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13. Virtual reconstruction of the Borġ in-Nadur megalithic temple

Filippo Stanco – University of Catania, Italy
fstanco@dmi.unict.it

Davide Tanasi – Arcadia University,
The College of Global Studies, MCAS, Italy
TanasiD@arcadia.edu

Dalma Cultrera – University of Catania, Italy
dalmacultrera@hotmail.it

Abstract. In the past decade, Computer Graphics have become strategic for the development of projects aimed at the interpretation of archaeological evidence and the dissemination of scientific results to the public. Among all the solutions available, the use of 3D models is particularly relevant for the reconstruction of poorly preserved sites and monuments destroyed by natural causes or human action. These digital replicas are, at the same time, a virtual environment that can be used as a tool for the interpretative hypotheses of archaeologists and an effective medium for a visual description of the cultural heritage as it is crosses linguistic barriers. In this paper, the methodology, aims and outcomes of a virtual reconstruction of the Borġ in-Nadur megalithic temple, carried out by Archeomatica Project of the University of Catania, are offered as a case study for a Virtual Archaeology of prehistoric Malta.

Keywords: 3D modeling, virtual archaeology, virtual heritage, Archeomatica Project.

13.1. Virtual archaeology: the future of the past

In the last fifty years, the growing use of computer applications has become a main feature of archaeological research[1]. Since the 1990s when computer science was oriented towards the creation of tools and solutions for the archive and management of quantitative data, to the development of virtual models and to the dissemination of knowledge, computer applications came to embrace a true theoretical approach to the problems of archaeology. Indeed, they are now able to direct interpretative models and affect the language and contents of the study of the past[2].

Nowadays, among all the branches of computer science, Computer Graphics is in general the more effective tool for dealing with cultural contents[3]. Their importance lie in the four main steps of the archaeological process: fieldwork, recording, interpreting, dissemination of results. If during an excavation their application is restricted to the use of laser scanners and 3D GIS, where archaeologists can be considered as mere 'users' of technologies made available by the research efforts of computer scientists, in the moment of decoding ancient data and in the subsequent phase of encoding and simplifying them, research strategies and goals of archaeology and computer science coincide[4]. In this perspective, the digital solution would appear to be the most successful strategy for passing on our shared heritage to future generations.

Heritage is considered to encompass more than the archaeological retrieval of past material evidence. It also includes tradition, artistic expression and cultural evidence. UNESCO defines heritage as 'our legacy from the past, what we live with today, and what we pass on to future generations'[5]. In both definitions, the concept is not restricted to human-made artefacts, but includes natural landscape sites and abstract cultural manifestations.

The term Virtual Heritage is similar to that of 'virtual archaeology' intended as 'digital reconstructive archaeology applied

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[1] Zubrow 2006.
[2] Vannini 2000.
[3] Stanco and Tanasi 2011a.
[4] Daly and Evans 2006.
[5] UNESCO World Heritage Centre: http://whc.unesco.org

to the reconstruction of three-dimensional archaeological ecosystems'[6]. But independently of the term's meaning the common ground for research seems to be to approach Virtual Archaeology (henceforth, VA) as a means of producing tools that aid understanding.

The birth of VA was not simply caused by the proliferation of 3D modeling techniques in many fields of knowledge, but as a necessity to archive an overgrowing amount of data and to create the best medium to communicate those data with a visual language. From this point of view, the application of 3D reconstructions, obtained using different techniques, became the core area of study in VA, particularly for its potential of facilitating the sort of cognitive interaction offered by a 3D model[7]. In this way, virtuality turns into a communication method more effectively if applied to particular fields, especially archaeological sites which are well preserved but are not accessible or sites which are not preserved but known through traditional documentation[8].

The process of creating images for the visualisation of historical buildings is not exclusive to the digital age. Recent computer-generated imagery represents a modern version of previous hand-drawn reconstructions, and likewise old image production techniques aim at producing visual outputs from the acquired or generated three-dimensional information. Heritage virtual models disseminated through the Internet and numerous websites provide a vast number of examples with diverse objectives and presentation technologies.

Directly linked to technological resources, virtual heritage has benefited from the recent fast growing stream of digital advancements originating from academic, government and industry laboratories[9]. Historically, virtual reconstruction projects basically targeted three separate groups: the conservator, who expected to encounter relevant documentation, the historian who sought interpretation, and the general public, which required visual realism[10]. Each user category holds its set of demands, expecting

[6] Ryan 2001: 245.
[7] Stanco and Tanasi 2011a.
[8] Cultraro *et al*. 2009; Stojakovic and Tepavcevica 2009.
[9] Addison 2000.
[10] Addison 2000.

diverse and specific results that determine the degree of success of a reconstruction project. Equally, virtual heritage contributes in different ways to each group.

