CAA
2017

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http://dx.doi.org/10.15496/publikation-43142

Digital Documentation of Masada Fortress in Israel: Integrated Methodologies of Survey and Representation

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Abstract

The general aim of the MRP - Masada Research Project is to create a comprehensive digital documentation of the archaeological site of Masada. Integrated 3D digital survey methodologies allowed the acquisition of all the information necessary for the creation of a digital database. This paper describes some results about the interaction between complex sets of data, acquired with various tools, and its dissemination through contemporary representation systems. The research conducted explains how the "migration" of reality in a virtual environment depends strongly on the structure of an efficient workflow and the proper use of available technologies. Digital tools allow the creation of customized and open-ended knowledge systems through which users can interface with the elements of the space around them interactively and be/become more conscious about the archaeological heritage.

Keywords: virtual heritage, digital survey, 3D laser scanning, structure from motion, Masada

Introduction

This research project is about the digital documentation of the Masada archeological site, which was conducted in accordance with the heritage sites management rules of UNESCO and with the agreement of Israel Nature and Parks Authority (NPA). The research took place during four years of international missions in which professors and researchers from the Italian Universities of Florence and Pavia participated, in collaboration with the Schenkar college of Ramat Gan (Tel Aviv), and the results were made available to the NPA in the form of a digital document to support the development of the site's "management plan." The work represents the first complete digital documentation of the current state of the site and demonstrates the possibility of using advanced digital technologies in conditions of extreme environmental difficulty, as the orographic and morphological nature of the site present terrain unevenness of over 300 m and inaccessible mountains sides. Thus, the use of Laser Scanners with 300 m range and SfM terrestrial photogrammetry methods have permitted the realization of the photogrammetric survey of the inaccessible slopes (obviously with less detail than the plateau of the site). Today there are no complete 2d drawings of the entire site of Masada, but only some planimetries realized through topographic survey, and therefore not detailed.

Each participating University developed research guidelines, specifically, the University of Florence team created interactive multimedia resoureces to help promote tourism at the archaeological park. The highly reliable 3D digital models made by the working group also serve to virtually preserve the site, which is in clear and indisputable danger from environmental and anthropogenic factors. Finally, the paper outlines case studies that show the possibility and/or opportunity of specific in-depth analyses regarding the architectural structures of the site and decorative details, such as the floor mosaics.

