SCIRES-IT
SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 1, Issue 2 (2011), 71-86
e-ISSN 2239-4303, DOI 10.2423/i22394303v1n2p71
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REALITY-BASED AND RECONSTRUCTIVE MODELS: DIGITAL MEDIA FOR CULTURAL HERITAGE VALORIZATION

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Abstract

Cultural Heritage represents an aspect of our historical memory that in the last decade has suffered transformations, reductions or destructions for different human or external factors. In this situation the introduction of technologies and methodologies suitable to reduce this deterioration process has been perceived as mandatory, leading to the development of strategies that permit to preserve and explain the information embedded in Cultural Heritage, supporting the process of valorization through the application of different representation instruments.
3D acquisition and modeling technologies represents a possible aid because they allow to generate the digital simulacrum of a real artifact, and the availability of digital tools for manipulating, exploring, comparing and explaining a virtual object, can greatly increase the comprehension and the valorization of monuments. In addition to these applications orient to the common public, once an artifact is represented in digital form also analysis, management and conservation can be allowed with instruments oriented to experts.
This paper critically presents the two possible complementary approaches to 3D modeling in CH: the representation of a monument "as is" through precise 3D capturing and modeling vs. the representation of a previous hypothetical state through a scientific reconstructive process. Such presentation is based on two exemplar cases of the two approaches: the reality-based modeling of the Pompeii Forum and the diachronic reconstruction of the San Giovanni in Conca basilica in Milan.

Keywords

Heritage, 3D Survey, Virtual Modeling, Data Integration, Valorization

1. Introduction

In the last centuries manual drawing has represented an essential instrument of knowledge, which allowed to fix on paper the surveys of the most famous buildings and archaeological areas, deriving the essential advices of the ancient Architecture. This traditional method permitted to freeze on a drawing the actual condition of an artifact, becoming an essential document for its study and conservation.
With the introduction of digital survey systems, the means of comprehension and communication of a real monument was radically changed; as a matter of facts 3D models represent an unlimited repository of information from which different kind of representations can be extracted. In the last years 3D models have demonstrated also an important role in digital cataloguing, virtual restoration, simulation of structural interventions, maintenance and management of the artifact conservation, needed also for its promotion and valorization.

From the 90s to now, a considerable increase in the application of digital survey has occurred, due both to the technological evolutions of 3D survey instruments and to the rising awareness about the potential of digital Heritage in terms of public visibility and cultural contents. This involved a progressive growing of researches in the field, leading to the current international interest for this strategic topic.

2. State of the art

One of the main aspects that has characterized the evolution of digital models in the last decade is represented by the research on the 3D survey and modeling procedures for Cultural Heritage (CH) objects, leading to the so-called "reality-based" modeling. The wide range of variations in terms of possible size and materials has required the definition of different approaches for surveying, modeling and visualizing the objects.

The firsts techniques of integration between 3D acquisition and 2D pictures were tested on small scale objects, like archaeological findings, sculptural groups or portion of buildings, with the aim to create realistic digital models [1, 2]. This area has had a strong evolution in the last years, thanks both to the introduction of a wide variety of triangulation-based 3D active sensors, that has allowed to obtain reliable and precise 3D data on small volumes [3], and the purpose to enlarge the field of application of these instruments, that has led to the integration with digital photogrammetric systems [4].

A similar evolution has happened in the architectonical scale. Also in these fields digital photogrammetry [5] and 3D laser scanning [6, 7] has represented the most used techniques mainly for the performances in terms of data acquisition speed. The aim of integration between these two techniques, in order to reach a better global accuracy and improve the data reliability, has led to the definition of integrated 3D survey approaches that allow to face the global complexity of an architectural system, from the survey of the global structure to the smallest details. For this reason in the last years some research efforts have been spent on the optimization of 3D survey methodologies with respect to the physical characteristics of the object to be digitally modeled, with the purpose to solve some critical bottlenecks implicit in the multi-resolution approach [8, 9, 10, 11].