The historical reliability of the 3D models produced by the growing number of virtual reconstructions constitutes a major concern expressed by several researchers worldwide. The necessity to recognise whether an image portrays a scientifically based version of a historical building or artefact comprises a fundamental question affecting all virtual heritage projects.

Furthermore, one largely neglected potential of 'virtuality' centered on evidence coming from the past is that it can offer a valuable experimental environment in which to test the reliability of one's assumptions. From this point of view, 3D computer graphics came to be considered on the same level as archeology itself, as a digital version of archaeology by experiment[11], characterised by the study of the 'practice supporting the theory'[12]. It aims to replicate experiments involving site formation process, test methodological assumptions by applying them to known contexts. In the same way similar research can be conducted virtually, interacting with a 3D model replicating reality[13]. In this sense of a cognitive tool, the use of 3D models in archaeological research can be intended as a sort of benchmark of what the perceptual senses and the mind perceived in the first instance: a sort of 'seeing causes believing' opposed to a simple and sometimes misleading 'seeing is believing' which is often altered by the cultural biases of the archaeologists[14]. So digital technology is not only used to provide tools of discovery and communication but mostly interactive feedbacks[15].

13.2. From field to screen: archaeological 3D modeling

Against this background, in 2007 an interdisciplinary research programme of VA, named Archeomatica Project, was begun by the Image Processing Laboratory of the University of Catania[16]. It is

[11] Longo 2003; Bellintani and Moser 2003; Thomas 2009.
[12] Coles 1981.
[13] Moser *et al*. 2009.
[14] Dennett 1996.
[15] Frischer 2009.
[16] www.archeomatica.unict.it

aimed to create new tools for archaeological research within the field of 2D digital imaging and 3D graphics, in particular to: (1) produce automatic systems of recognition and classification of graphic data; (2) to develop virtual models of archaeological sites and items with a high degree of accuracy following the data obtained during excavation and study, through the use of laser scanner and 3D modeling techniques[17].

The essence of this project is a cognitive process based on a peer-to-peer exchange of knowledge between experts of computer science and archaeology working side by side. The Archeomatica Project, which represents through its scientific results one of the most recent trends in VA and in the modern policies in the conservation of archaeological heritage, is also aimed at defining a common multidisciplinary language to improve the quality of the message of this new discipline to the outside world.

Several achievements were obtained by the Archeomatica Project through archaeological 3D modeling, namely the recreation of landscapes, architecture, and objects by digital means based upon the current state of the salvaged monuments integrated with the data coming from historical and archaeological research using software for developing 3D models[18]. 3D modeling is probably the most popular computer-based technique applied to cultural heritage as it represents the core of the 'serious games' used in many multimedia projects[19]. The archaeological 3D modeling is not just a simple cognitive tool used to reproduce virtual aspects of the past, like objects of everyday life[20], but to improve knowledge and aid or facilitate comprehension. It is also, above all, a method of recording all the archaeological data in a much more complete way than traditional photography and drawing; besides, it is also a tool aiding interpretation for researchers involved in the theoretical reconstruction of the past itself. From this point of view, it is a kind of virtual benchmark of the archaeologists' theories where the hypothesis is tested and corrected in order to produce a truthful

[17] Sangregorio *et al*. 2004; Stanco and Tanasi 2008; Gallo *et al*. 2011; Stanco and Tanasi 2011a.
[18] Margounakis 2008.
[19] Anderson *et al*. 2009.
[20] Salvadori 2009.

image of something buried by time; a kind of 'solid modeling to illustrate the monument' becoming 'solid modeling to analyse the monument'[21].

A useful field for the application of this technique is prehistory, for which the scarcity of iconographic sources and the generally poor state of conservation of the finds, makes extremely complex both the process of decoding the information and of transmitting knowledge to the public[22]. And it is also extremely suitable for the virtual reconstruction of vanished heritage due to the growing capacities of digital media to replicate and interpret lost or inaccessible cultural heritage sites. The best example of this kind of digital research is represented by the reconstruction of the Bamiyan buddhas in Afghanistan (destroyed by the Taliban in 2001)[23], of the Iranian Arg-e Bam citadel (devastated by an earthquake in 2003)[24], and of the Archaeological Museum of Baghdad (looted in 2003 in the wake of the turmoil of the Second Gulf War) [25].