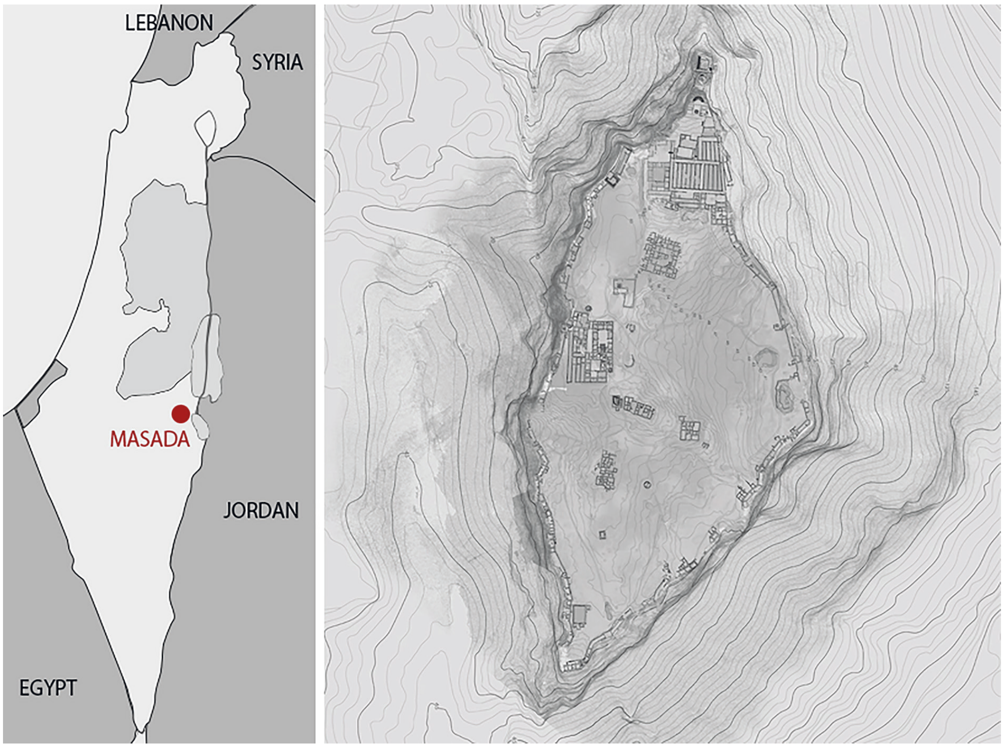

Figure 1. Location map of Masada and general plan.

Background: Virtual Reality and Visualization Tools

The documentary corpus acquired during a survey campaign is crucial for the knowledge and understanding of a site. In the archaeological field, traditional 2D documentation is useful for recording excavation documentation, status of sites, and activities. 2D plans are supplemented by 2D drawings of elevations for the documentation of masonry technologies, architectural types, and stratigraphic analysis.

3D models, on the other hand, are more suitable tools for remotely assessing the preservation conditions of the site, understanding architectural typologies, virtual tours, and virtual reconstructions. The construction of 3D models offers the opportunity to generate highly immersive "virtual words" where it is possible to reach a high level of realism. The experience of navigating and discovering virtual worlds is now available to everyone, and it is also possible to easily build virtual scenarios and interactive 3D models. VR (Virtual Reality) and AR (Augmented Reality) applications allow the creation of interaction and visualization systems that enable active and constructive participation by the end user. These dynamic worlds, easy to use and content-rich, are able to arouse emotions in those who use them and encourage them to increase their use. Virtual worlds have been created because people have exhausted geographic space. The virtual worlds are complementary, and do not serve as substitutes for the real world (Dodge and Kitchin 2001; see also Gerosa 2008).

For every different research field, diversified methodologies must be adopted, in fact "a computer-based visualization method should normally be used only when it is the most appropriate available method for that purpose," and "it should not be assumed that computer-based visualization is the most appropriate means of addressing all cultural heritage research or communication aims" (London Charter 2009:2.1; see also Brusaporci 2016). The 3D models that make up these "new worlds" often reach such complexity that they might fail to guarantee the quality of the interactions that the user would like, such as the rendering quality or the fluidity of the visualization. It is therefore necessary to carefully study the possible end-user applications in order to build low-poly 3D models (Guidi and Angheleddu 2016).[1]

1 "The article explains a re-coding method based on displaced subdivision surfaces that makes it possible to adapt the re-coded 3D representation to the metrological limitations of the 3D capturing technique used for generating the original mesh. The resulting re-coded model can be therefore considered as close to the physical object/scenario, as the original acquired mesh, with a

Figure 2. View of Masada plateau on the side of the Roman Ramp.

In this sense, we find the concept of multi-scaling 3D models useful. This is the ability to create 3D models at different scales, where general 3D models can contain detailed 3D models rich in specific and more detailed content. Thanks to AR applications, it is possible to overlay infinite layers of enriched content, continuously upgradable and implementable (Parrinello, Picchio & Bercigli 2016).

The Archaeological Site of Masada

The site of Masada, discovered in 1828 by Edward Robinson and Eli Smith, stands on a mountain that rises east of the Dead Sea in southeastern Judea, and is nowadays one of the most important archaeological UNESCO sites in Israel. The historian and archaeologist Adolf Schulten studied the Roman siege camps around the site in 1933, but the top of the fortress was dug only during the excavation activities that were carried out between 1963 and 1965 by the expedition under the supervision of the archaeologist Yigael Yadin (1968)[2]. In 1966, Masada and its territory become a protected area by the NPA and it was opened to the public. It became a UNESCO protected site in 2001, and today the complex is open to tourists and includes a Visitors' Centre, a cableway for the faster connection between the Centre and the main site area of the fortress on the plateau atop the mountain (Figure 1).