The aforementioned technologies have been adapted also to the territorial scale by installing photogrammetric cameras and properly customized laser scanners on flying vehicles such as

Unmanned Aerial Vehicles (UAVs), helicopters or airplanes, in addition to the more traditional remote sensing based on radar and imaging satellites. These image-based approaches are complemented by those methods capable to detect the position of a specific point on the earth surface, like the many Global Navigation Satellite System (GNSS) developed by different countries, an example of which is the well known GPS.

At this scale also Geographic Information Systems (GIS) play a key role, once populated with 3D data gathered through the aforementioned technologies, for the geo-referred localization of buildings and landmarks, and the connection of geometric information with archaeological, historical or administrative data.

Besides reality-based models, in the last years reconstructive models have also assumed an interesting role, for the possibility to visualize not-existing architecture through an analytical process based on the integrated knowledge of historical sources and real 3D data. For more than a decade many researchers [12, 13] have discussed about the use of virtual reconstructions of environments not anymore existing, as an instrument for the shared synthesis of knowledge, for interactive interpretation of archaeological ruins or heavily stratified architectures, and for cultural diffusion. To define a shared standard based on strict methodologies, different relevant initiatives have been suggested from the CAA Virtual Archaeology Special Interest Group (VASIG), the Cultural Virtual Reality Organization (CVRO), from the European project EPOCH (www.epoch-net.org) and Europeana (www.europeana.eu). Some of these contributions have been reported in the London Charter whose main aim is establishing internationally-recognized principles for the use of computer-based visualization by researchers, educators and Cultural Heritage organizations (www.londoncharter.org).

Visualizing reality-based or reconstructive models represents an important level of interaction for communicating cultural contents, which is crucial for the comprehension and valorization of the associated CH objects [14].

For this reason different projects have faced this issue, from the digital reconstruction of large cities (www.romereborn.virginia.edu) to the interactive navigation of single geographical area or single 3D models (3d.cineca.it/storage/demo_vrome_ajax/virtualrome_3d.html), from the analysis of 3D digital reconstructions (www.pompey.cch.kcl.ac.uk/3D_ Visualisations.htm) to the different interaction typology between user and digital contents [15].

3. Case studies

The following case studies may be considered two archetypal examples of reality-based and reconstructive modeling, for highlighting role and scope of such complementary tools in Cultural Heritage.

The generation of a digital model for Cultural Heritage preservation requires an amount of complex and mixed information to be acquired entirely. The application of a survey methodology and the consequent use of research instruments have the primary scope to reach a level of knowledge of the monument or artifact suited with the aim of the project. Generally this knowledge requires the integration between different instruments to face correctly the data complexity contained inside the ruin or a building.

In the following case studies this integration approach was applied, in order to exploit the different instruments capacities on one side, verifying mutually the traditional instruments of analysis with the digital one on the other. The methodological processes that have led to the definition of such models present some peculiar aspects, due to the project requirements and the application context.

3.1 Pompeii Forum

The 3D survey and modeling of the Pompeii Forum is part of a wider project based on the agreement between ARCUS company, Soprintendenza Speciale ai Beni Archeologici of Naples and Pompeii (SSBANP) and Scuola Normale Superiore (SNS) of Pisa. The suggested methodology has foreseen a close synergy between archaeologies and experts in 3D survey and modeling, leading to an optimized methodology to create a modeling pipeline adapted to the wide shape and size variation of the actual ruins [10].

The Pompeii Forum was the principal square of the ancient Pompeii town, centre of the political, commercial and religious life of the city. Positioned in the most ancient part of the city called “Altstadt” on the south-west side of the settlement, is crucial today for the analysis and interpretation of the growth of the city from the VII century B.C. until its final destruction.

In the first urban configuration, during the Samnite period, the shape of the forum was trapezoidal and oriented to north-west and south-east axes, a configuration maintained until the second half of the II century B.C., during which the shape of the forum was changed in a rectangular area with north-south axis. During this last period the Forum aspect changed radically, some new temples were built and an arcade called “Porticus” o “Popidius” was added along the south-east axis, contributing to the new Forum orientation.