13.3. Computer graphics and Maltese prehistory

The research carried out between 1987 and 1994 by the Anglo-Maltese team working at the Brochtorff Circle at Xagħra (Gozo)[26] resulted in seminal contributions for the virtual reconstruction of some features of Maltese prehistoric sites. These include the study of inter-visibility and of the influence of light sources on ritual practices, the interaction between the participating audience and the space defined by the architecture of the temples, alternative virtual reconstructions of ritual furniture and liturgical artefacts, reconstruction of no longer existing structures represented in later graphic and photographic documentation; these are just a few examples of those achievements[27].

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21 Reilly 1992: 99.
22 Hodder and Doughty 2007.
23 Gruen *et al*. 2004; Gruen and Hanusch 2008.
24 Reza Matini and Ono 2010.
25 Cultraro *et al*. 2009.
26 Malone *et al*. 2009.
27 Chalmers *et al*. 1995; Belcher *et al.* 1996; Chalmers and Stoddart 1996; Chalmers *et al*. 1996; Lim *et al*. 1996; Stoddart and Chalmers 1996.

Of particular importance is the work of Chalmers and Debattista[28] in which for the first time guidelines for the virtual reconstruction in 3D modeling of Maltese megalithic architecture (both built and rock-cut) are provided. Relevant was also the effort to apply methodologies from computer games, like narrative and environment interactivity, for enhancing the on-site evaluation of visible and invisible features of Mnjadra temple, carried out by an Australian researcher[29].

In 2006 some major projects were carried out by Heritage Malta as part of its long-term objective of creating a visual portfolio of all its sites as tools for better heritage management and monitoring[30]. Among its major achievements is the completion of the 3D models of the temple sites of Ħaġar Qim and Mnajdra, which formed part of the groundwork for a much larger project which aimed to build shelters to protect the temples from natural and human induced causes of deterioration. At the same time, Heritage Malta commenced preparations for the 3D modeling, using laser scanning technology, of three other sites, namely Ta' Ħaġrat, Skorba, as well as the interior of the Hypogeum. In a project promoted and implemented jointly by the Department of Archaeology of the University of Cambridge (UK) and the National Museum of Archaeology (Heritage Malta), funded by the Templeton Foundation, emphasis was placed on the digitisation of archaeological artefacts and sites related to Maltese prehistoric figurative art.

13.4. The virtual model of the Borġ in-Nadur temple

In the summer of 2010, an interdisciplinary team from the Archeomatica Project was actively involved in a research plan drawn up by Arcadia University of Philadelphia to understand the temple of Borġ in-Nadur in Malta, in collaboration with the University of Malta and Heritage Malta (the Maltese national agency responsible for the management of museums and

[28] Chalmers and Debattista 2005.
[29] Flynn 2000; Flynn 2004; Flynn 2005.
[30] Mallia 2007.

archaeological sites). The temple in question goes back to the end of the fourth millennium BC but was reoccupied and reused from the beginning of the third millennium right down to the Phoenician settlement of the island in the course of the eighth century BC.

About 20 megalithic sites are known in Malta and Gozo and together they probably represent the most relevant tourist attraction of the archipelago and, indirectly, the backbone of its economy. However, the temple of Borġ in-Nadur is less well known than the rest, even though it started off as a major attraction for Grand tourists and travellers in the Early Modern and Colonial periods[31]. It was explored in the second half of the 1920s by a team of British archaeologists. The excavations uncovered a monumental sacred complex, characterised by a singular plan including a megalithic enclosure with different cult places. A large number of finds were unearthed, demonstrating the wealth of the community using the site. At that time, the conditions of the temple building were rather good. Orthostats and megaliths were still standing, paving slabs and cultic stone objects located on them were preserved in situ and a good part of the original plan of the sanctuary area could be clearly made out. The preliminary reports of the explorations, published promptly in 1923, 1925 and 1929, were accompanied by a thorough drawn and photographic documentation of the main structures and included accurate measurements of nearly all megaliths (Fig. 13.1).

In the past 80 years, for different reasons this site was forgotten and generally neglected with the result that the current conditions of the entire archaeological area are unfortunately rather poor[32] (Fig. 13.2). As a consequence, Borġ in-Nadur has not been included in any tourist itinerary and the site is currently only open to the public by appointment.

For these reasons, the attempt to develop a virtual archaeology project around the site seems timely especially to clarify some features of the temple which now appear to be lost and to offer a new tool for promoting the site. In this context, the work done to date in the field of computer graphics and digital imaging on

[31] See Bugeja, this volume (chapter 2).
[32] See Grima, this volume (chapter 11).

