildings, built around the second half of the XII century by king Jaya Harivarman I, who left several signs of his exploits in different places of Champa territory [2][3][4].

The buildings have the following numeration:
G1 = the sanctuary (Kalan)
G2 = the gateway, miniature copy of the temple (Gopura)
G3 = the assembly hall (Mandapa)
G4 = the south building (Kosagrha)
G5 = pavilion for the foundation stone (Pośa)

Figure 1. Conservation conditions of the kalan temple in the G group: a) in 1903 (picture by Parmentier); b) before 1997; in 2011, after restoration.
Before the restoration of the complex, an intensive excavation campaign has been carried out in the area, revealing numerous architectural decorations [5]. For this reason the digital model here presented includes also sculptural decoration found in this archaeological context and 3D digitized, that allowed us to reconstruct the model with an high degree of reliability.

III. METHODOLOGY

The process supporting the transformation from a set of 3D point clouds to a polygonal model is well known since more than a decade [6][7][8], even if in it has been progressively improved to suite better with the field of application [9]. For this reason in the last years many advances have been suggested in order to improve this process in the archaeological field [10][11][12].

The reality-based digital model, generated by a set of 3D laser scans, had a double purpose in this project. On the one hand it allowed an accurate documentation of the current site status, on the other hand it was a useful support for explaining the structure of the G group, possibly to non-expert people like students or common visitors.

Differently from the reality-based models, the archetypal reconstructive digital models presents very different purposes [13][14][15]. Thanks to the virtual representations of the current and reconstructed temples, an effective diachronic analysis becomes possible, stacking on the possibility to “see” what in the past was only possible to be imagined through descriptions [16].

The path from reality-based to interpretative models is not so widely developed as the conventional modeling from real data [17]. In this case, besides the particular attention given to the integration between 3D surveyed data and historical sources, a precise iterative feedback strategy was defined in order to check every important interpretative step during the virtual reconstruction. This procedure was based on a sequence of archaeologist’s controls on the modeling evolution, starting from a volumetric simplified version to the best detailed one. The application of this approach should allow to reach a better shared solution between 3D starting data, historical sources and archaeological knowledge, simplifying the communication between historical and technological experts.

For the whole process different software were used (Cyclone, Geomagic, Polyworks, Rapidform, Modo) in order to avoid the use of one program with relative pro and cons, exploiting the best performances from every single system.

IV. SURVEY EQUIPMENT AND OPERATIONS

A. Planning

As known several factors that can deeply affect the quality of the acquired 3D data. Equipment choices, logistics and environmental conditions, has to be considered in a survey planning, especially when operating in the middle of a forest, like in this specific case. An accurate evaluation of such factors allows to optimize the 3D acquisition, minimizing any problem that can occur during the survey. In particular logistics and weather condition forecast become crucial specially if the survey project has to be planned abroad, with no possibility to travel back and forth to the lab, and little or no possibility to lose operating days for possible delays at custom controls.
The range sensing technology chosen for this project was a relatively new 3D lasers scanner based on Continuous Wave with detection of phase deviation (Faro Focus3D). This because it appears as the most suitable for low-middle ranges in terms of tradeoff between precision (around 2 mm standard deviation tested on a planar target located at 20 m from the instrument), working speed (1 million points per second max), equipment weight and size (5 k of material fitting in a small bag, compliant with airlines standards for hand-luggage), and, last but not least, a cost definitely lower than other analogous products on the market.

Before starting the project a few considerations have been made about the possibility to use “Structure From Motion” (SFM) as an alternative to laser scanner, being nowadays a powerful tool for generating textured point clouds. The advantage would have been to limit even more the amount of equipment to carry from the lab, consisting in just a camera, a tripod and a PC for checking the data. At the moment of project planning (December 2010) such technologies were very promising but not yet developed as today (April 2012). As a consequence the choice was, as often happen in project where the site to be digitized is not easily reachable, to get redundant 3D information moving on site both the equipment needed for laser scanning and SFM image processing. Laser scanning was therefore the main tool being metrical, reliable, and already used by the authors in plenty of other projects, while image processing was only experimented on the site with a few datasets.

For all these reasons two different instruments were chosen: a 5D Canon Mark II digital camera and a Focus3D laser scanner (Faro). Before the survey the scanner performances were accurately tested in laboratory, verifying the data quality, reliability and ideal working distance. A similar performance test was repeated in situ, verifying the real behavior of the electronic and optical system with high temperature and extreme humidity condition, using the actual surfaces of the monument as test objects. Different instrument set-ups were then defined, connecting a set of distances with relative 3D scanner performances.

### Table I. 3D Laser Scanner Set-Up

<table>
<thead>
<tr>
<th>Scan Scale</th>
<th>Operating Distance (m)</th>
<th>Resolution Qualitative</th>
<th>Resolution mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework</td>
<td>8 - 16</td>
<td>Coarse</td>
<td>7 – 60</td>
</tr>
<tr>
<td>Architecture</td>
<td>4 - 8</td>
<td>Medium</td>
<td>4 – 15</td>
</tr>
<tr>
<td>Details</td>
<td>1</td>
<td>High</td>
<td>1</td>
</tr>
</tbody>
</table>

At the end the archaeological plan was examined in order to suggest a first optimized network of scan positions, trying both to minimize the acquisition time and to consider all the morphological characteristics of the architectural examples.