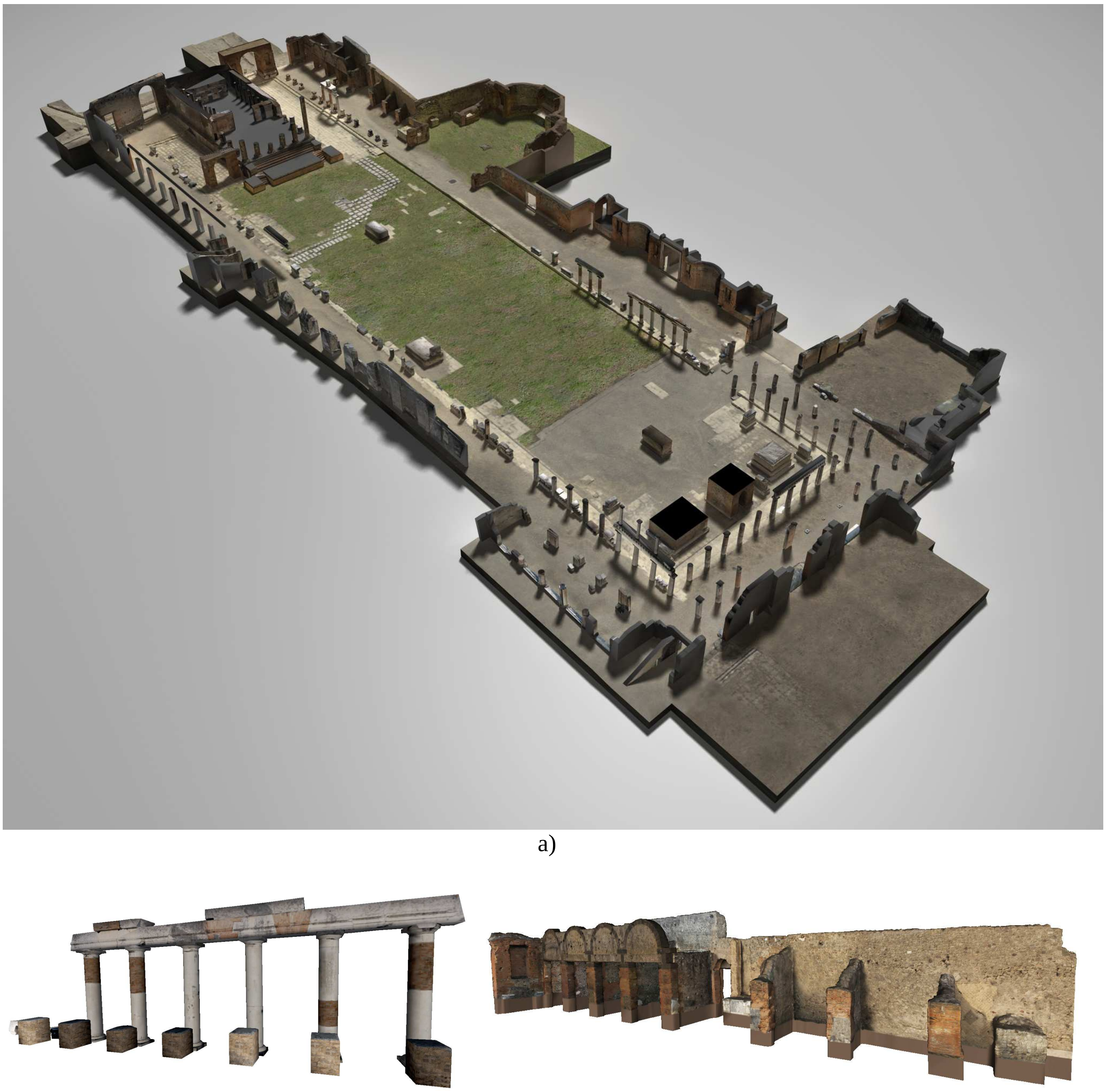
The square was finished with the insertion of two monumental arches positioned both aside the Capitolium. In the 62 A.D. an intense earthquake damaged heavily Pompeii and its monuments. While its restoration was still in progress, the city was definitely destroyed by an extraordinarily powerful Vesuvius eruption in 79 A.D.

a)

b) c) d)

Figure 1: The forum of Pompeii: a) an oblique aerial view; b-d) some of the finds spread all over the archaeological area.