Maltese prehistoric sites provided useful information for planning the Borġ in-Nadur reconstruction.

In the case of the megalithic temple, the starting point for this archaeological 3D model work (Fig. 13.3) was the collection of all the graphic and photographic documentation available for this monument, consisting mostly of publications from the 1920s, and carrying out a site survey to evaluate what has been lost or is covered. In addition, extruded multilayered plans containing information about orography, provided by the Malta Environment and Planning Authority[33] with superimposed high resolution aerial photographs of the Marsaxlokk Bay area, taken at an altitude of 2000 m, were elaborated in order to develop a Digital Elevation Model (DEM)[34] to be used as a 'visualscape'[35] for the location of the model. The temple has been rebuilt using the measurements provided in Murray's reports, while all the other structures were reconstructed using dimensions recorded on site or through comparisons with other temple sites.

The work tool used is Blender[36], an open source cross-platform software for modeling, rendering, animation, post-production, creation, and playback of interactive 3D contents. It is extremely versatile, functional, and constantly open to implementations based on the research of its application in various fields, including archaeology[37].

The 3D model was not intended to reconstruct in elevation the missing parts of the temple but was aimed at rediscovering digitally what was found by the archaeologists nearly 80 years ago. Therefore, the model of the temple and of the surrounding territory became a useful virtual environment for carrying out tests of inter-visibility between the temple and another two adjacent sites occupied in the same period, namely the Borġ in-Nadur village and the Għar Dalam cave. Furthermore, the visibility of the temple's ruins from the sea and from the Roman Villa of Ta' Kaċċatura was checked in order to validate the visual importance of the site in later times. In order to add realism to the digital replica, a study of light sources was

[33] www.mepa.org.mt
[34] Maune 2007.
[35] Llobera 2003.
[36] www.blender.org
[37] Stanco and Tanasi 2011b.

carried out, simulating a complete cycle of the sun on mid-summer day through the use of the Radiance raytracer[38]. The final outcome of the processing and post-processing phases is a 10-minute video, in which the virtually rebuilt megalithic temple of Borġ in-Nadur is shown in its landscape accompanied by music composed for the project by the Maltese musician Renzo Spiteri[39].

The last phase of the exercise includes also the development of an interactive 3D model of the temple in the conditions in which it was in the 1920s. An advantage of interactive visualisation is to insert users in the loop. Conversely to passive media such as computer animation, it is now the users that drive the navigation and the inspection of the digital artefact. An interactive system allows users to follow their specific interest while choosing the exploration path, focusing on the details that hit personal interest and giving the possibility to choose the duration of the visualisation session on the basis of the specific insight experience and needs[40].

For making lighter the rendering process without losing quality and limiting interactivity, a system with 17 static stations of observations was developed for the interactive 3D model. In Blender environment, 17 stations with wide-angle cameras, located in specific positions inside the temple area, pointing front, left, right, up, back, and down rendered the scene into 90° views. These views were then smoothly stitched into required fish-eye projections by the panorama stitcher Hugin[41]. From the projections, proper textures were extracted for creating 17 spheres, one for each station, inside which the camera of the Blender Game Engine was located. The passage from one station/sphere to another is through simple links, causing the sensation of walking inside the temple, following the available paths.

The navigation interface includes an interactive map of the temple, indicating the current position of the human-sized avatar moving inside the ruins[42], as in the popoular Virtual Museum of the Ancient via Flaminia.

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38 http://radsite.lbl.gov/radiance
39 www.renzospiteri.com
40 Dellepiane *et al*. 2011.
41 http://hugin.sourceforge.net
42 www.vhlab.itabc.cnr.it/flaminia

13.4. Final observations

In conclusion, the life history of the Borġ in-Nadur temple demonstrates that the archaeological heritage is under constant threat and danger: danger to be vandalised or, even worse forgotten.[43] Architectural structures and cultural and natural sites are exposed to pollution, tourists, and wars, as well as environmental disasters such as earthquakes, floods, or climatic changes. Hidden aspects of our cultural heritage are also affected by agriculture, changes in agricultural regimes due to economic progress, mining, gravel extraction, construction of infrastructure, and the expansion of industrial areas. 3D modeling could be extremely useful for the identification, monitoring, conservation, restoration, and promotion of archaeological sites. 3D computer graphics can support archaeology and the politics of cultural heritage by offering scholars a 'sixth sense' for understanding remains from the past, as it allow us to experience it[44]. 3D documentation of still extant archaeological remains or building elements is an important part of collecting the necessary sources for a virtual archaeology project. New developments permit this documentation phase to be accomplished, using tools available for free to obtain correct measurements and ground plans from photographic representations. This is important when preserving archaeological remains, when older phases are reconstructed in a virtual way. The original state, the restored state, and eventual in-between states can be recorded easily through photo modeling techniques[45]. Furthermore, the recent application of 3D computer graphics has proved crucial in planning strategies of conservation and restoration issues concerning monuments that are part of world cultural heritage, on which there is still an open debate, as in case of the restoration of the Parthenon on the Acropolis of Athens[46].