An important aspect of the actual management plan of the site is the decision to proceed without further research excavations on the main site "in the period of the current generation," limiting this type of activity only to the finalization of projects for preservation, maintenance, or restoration. According to the WHC Nomination Documentation (2001):

> [t]his is a site that remained untouched for more than thirteen centuries. The buildings and other evidence of human settlement gradually collapsed and were covered over until they were revealed in the 1960s. There have been no additions or reconstruction, beyond an acceptable level of anastylosis, and inappropriate materials used in early conservation projects are being replaced. Limited restoration works have been carried out to aid visitor interpretation with original archaeological levels being clearly defined by a prominent

great advantage in terms of 3D representation size, UV parametrization, topological coherence, and scalability".

2 The work concerning the stratigraphy and architecture of the buildings of the site, began in 1989, after the death of Yadin in 1984, and was finally published in 1991. The author was Ehud Netzer, who participated in the expedition and, at the end of the excavation campaigns, he was the architect responsible for the preservation and restoration of the site before it was opened to the public in 1966 (Netzer 1991).

Figure 3. Example of division of the Western Palace rooms and denomination with unique identification codes.

> black line set in the new mortar joints. Certain significant archaeological elements, such as the Roman camps and siegeworks, remain virtually untouched. The authenticity is therefore of a very high level.

The archaeological site of Masada is built on a rocky plateau standing between the elevations of 35 m and 60 m above sea level (about 450 m above the Dead Sea). The plateau is about 650 m long and 300 m wide overlooking the depression of the Dead Sea, and the morphology of the mountain gives it the appearance of a natural fortress (Figure 2). The most important phase of evolution of the site, from the perspective of quality and quantity of structures, dates to the reign of King Herod who oversaw the construction of a complex of well-structured and designed. Construction took place in several stages throughout his reign. Subsequently, with the outbreak of the Jewish revolt against the Romans in 66 CE, one thousand zealots conquered the fortress of Masada, and the great palaces of Herod suffered several changes. New rooms were created in the existing ones, in order to adapt them to everyday life. A few years later, after the destruction of the Temple of Jerusalem by Titus, Masada was the last bastion of resistance against the Romans until the siege that saw the construction of the Roman ramp and the defeat of the zealots (73 CE). For a long period, the site was uninhabited. Later, during the Byzantine period, a small monastic community settled on the plateau and built a church. There is no further documented information about the presence of other occupants and even for this the site was discovered only in the nineteenth century.

The Complexity of the Site and the Management of the Survey

The general aim of the Masada Research Project is to create the comprehensive digital documentation of the archaeological site. The site is subjected to various types of risks:

- Seismic risk (the site sits close to the Great Rift fault line).

- Hydraulic risk (the soil is very dry and occasional storms can create strong runoff events)

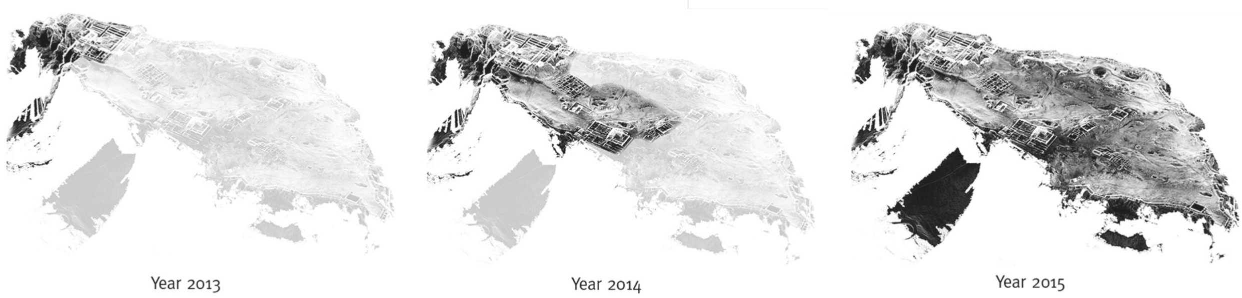

Figure 4. Progress of the digital database (point cloud) during the years of Research.