The Pompeii forum is a 150 x 80 m wide area that contains more than 350 archeological finds of different size and geometrical articulation, all included inside an architectonical scene of 12 temples and buildings. The interpretation of different constructive phases and the interconnections between walls, represents nowadays a relevant subject of analysis for the Pompeii history. An interesting source of information in this sense can be derived by the integration of different 3D acquisition techniques, with the aim of defining a complex reality-based 3D model. In fact this methodology allows to adapt the different level of geometrical and material content of every single artifact to the survey instrument, meanwhile introducing a level of redundancy useful to optimize the accuracy and verifying the metric errors contained in the whole model.



a)

b) c)

Figure 2: Rendering of the reality-based model integrating different modeling methods: a) the whole forum b) a colonnade and finds generated with photogrammetry; c) the "macellum", obtained from laser scanning.

To cover a huge area of the Pompei Forum, an exhaustive documentation of the whole site and its single finds requires a 3D data system characterized by a high resolution dynamic, that has to be aligned and integrated carefully to produce a realistic virtual model without perceivable resolution transitions. For this reason a top-bottom approach was considered in order to employ different instruments and methodologies (GNSS, topography, TOF laser scanning, aerial imaging, close range photogrammetry) in order to cover a full archaeological area with details ranging from the geographical level to a small a bas-relief and ending up in a 3D repository.

The 3D data has come from different sources: a triplet of aerial images (1:3500 image scale), oblique aerial images for texturing purposes, terrestrial range data from two different TOF laser scanner (HDS3000 and HDS6000 by Leica Geosystems) and terrestrial images.

The laser scanning campaign was primarily devoted to create a geometrical framework on which orient each photogrammetric model and to check, thanks to the data redundancy, the possible dimensional errors (point cloud of 18 millions of points @ 25 cm of resolution). In some particular cases range data were used also to acquire the more complex monuments.

The photogrammetric processing of all the 3600 terrestrial images produced 3D models of simple structures (arches, walls, columns) or larger complexes (e.g. temples). Detailed ornaments or relief, modeled in high resolution with an advanced multi-photo matching approach [16] were afterwards integrated with the other low-resolution data. The geometric resolution obtained by this complex integrated survey system spans from 25 cm to few mm in geometry and from 15 cm down to few mm in texture.

The final 3D model composed by 370 000 polygons is a 3D data repository that can be used both from the studious and the persons in charge of the site maintenance, until the tourists: the first can explain historical and conservation details of a specific artifact in the Forum from the geometrical model to the connected data, the second can define the corresponding location of the artifacts in the 3D space from a specific document or philological detail. At the end the common public can visualize in situ or with a remote control the single virtual models or the whole area thorough virtual walk inside the forum or the stereoscopic visualization.

3.2 San Giovanni in Conca

The project of 3D survey and modeling of the San Giovanni in Conca basilica starts from a precise request of Regione Lombardia public body to define a methodology that would allow to explain the architectural evolution in time of archaeological and historical buildings that are present in the city of Milan, often hidden by the modern urban fabric. The virtual model obtained should than be usable both for experts or a larger public, valorizing the archeological area and the architectonical monument, showing in addition virtual reconstruction of non-existing parts of the building. The church of San Giovanni in Conca in Milan represents in this sense an interesting pilot project because it contains well defined historical phases and partial ruins of a complex monument.

Different historical sources date the foundation of the church to the first centuries A.D. and the probably conclusion to the V-VI century A.D. In the XI century the introduction of a crypt and the reconstruction of a portion of the Basilica changed the architectonical structure of the church. Also the XIV century was a relevant historical period because the monument was enriched from the architectonical and sculptural point of view and enlarged thanks to the Visconti patronage.