[43] In actual fact, round the clock security is provided at the site. See Grima, this volume (chapter 11).
[44] Moser 2005.
[45] Pletinckx 2009.
[46] Toganidis 2007.

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References

Addison, A. C. [2000] "Emerging Trends in Virtual Heritage", in *IEEE Multimedia* 7/2: 22-25.

Anderson, E. F., McLoughlin, L., Liarokapis, F., Peters, C., Petridis, P., and de Freitas, S. [2009] "Serious Games in Cultural Heritage," in M. Ashley, F. Liarokapis (eds), *State of Arts and Reports*, Proceedings of the 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST), (St Julians, Malta, 22-25 September 2009), pp. 29-48. Eurographics Association, Aire-la-Ville.

Belcher M., Chalmers, A., Harrison, A., and Stoddart, S. K. F. [1996] "Teaching the visualisation of landscapes", in H. Kamermans and K. Fennema (eds), *CAA 95. Interfacing the past, Proceedings of Computer Applications and Quantitative Methods in Archaeology* (Analecta Praehistorica Leidensia I), pp. 483-487. University of Leiden, Leiden.

Bellintani, P. and Moser, L. (eds) [2003], *Archeologie Sperimentali. Metodologie ed Esperienze fra Verifica, Riproduzione, Comunicazione e Simulazione*, Atti del Convegno (Comano Terme – Fiavè, 13 - 15 settembre 2001). Provincia autonoma di Trento, Trento.

Chalmers, A. and Debattista, K. [2005] "Investigating the Structural Validity of Virtual Reconstructions of Prehistoric Maltese Temples", in M. Mudge, N. Ryan and R. Scopigno (eds), *Proceedings of the 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)*, pp. 1-6. Eurographics Association, Aire-la-Ville.

Chalmers, A. and Stoddart, S. K. F. [1996] "Photorealistic graphics for visualising archaeological site reconstructions", in A. Higgins, P. Main and J. Lang (eds), *Imaging the Past. Electronic imaging and computer graphics in Museums and Archaeology* (British Museum occasional Paper 114), pp. 85-93. British Museum, London.

Chalmers, A., Stoddart, S. K. F., Lamprell, A., Salisbury, A. [1996] "An integrated information system for archaeological evidence", in H. Kamermans and K. Fennema (eds), *CAA 95. Interfacing the past, Proceedings of Computer Applications and Quantitative Methods in Archaeology* (Analecta Praehistorica Leidensia I), pp. 37-41. University of Leiden, Leiden.

Chalmers A., Stoddart S.K.F., Tidmus J., Miles R. [1995] "INSITE: An Interactive Visualisation System for Archaeological Sites", in J. Huggett, N. Ryan (eds), *Computer applications and Quantitative methods in archaeology 1994* (BAR International Series 600), pp. 225-228. Tempus Reparatum, Oxford.

Coles J. [1981] *Archeologia sperimentale*. Longanesi, Milano.

Cultraro, M. Gabellone F., Scardozzi G. [2009] "The Virtual Musealization of Archaeological Sites: Between Documentation and Comunication," in F. Remondino, S. El-Hakim, L. Gonzo (eds), *3D Virtual Reconstruction and Visualization of Complex Architectures*, Proceedings of the 3rd ISPRS International Workshop" (3D-ARCH 2009), (Trento, 25-28 February 2009), *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* XXXVIII-5/W1: 1-6.

Daly, P., Evans T. L. [2006] "Archaeological Theory and Digital Pasts", in T. L. Evans and P. Daly (eds), *Digital Archaeology. Bridging Method and Theory*, Routledge, London.

Dellepiane M., Callieri M., Corsini M., Scopigno R. [2011], "Using Digital 3D Models for Study and Restoration of Cultural Heritage Artifacts", in S. Battiato, G. Gallo and F. Stanco (eds), *Digital Imaging for Cultural Heritage*, pp. 39-70. CRC Press, New York.