### B. 3D Laser Scanning

The survey of G Area regarded both the 3D geometrical acquisition of five different architectures with associated findings and the 2D image acquisition for texture and environment documentation.

The 3D survey of the area was planned following three different temporal steps. In the first one all the architectures were acquired, adapting the number of scans and working distance set-up to the different level of geometrical complexity of every single ruin. For the Kalan temple the level of morphological complexity led to a multi-resolution approach in order to survey the whole structure, the different bricks carvings and the sculpted decorations. The second step consisted in DTM acquisition for creating a geometrical framework in order to locate the whole architectures in a common reference system. For this reason a wider surface respect to the archaeological area was considered, in order to acquire part of the morphological terrain context. The last phase focused on the 3D acquisition of some archaeological artifacts that were found during the excavation of the G area and were then classified inside the store-room of the local museum. This step was planned both to store digitally these important sources and to create 3D models that could be re-positioned afterwards on the virtual architectures. For this task a precise survey set was defined, in order to optimize the geometrical resolution coherently with the formal complexity of the sculpted finds.

### Table II. Point Clouds Acquired at Different Resolution Levels

<table>
<thead>
<tr>
<th></th>
<th>Coarse</th>
<th>Medium</th>
<th>High</th>
<th>Points x 10^6</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 (Kalan)</td>
<td>7</td>
<td>43</td>
<td>22</td>
<td>126</td>
</tr>
<tr>
<td>G2 (Gopura)</td>
<td>/</td>
<td>9</td>
<td>/</td>
<td>21</td>
</tr>
<tr>
<td>G3 (Mandapa)</td>
<td>/</td>
<td>8</td>
<td>/</td>
<td>15</td>
</tr>
<tr>
<td>G4 (Kosagrha)</td>
<td>/</td>
<td>13</td>
<td>/</td>
<td>31</td>
</tr>
<tr>
<td>G5 (Pośa)</td>
<td>/</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>DTM</td>
<td>49</td>
<td>/</td>
<td>/</td>
<td>27</td>
</tr>
<tr>
<td>21 Finds</td>
<td>/</td>
<td>/</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td>79</td>
<td>86</td>
<td>226</td>
</tr>
</tbody>
</table>

The photographic campaign was devoted to the acquisition of: i) architectonic images for texturing projection purposes; ii) detailed images for the creation of seamless material pictures; iii) panoramic images to gather a believable representation of the surrounding environment through the stitching of multiple fish-eye photographs; iv) few image sets around four monuments for experimenting SFM. The main difficulty with these latter images were related to the presence of architectural elements inside dense vegetation, slightly moving due to wind, that involved the presence of images difficult to match each other, with SFM results not always good, that for this reason are not shown in this paper.

### C. Digital Data Management

A database structure was created to store this huge amount of 2D and 3D data, adding, for every scan, some useful information like date, cloud dimension, scanner set-up, allowing to manage easily all these information also after a long period. Such database was integrated with a reference plan.
in which all the scanner positions were annotated during the survey. This support allowed to careful plan and manage the whole 3D scanning campaign, avoiding the post-processing of excessive amounts of data that a device capable to generate 1 million of Points/sec might easily produce.

V. REALITY-BASED MODELING

The only drawback of the compact scanner employed in this project was the generation of non-existing points in correspondence of the building edges, when the acquired surfaces were too much tangential with respect to the laser beam (see figure 4). For this reason, although some automatic filtering allowed to reduce this effect, before starting the point cloud alignment process, a considerable manual preprocessing for deleting outliers was needed.

Every cleaned scan was then aligned by means of the ICP algorithm implemented in the Leica Cyclone 3D processing software in order to position the point clouds of every architecture in the same reference system. The resulting point clouds were then decimated at 1 cm sampling step, leveling all the over-sampled portion of the architecture and lowering the amount of 3D data.

Each point cloud was subdivided in sub-units whose size was limited to 3 million of points in order to make easier and more controllable the following meshing step.

Figure 4. Tangential edge error in 3D point clouds: the red points represent the incorrect data respect to the real ones (black-grey color)

Such subdivision did not follow a semantic thinking because the principal aim was just the identification of area suitable to be closed afterwards with a polygonal post-processing.

Every sub-scan was then meshed uniformly. However the resulting high-resolution polygonal models presented both several topological errors, due to residual errors survived to the cleaning phase, and a huge numbers of holes, related to the shadows effects of the complex geometry. These conditions have been critical in particular with not well-preserved buildings; in that case a rather long post-processing phase was faced to generate a watertight polygonal model.

This stage allowed to build the 1cm resolution geometry of all the five buildings in the G Area, a 10 cm resolution DTM of the hill where G Area is located, a set of polygonal models of sculpted finds with a geometrical resolution of 2 mm.