- Tourist pressure (the site endures 1.25 million visitors per year, mostly during the summer).
- Sun exposure (most of the site is exposed to direct sunlight and high temperatures).
- War / terrorism (the unstable political situation in the Middle East exposes the site to the threat of terrorist or war damage).

The Masada Research Project includes a series of survey campaigns organized over four years[3]. Data acquisition was accomplished by laser scanning and photogrammetry. The point cloud obtained by the laser scanner forms the raw data of the documentation database together with all the photos acquired. Furthermore, the team has processed the point cloud in order to extract data useful for 2D drawings (plans, sections, and elevations), 3D models, and multimedia content. 3D models can represent the site "as-is" but can also serve as the basis for a digital reconstruction that will be able to illustrate the state of knowledge about the site and the various transformations it underwent during the course of history. Among the aims of this project is the development of opportunities for cultural partnerships between Italian and Israeli academic institutions.

The technological progress in the field of archaeological survey, where the use of digital techniques is now strengthened (from the organization and acquisition of data to post-production), has a series of consequences, the most significant of which appear to be the increase in the amount of data and of acquired information. This consequence translates into the ability to develop new documentation and dissemination methodologies in order to obtain the best results from the digital potential. For system consistency, but also for convenience in terms of space and time costs, all these results must be organized in a tidy system, which needs to comply with the digital tools. The database, the website, and the interactive map are intended to be concrete examples of the ability to structure the complex data collected, to organize open systems for conserving and disclosing information, and above all, to contribute to the preservation of an archaeological site that is truly a part of the human heritage.

Integrated Methodologies of Survey

In order to build a complete digital documentation of the Masada site, many data were acquired during the various survey campaigns. The first necessary step was the planning of operations and the construction of a project timeline. Masada is built on a plateau that does not allow easy access to all areas. It is also composed of morphologically complex rooms, particularly in the northern area of the terraced palace. Simultaneously with the planning of the survey phases, a data archive was built for the purpose of organizing past records according to a system of codes referring to the publication of E. Netzer (Netzer 1991:xvii-xxviii) and in order to preserve the original data acquired so that could be orderly and easily accessible in the future. Each of the rooms in the site corresponds to an easily identifiable code on the 70s baseline map and later up-

3 In 2013, 2014 and 2015 campaigns ware directed by a team of professors from Italy, S. Bertocci (University of Florence) and S. Parrinello (University of Pavia), and from Israel, R. Vital (Shenkar College of Tel Aviv). In 2016 the campaign was directed by S. Bertocci and was coordinated by M. Bercigli. (University of Florence). For further information please refer to (Bertocci, Parrinello & Vital 2013; Bertocci, Parrinello & Vital 2014; Bercigli 2016).

Figure 5. Planimetry of the site, oriented and referenced according to Israel Transverse Mercator (ITM) coordinates.

dated with the contribution of the new survey performed (Figure 3).

After a careful planning phase, a laser scanning was performed using two different types of instruments: a Leica C10[4] laser scanner was used for the bulk of architecture and for the survey of the (largely empty) central part of the plateau since this instrument has a greater range; a Z+F Imager 5006h[5] laser scanner used mainly for the "casemate-wall." Through the use of various target types, like paper targets, it was then possible to record, in the Leica Cyclone software, the data from the two lasers in a single point cloud. The C10 laser scanner also acquired reference points for referencing the database according to a GPS coordinate system. The total number of laser scanning stations is 617, distributed equally across the archaeological site and within all individual spaces. Figure 4 shows the progress of the three laser scanner campaigns.