Dennett D. C. [1996] "Seeing is believing", in K. Akins (ed.), *Perception. Vancouver Studies in Cognitive Science. Vol. 5,* pp. 158–172. Oxford University Press, Oxford.

Flynn B. [2000] "A Maltese temple as game space", in H. Thwaites (ed.), *VSMM 2000 Proceedings of the 6th International conference on Virtual systems and multimedia*, pp. 50-56. International Society of Virtual Systems and Multimedia, Ohmsha.

Flynn, B. [2004] "Games as inhabited spaces", in *Media Studies and Computer Games* 110 (Special issue of Media International Australia incorporating Culture and Policy): 52-61.

Flynn, B. [2005] "Exploration of Maltese Prehistoric Temples through the application of Multimedia Technologies", in *Mediterranean Archaeology and Archaeometry* 5/2: 23-34.

Frischer, B. [2009] "Art and Science in the Age of Digital Reproduction: From Mimetic Representation to Interactive Virtual Reality", in *Arqueologica 2.0*, Proceedings of 1st International Meeting on Graphic Archaeology and Informatics, Cultural Heritage and Innovation, (Seville 17-20 June 2009), pp. 35-48. SEAV, Seville.

Gallo, G., La Rosa, V., Stanco, F. and Tanasi D. (eds) [2011] *Radamante al computer. Archeologia e informatica nel mondo minoico: l'esperienza catanese*, Atti delle giornate di studio, Catania 11 e 28 novembre 2008. Regione Sicilia, Caltanissetta.

Gruen, A. and Hanusch, T. [2008], "Image- and model-based reconstruction of the small Buddha of Bamiyan, Afghanistan, in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVII, B5*: 1-6.

Gruen, A., Remondino, F. and Zhang, L. [2004] "Photogrammetric reconstruction of the great Buddha of Bamiyan, Afghanistan, in *The Photogrammetric Record* 19/107: 177–199.

Hodder, I. and Doughty, L. (eds) [2007] *Mediterranean Prehistoric Heritage: Training, Education and Management*. McDonald Institute of Archaeology, Cambridge.

Lim, E., Stoddart, S.K.F., Harrison, A. and Chalmers, A. [1996] "Recent examples of geographical analysis of archaeological evidence from central Italy", in H. Kamermans and K. Fennema (eds), *CAA 95. Interfacing the past, Proceedings of Computer Applications and Quantitative Methods in Archaeology* (*Analecta Praehistorica Leidensia* I), pp. 331–336. University of Leiden, Leiden.

Llobera, M. [2003] "Extending GIS based analysis: the concept of visualscape", in *International Journal of Geographic Information Sciences* 1: 1-25.

Longo, L. [2003] "Archeologia Sperimentale, Esperimenti in Archeologia, Divulgazione. Osservazioni su Significato e Ruolo dell'Archeologia Sperimentale", in *Rivista di Scienze Preistoriche* 53: 549- 568.

Mallia, J. [2008] "Bridging the gap: the Megalithic Temples in the 21st century", in M. E. Zammit and J. Mallia (eds), *Ta' Ħaġrat and Skorba, Ancient Monuments in a Modern World*, pp. 119-130. Midsea Books, Malta.

Malone, C., Stoddart, S., Bonanno, A. and Trump, D. (eds) [2009], *Mortuary Customs in Prehistoric Malta: Excavations at the Brochtorff Circle at Xagħra (1987-94)*. McDonald Institute of Archaeology, Cambridge.

Margounakis, D. [2008], "Virtual Reconstructions in Archaeology", in D. Politis (ed.), *E-Learning Methodologies and Computer Applications in Archaeology*, pp. 146-156. Information Science Reference, Hershey.

Maune, D. F. [2007] *Digital Elevation Model Technologies and Applications: the DEM users manual.* American Society for Photogrammetry and Remote Sensing, Bethesda.

Moser, M., Hye, S., Goldenberg, G., Hanke, K. and Kovacs, K. [2009] "Digital Documentation and Visualization of Archaeological Excavations and Finds Using 3D Scanning Technology", in *Arqueologica 2.0*, Proceedings of 1st International Meeting on Graphic Archaeology and Informatics, Cultural Heritage and Innovation, (Seville 17-20 June 2009), pp. 351-355. SEAV, Seville.

Moser, S. [2005] "Archaeological Representation. The virtual Conventions for Constructing Knowledge about the Past", in I. Hodder (ed.), *Archaeological Theory Today*, pp. 262-283. Polity Press, Malden.