At the end different approaches were followed to texturize the such reality based models. For the worst cases of conservation, like G2 and G4, a seamless shading pattern originated from real images was chosen as the most practical way.

Figure 5. Reality-based model of G5 obtained from 3D data generated by a laser scanner at 1 cm resolution, texturized with the actual images of the ruin.

For the Kalan temple and for the well-preserved architecture, like G3 and G5, most of the texturing was done with the actual images of the ruins projected on the model with the integration of seamless shading patterns for the less characterized components. For example in the model in figure 5 the lateral walls and the stela with inscriptions have been texturized with images while the central stone basement and the sand surrounding it have been done with patterns.

The approach followed for acquisition and modeling of the sculpted findings was in principle similar to that employed for the architectural structures, with a change in terms of geometrical resolution settings for the Faro Focus3D scanner.

Such equipment showed a fairly good capability to reproduce thin details in the final polygonal model. For this reason an optimized post-processing procedure was analyzed to preserve such useful geometrical information. The models obtained from this process were reconstructed using both a mesh directly generated from the acquired 3D data, optimized for preserving thin geometric details, or manually drawing CAD models for reconstructing polygonal shapes close to the original data. In this step the archeologist’s feedback was necessary to suggest the virtual reconstruction of some lacking parts, that was hypothesized coherently with the iconographical sources.

VI. RECONSTRUCTIVE MODELING

The creation of reconstructive models was based principally on the integration between bibliographical or iconographical sources [18][19][20] and 3D data acquisition.
A first important analysis regarded the height estimation of the architectures. No information was found in the historical sources, for this reason a comparative analysis with other contemporary and better-preserved architectures was carried out, together with an estimation of the volume of debris found during the excavation phase, evaluating a building height in the range from 15 to 20 meters as suitable for the Kalan temple.

In addition to this rough approximation, the role of each architecture was considered for refining the Kalan height estimation. During the religious ceremony the young monks accompanying the Brahmin during his journey to god (that for the Hindu religion is inside the Kalan) enter into the Mandapa and stop here, leaving the Brahmin alone to enter into the holy enclosure from the Gopura (i.e. the portal). For this reason the Gopura entrance door surely prevented to see the holiest building, i.e. the Kalan. This consideration, explained graphically in figure 8, allowed to define a believable dimensional range for the Kalan and the Gopura, identifying 8 meters as suitable hypothesis for the Gopura height.

As shown in fig. 9a the volumetric model of every single architecture was then built, considering both sequence of sections extracted from 3D data and historical documents. At this step three different versions of the most complex building - the Kalan Temple - were created, working in particular on the ratio between the different levels of the architecture. These raw outputs allowed to visualize for the first time the 3D virtual reconstruction, evaluating with the archaeologists pros and cons of the different solutions. In the second step every architecture was refined, carving the virtual walls with hypothetical pilasters and niches as shown in fig. 9b. The introduction of these elements was quite complex for the very little information coming from the ruins. The comparison with other similar stylistic elements was essential at this stage in order to identify common structural patterns, that have been afterwards adapted to the G buildings. Also in this delicate passage the archeologists participation was essential to validate the solution adopted. In the following modeling step, illustrated by fig. 9c, the latest architectonic refinements were applied and all the sculpted decorations digitized in the store-room were located in the supposed right places. The introduction of these decorations constrained the architecture structure, trying to fit them in their hypothesized position. In this last passage the modeling level led to such an advanced level of detail that even the experts demonstrated doubts and decided not to introduce unknown elements inside the architecture, leaving intentionally some informative lacks on the reconstructive models. In the final step (fig. 9d) the different texture mapped architectural models, including all their decorations, were merged in a single three-dimensional virtual reproduction of the G group.

The environment was finally added mapping a panoramic view of the true surroundings on a sphere containing the whole model and adding 3D models of vegetation to the true DTM, leading to the final reconstructive view shown in figure 10.
Figure 9. Four progressive modeling versions of the Kalan Temple: a) raw shapes; b) same with addition of mouldings; c) same with addition decorations; d) same with addition of textured materials.

Figure 10. Final reconstruction of the G group, in a virtual environment generated from the original DTM and a real panoramic view taken from the top of the kalan temple.

I. CONCLUSIONS

This paper describes a process of acquisition and modeling applied to create a virtual reconstruction of lost architectures located in a striking context, the Mỹ Sơn archaeological area in Vietnam. Inside a common used 3D acquisition and modeling approach some different topics are discussed, suggesting both optimized procedures for data processing and communication. In particular, as synthesized in figure 11, an iterative methodology is suggested to support the interpretative modeling step, simplifying the feedback on virtual models by
the archeologists. This solution gives a significant improvement on the complex procedure of 3D reconstruction modeling, supplying both an instrument of communication and valorization of the cultural heritage site helping the interpretation of archaeological and architectural ruins. As future development it would be interesting to explore an enhanced communication level between the different historical and technological experts, based on social networking instruments, and annotations on renderings or directly on 3D models.

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