The 3D database consisting of the point cloud has allowed the extrapolation of 2D drawings, so as to obtain a horizontal plan of the site updated in 2015 and referenced with the GPS system. This was performed through the Leica Cyclone software, setting the parameters of Display in "elevation map" to display coloured areas every 5 meters according to the different altitude, with the 0 m height set on the plateau of the site and corresponding to the elevation 0 m a.s.l. Subsequently, orthoimages were exported and imported into Autocad so as to "trace" the point cloud to get a CAD drawing.[6] The final drawing represents a general planimetry at the large-scale of the archaeological site but does not contain all details of individual spaces (Figure 5).

Concurrent with the laser scanner campaign on the plateau, the photographic acquisition of all inner (architectural) spaces and the external part of the plateau was carried out so that the entire site could

4 Leica Scan Station C10 is a TOF (time of flight) scanner that acquires 50,000 points/sec, with a minimum range of 0.1 m and maximum of 300 m, with a field-of-view 360° horizontal and 270° vertical.

5 Z+F Imager 5006h is a phase-shif laser scanner that acquires about 1.000.000 points/sec, with a minimum range of 0,4 mm and maximum of 79 m, with a field-of-view 360° horizontal and 310° vertical.

6 For more information about the methodology please refer to (Bertocci, Parrinello & Vital 2013; Bertocci, Parrinello & Vital 2014; Bertocci et al. 2015).

Figure 6. Detailed planimetry of the Western Palace.

be reconstructed photogrammetrically. These Structure from Motion (SfM)[7] survey techniques have allowed us to produce 3D models used for various purposes. Specifically, it was possible to set the same laser scanner point cloud reference system, then orient and scale all models to obtain information and details that can be integrated with the previous 2D drawing.

This led to the acquisition of thousands of photographs and in particular about 850 for the exterior only. In fact, it was not possible to acquire the external part through a laser scanner due to the morphology of the mountain and the impossibility of creating a closed polygonal path due to the cliffs. During the survey campaigns, two main methods of capturing photo sets were used: close-range photogrammetry and aerial photogrammetry (middle-range). The first instrument used was a Phantom II drone with camera. The flight speed was about 15 m/s and the installed camera was a 12 megapixel GoPro H4 that shoots up to 30 fps. This allowed us to take pictures from above and to obtain a 3D model of a large area, thus providing a basis for the integration of other detailed 3D models. Regarding close-range photogrammetry, two instruments were used: a Nikon D3000 10.2 megapixel digital camera and a 18.2 megapixel Sony Camera with the 3D-Eye system[8]. Photo alignment and calculation processes were made using Agisoft PhotoScan software, and the next step of aligning the different point clouds produced through the various survey tools took a long time. At this stage of the work, the organization of the acquired data and the precise cataloging of photographs were of paramount importance, as the data archive obtained was so vast.

The work proceeded by exporting the clouds produced by Agisoft PhotoScan and importing them into Rapidform to be able to extrapolate numerous sections in an automatic way. These were embedded in a CAD environment within the large-scale design in order to complete the 2D drawings in detail, portraying and representing each individual element in the rooms (stones, stairs, railings, mosaics, etc.). The major advantage of 3D models made by using SfM techniques is to be equipped with high definition textures; CAD drawings can therefore easily be integrated with the representation of the colour (texture) of artifacts and spaces (Figure 6).

Virtual Reconstruction: The Case Study of a Mosaic

This section reports on a case study of the Western Palace. This is the largest building of Masada, which stands on the west side of the cliff, near the Roman ramp and consists of three large main bodies. Here, as in the rest of the site, Laser Scanner and Photogrammetry surveys were made. 7020 photographs were taken and each single space has been described and cataloged through .raw[9] and .jpeg format photos.

7 Image-based surveying techniques allow the reconstruction of point clouds and three-dimensional models using the photographs (Remondino 2011; Remondino and El-Hakin 2006).