Pletinckx, D. [2009] "Virtual Archaeology as an Integrated Preservation Method" in *Arqueologica 2.0*, Proceedings of 1st International Meeting on Graphic Archaeology and Informatics, Cultural Heritage and Innovation, (Seville 17-20 June 2009), pp. 51-55. SEAV, Seville.

Reilly, P. [1992] “Three Dimensional Modeling and Primary Archaeological Data”, in P. Reilly and S. Rahtz (eds), *Archaeology and the Information Age: A Global Perspective*, pp. 97-122. Routledge, London.

Reza Matini, M. and Ono, K. [2010] “Accuracy Verification of Manual 3D CG Reconstruction: Case Study of Destroyed Architectural Heritage, Bam Citadel, in M. Ioannides (ed.), *EuroMed 2010*, pp. 432-440. Springer-Verlag Berlin, Heidelberg.

Ryan, N. [2001] “Documenting and validating Virtual Archaeology”, in *Archeologia e Calcolatori* 12: 245-273.

Salvadori, F. [2009] “Modellazione dei Reperti” in V. Fronza, A. Cardini and M. Valenti (eds), *Informatica e Archeologia Medievale. L’esperienza senese*, pp. 131-147. All’Insegna del Giglio, Firenze.

Sangregorio, E., Stanco, F. and Tanasi, D. [2008] “The Archeomatica Project: Towards a new application of computer graphics in Archaeology”, V. Scarano, R. De Chiara, U. Erra (eds), *Proceedings of 6th Eurographics Italian Chapter Conference (EG_It)* (Fisciano 2-4 luglio 2008), pp. 1-4. Eurographics Association, Aire-la-Ville.

Stanco, F. and Tanasi, D. [2008] “La computergrafica nella ricerca archeologica. Dal 3D Modeling alla Digital Archaeology”, in A. Gueli (ed.), *Scienza e Beni Culturali*, Atti del V Congresso Nazionale di Archeometria, (Siracusa 26-29 Febbraio 2008), pp. 605-617. Morrone, Siracusa.

Stanco, F. and Tanasi D. [2011a], “Experiencing the Past: Computer Graphics in Archaeology”, in S. Battiato, G. Gallo and F. Stanco (eds), *Digital Imaging for Cultural Heritage*, pp. 1-37. CRC Press, New York.

Stanco, F., Tanasi, D. and Gallo, G. [2011b] “Free to rebuild. Software open source per la ricostruzione virtuale delle architetture minoiche di Haghia Triada (Creta)”, in *Archeofoss 2010*, Atti del V Workshop Open Source, Free Software e Open Format nei processi di ricerca archeologica, (Foggia 6-7 maggio 2010).

Stoddart, S. K. F. and Chalmers, A. [1996] “La validità scientifica della ricostruzione virtual reality: Esempi da Sud Africa e Malta”, in G. Bermond Montari (ed.), *Prehistoric Research in the Context of Contemporary Society. Colloquium XXXVII Prehistoric research in current society in relation to the economic development and evaluation of sites,* XIII Congress of the UISPP, (Forlì, 8-14 September 1996), pp. 109-117. Abaco, Forlì.

Stojakovic, V. and Tepavcevica, B. [2009] “Optimal Methods for 3D Modeling of Devastated Architectural Objects,” in F. Remondino, S. El-Hakim and L. Gonzo (eds), *3D Virtual Reconstruction and Visualization of Complex Architectures*, Proceedings of the 3rd ISPRS International Workshop” (3D-ARCH 2009), (Trento, 25-28 February 2009), *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* XXXVIII-5/W1: 1-6.

Thomas, G. [2009] *Experimental Archaeology*. Routledge, London.

Toganidis, N. [2007] "Parthenon Restoration Project", in A. Georgopoulos and N. Agriantonis (eds), *Anticipating the Future of the Cultural Past*, Proceedings of the XXI International CIPA Symposium, pp. 1-6. ICOMOS, Athens.

Vannini, G. [2000] "Informatica per l'Archeologia o Archeologia per l'Informatica?", in *Archeologia e Calcolatori* 11, 311-315.

Zubrow, E. B. W. [2006] "Digital Archaeology. A Historical Context", in T. L. Evans and P. Daly (eds), *Digital Archaeology. Bridging Method and Theory,* pp. 3-9. Routledge, London.

Filippo Stanco PhD is Assistant Professor with the Department of Mathematics and Computer Science, University of Catania. He is co-director of the Archeomatica Project (IPLab, University of Catania) aimed to develop new digital tools for archaeological research and the preservation of cultural heritage. He has been an organiser and associate editor of several conferences and symposia and peer reviewer for several international journals.