In the following three centuries the church was changed in different parts of its structure and in the ornamental elements until the XVIII century, in which the buildings fall began. Closed in the 1808, it was used as barrack from the Napoleonic recruits and afterwards as warehouse from private owners.

In 1879 during the big city rearrangement, the anterior spans were demolished with a cut oblique respect to the church longitudinal axis, determining a facade area larger than the original. The new reconstructed facade was therefore readapted to the extended shape of the church. With the Albertini's city plan the complete demolition was decided, leaving only the underground crypt and a little ruin of the apse, still present in Missori square.

The dimension of the ruin and its collocation inside the city represents the logical reasons why this church is little known to the common public, despite it represents a real historical sign of one of the most important Romanesque Basilica in Milan. The application of the 3D survey techniques and reconstructive modeling led to a larger visibility and valorization of this site.

The historical, iconographical and photographical sources have allowed to reconstruct the history of the church, evaluating and integrating at the same time the final results obtained 3D acquisition methodology applied in situ. This analysis has been focused in particular on the historical evolution of the church, picking up useful information for the 3D reconstruction modeling phase.

a) b)

Figure 3: Historic images: a) church facade before 1879; b) the same before 1952.

a) b)

Figure 4: Actual state of the building: a) ruin of the original apse; b) underground crypt still well conserved.

The integration of different 3D acquisition techniques for the geometrical survey and 2D images for the material analysis has allowed to reach a good knowledge about the ruin [17].

The 3D survey considered a 20x20 meters area composed by a middle-complex hypogeal portion with many columns and capitals and a less-complex external portion without sculpted elements. During the survey project it was decided to use the bigger part of the 3D acquired model as a reference for CAD modeling and partially as direct information source. This

assumption required the definition of a dynamic resolution step in 3D acquisition, starting from 2 cm for architectural portions up to 0.5 mm for the sculpted ones.
During the 3D survey the TOF laser scanner HDS3000 (Leica Geosystem) was used for the massive 3D acquisition of the architectonic portions of the apse and the crypt while the Vivid 910 (Minolta) instrument was applied in the 3D detailed acquisition of the most interesting capitals in the crypt.
Starting from the data survey and sections, a sequence of geometrical shapes was defined in order to generate a reference framework for a new archetypal geometry, preserving the original 3D surveyed data only for the more complex portion of the ruin. The use of mathematical primitives simplified the digital data management and allowed to create a flexible 3D model, suitable for an iterative interpretation process that implies frequent geometry modification.
The distance between the new CAD geometry and the reality-based model was verified to be never above 5 cm. The final model gathers the polygonal surveyed portions and the reconstructed ones in a 210 000 polygons digital representation, which was used as base for the application of the texture contained in the materials repository.
From the reality-based model the creation of the reconstructive one has started. The first step of the historic reconstruction started from redesigning the past iconographical and cadastral representations with CAD instrument. These historic data lack in objectivity and mutual coherence, due in part for the representation style and the graphical instruments used, in part for the introduction of errors in survey and measurement restitution, the low precision of drawings and the unsuited data preservation. The lack in objectivity requests a complex step of "translation" and "mediation" between the rough graphic output of the traditional representation technique and the precise CAD geometries reconstruction, maintaining a proportional coherence between the single pars and the whole. The presence of non coherent variations in dimension and proportion between drawings of different historical period can be avoided by an iterative comparison between the traditional representations and the real dimensions coming from the survey. In this case different sections extracted from the reality-based model were used to rescale the iconographical sources, verifying their correct representation.
Starting from the XII century Basilica plan as reference, a complex inspection process of all the other plans, fronts and sections was started in order to reach a sequence of 2D coherent representation, acceptable from the geometrical and historical point of view. The combination

between the complex level of 3D representation and the interpretation of reconstructive hypotheses, respecting the constructive and aesthetical rules of the period, represented the bottleneck of this step. A 2D drawing represents a form of incomplete spatial representation, effective for the geometrical description of a particular portion of the architecture but unsuitable for the global knowledge and representation of the entire building.