Davide Tanasi PhD is Adjunct Professor of Archaeology and Ancient History at Arcadia University – The College of Global Studies. He has authored several publications about Mediterranean prehistory including *La necropoli protostorica di Montagna di Caltagirone* (Polimetrica, 2008) and *La Sicilia e l'arcipelago maltese nell'età del Bronzo Medio* (Officina di Studi Medievali, 2008). He is co-director of the Archeomatica Project (IPLab, University of Catania) aimed to develop new digital tools for archaeological research and the preservation of cultural heritage.

Dalma Cultrera graduated with a MA degree in Archaeology in 2007 and is currently attending the School of Archaeology at the University of Catania. Her research involves the study of pottery of Bronze and Iron Age Sicily, archaeospeleology and digital archaeology. She participates actively in several research projects with the Superintendence of Catania and the Archaeological Museum of Siracusa.

Figure 13.1. The temple at the time of Murray's excavations: (1) General view from the North-East (1923); (2) Great Upright from the South-East (1923); (3) Great entrance, showing megalith built into wall (1925); (4) North-West Apse (1925); (5) Large biconical pillar (1923); (6) Mortar in situ (1925); (7) Niche showing the three standing stones (1923).

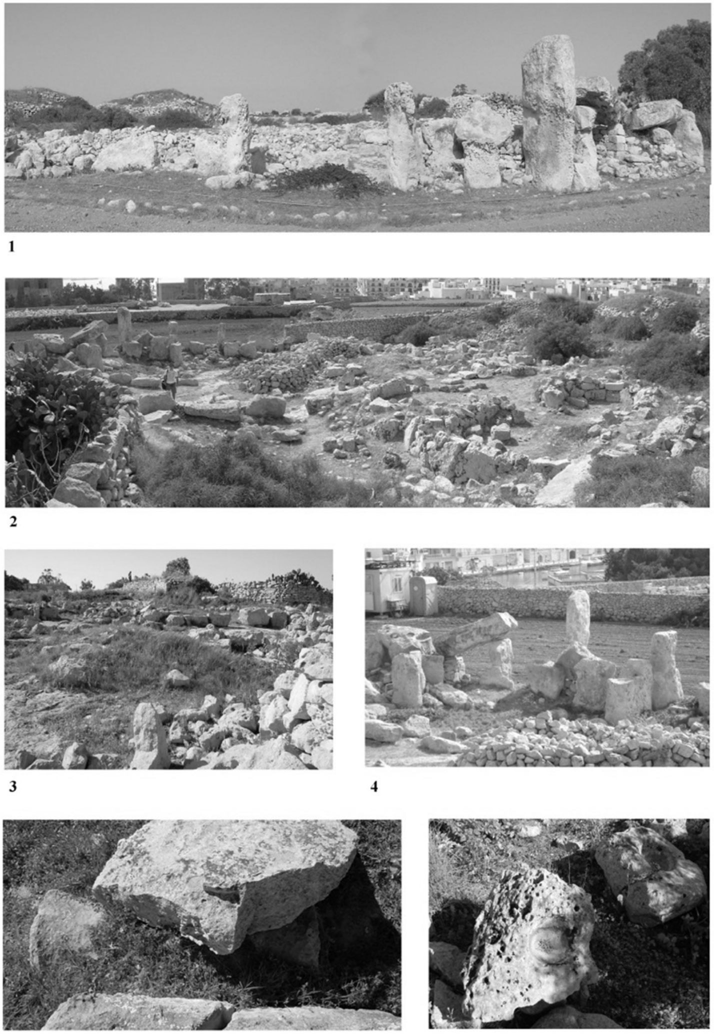

Figure 13.2. Current conditions of the temple: (1) Main entrance to the Forecourt, from the East; (2) Overview of the Forecourt and the Apsidal Building, from the West; (3) Southern Forecourt and Apsidal Building, from the North; (4) Dolmen and Great Upright from West; (5) Large biconical pillar, now half buried; (6) Grinders grouped together in the southern Forecourt.

Figure 13.3. (1) Digital Elevation Model (DEM); (2) DEM with a superimposed aerial photograph; (3) 3D model of the temple, aerial view; (4) Entrance to Apsidal Building; (5) Main entrance to the Forecourt; (6) Detail of the pierced megalith on the northern outer wall of the Forecourt; (7) Detail of the texture used to represent the limestone.