a) b) c)

Figure 5: Reconstructed models of the various periods: a) XIII century; b) XVI century; c) XIX century

Contrarily, in a 3D representation, every single element has to be geometrically described since every portion of the digital model is connected with the others in a complex system of spatial relationship. Despite on unavoidable lacks of historical data, such relationship between principal shapes and formal details can be more easily interpreted, thanks to the simultaneous presence of the actual 3D data attainable by laser scanning and ancient drawings. The modeling process, if not supported by historical sources, can be founded on constructive logics supported by an architectural vocabulary and local culture, defined in relation with the formal rules present in other churches nearby San Giovanni in Conca.

The reality-based model or the reconstructive versions in the different historical stages assume the double role of repository for the material useful for the studious and instrument for the communication of the historical and artistic data of the present and past, valorizing and giving visibility to the invisible monument.

a) b)

Figure 6: Rendering of the interior digital models: a) visualization of the reality-based model of the crypt; b) Interior reconstruction of VI century.

4. Conclusion

The principal aim of the article is the analysis of the role of 3D models in Cultural Heritage. In particular the approaches related to 3D model definition are from one side the project of survey and instruments in relation with the scale of the artifact, from the other the application of different 3D acquisition and modeling techniques for both the virtual representation of the physical object “as-is” and for the reconstruction of non-existing portions of building.

These two characteristics are peculiar of the methodologies used in the two case studies presented, the 3D survey and digital representation of the Pompeii forum (Naples) and the church of San Giovanni in Conca (Milan). A first strong analogy between the two projects is represented by the common purpose to create a digital model that freeze the conservative condition of the Cultural Heritage; beside this, also the possibility to use this digital data to valorize its presence and improve its management. In addition from the 3D survey point of view these two case studies can be considered representative for the level of geometrical complexity faced and the definition of multi-resolution and multi-scale models that led to the generation of digital reality-based and reconstructive models.

A mix of these two methodologies can suggest a new process of knowledge that can merge both complex reality-based models and reconstructive ones with diachronic representations of Cultural Heritage. In both cases the digital model defines a data source that may be explored as from the expert and the tourist, with different level of virtual interaction in relation with the digital platform. The digital representation improves the comprehension of the spatial and temporal relations, linking historical sources with pictures and 3D models. At the end this kind of representation of the reality can be considered an interesting and effective support for the knowledge, cultural transmission and valorization, suited with the evolution of the future technologies that will probably have a crucial role in cultural diffusion.

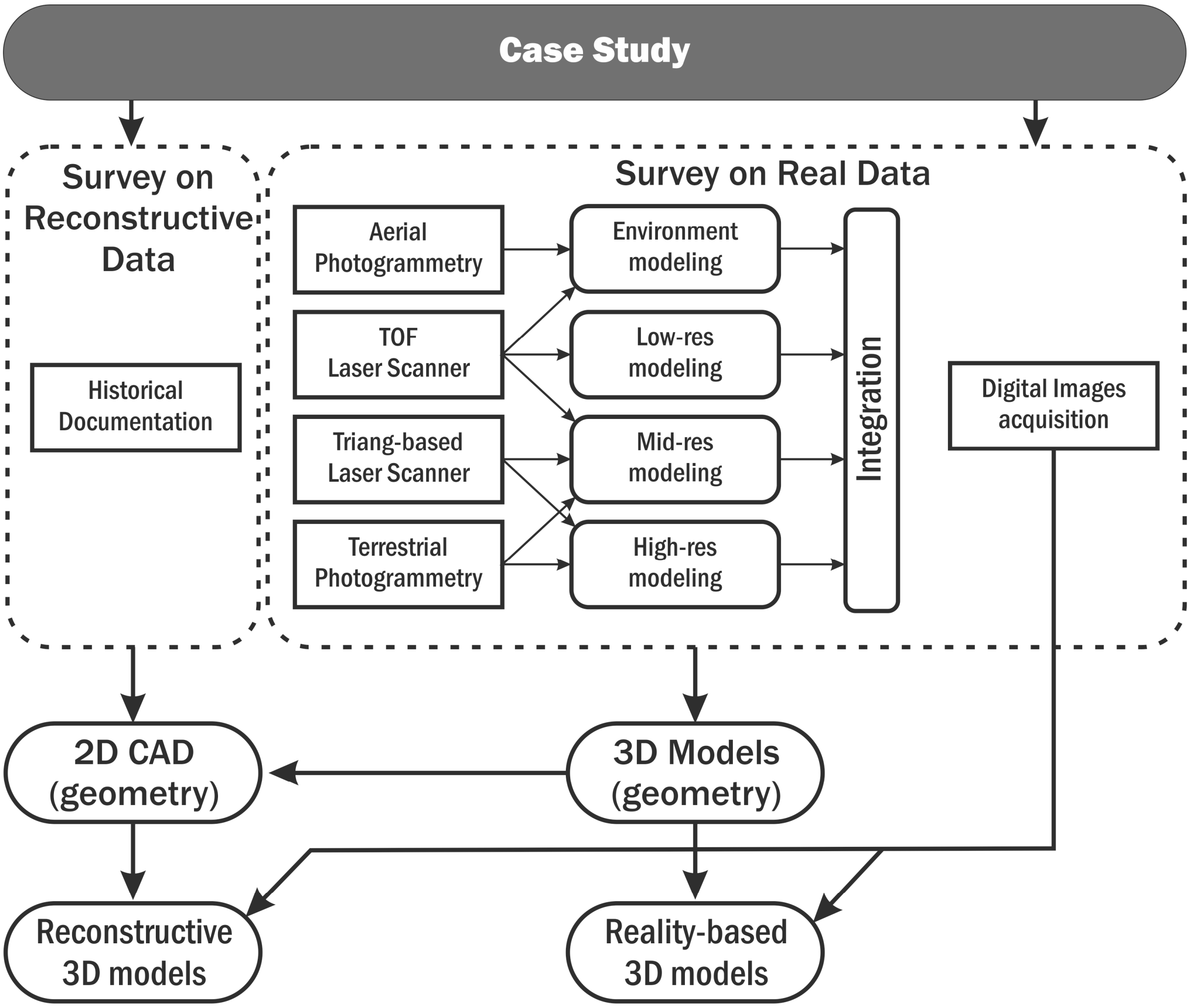


Figure 7: Block diagram of the reconstruction process based on the integration of 3D measurements and historical analysis

5. Acknowledgments

The authors wish to thank different people involved in the development of the two case studies presented.
A first acknowledgment have to be done to ARCUS S.p.a., in convention with ARCUS-SNS-SSBANP, and Regione Lombardia for supplying financing the two projects.
At institutional level a special thank goes to Prof. Pietro G. Guzzo, Dott. Antonio D'Ambrosio, Dott.ssa Anna Maria Sodo (Soprintendenza Speciale per i Beni Archeologici di Napoli e Pompei) and Dott.ssa Donatella Caporusso (Director of Archaeological Museum of Milan).
At scientific level the authors wants to acknowledge the important role of Prof. Maurizio Boriani (Director of DPA Department, Politecnico di Milano), Prof. Fabio Remondino, Alessandro Rizzi, Dott. Fabio Menna (3DOM- Bruno Kessler Foundation, Trento), Dott.sa Francesca Voltolini (Trento), Dott.ssa Laura Micoli, Dott.ssa Giorgia Morlando, Dott. Sebastiano Ercoli (INDACO Department, Politecnico di Milano) for actually contributing to the final result.
Finally the authors thanks Prof. Paolo Russo (Director of Topography and Photogrammetry Lab, University of Ferrara), Dott. Federico Uccelli and Dott. Sergio Padovani (Leica Geosystem) for their contribution with important survey instruments.

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