8 The 3D-EYE System provided by Microgeo s.r.l consists of a telescopic stick extending up to 13.5 m. A Sony digital camera is installed on it and is possible to control the orientation of the camera by a tablet. This way is possible to take high-definition photos from above.

9 A .raw file is an image generated by digital cameras and it contains uncompressed, raw image data that can be adjusted

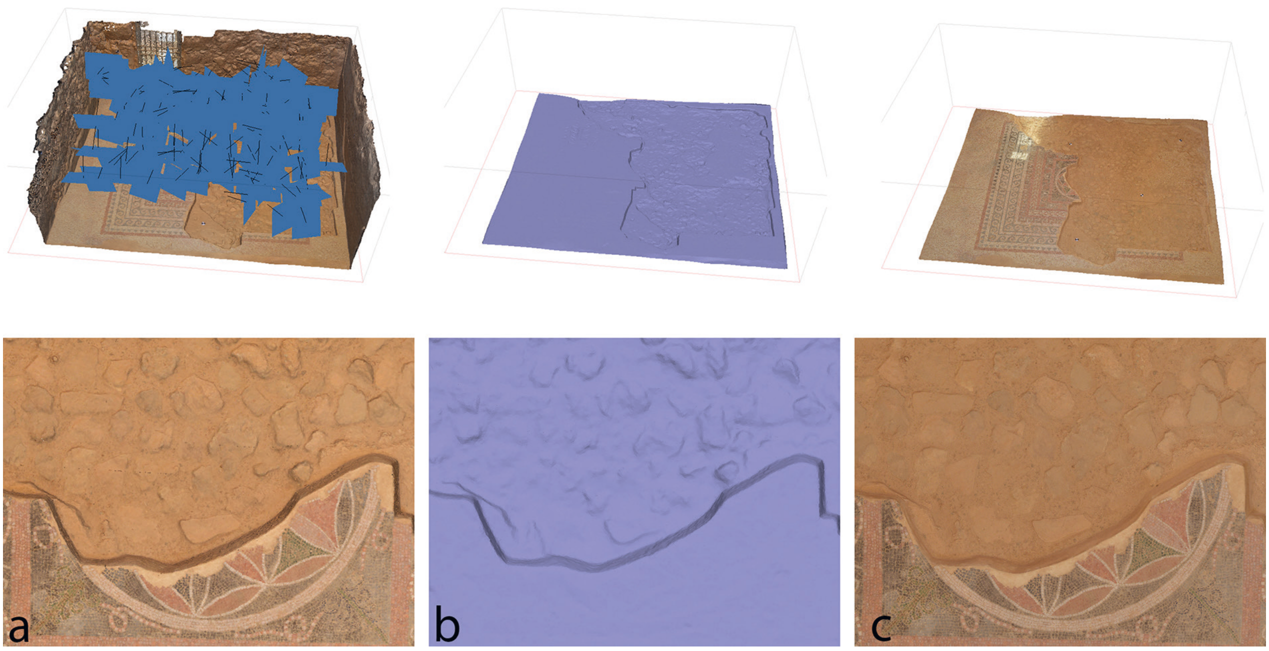

Figure 7. Figure shows 3d model realized through the use of Agisoft PhotoScan software. This model has a high definition texture and you can see above the details (orthorectified view) A: dense point cloud B: Mesh visualization C: Textured visualization.

The large number of photographs produced at the time of acquisition has prompted a structured data archive. During the photo shoot there were no special light arrangements, so they were later corrected using the .raw images.

Following all the photogrammetric processes, a detailed 3D model with a high-definition texture was obtained and some considerations were made on some parts, with a particular regard to a mosaic, which has only been partially preserved to date. An in-depth study was done on this mosaic at the entrance of the Hall of the Throne of the Western Palace. A total of 172 photos were taken and Agisoft PhotoScan (Figure 7) was used to obtain a point cloud and a high-poly mesh of about 1.5 million polygons with a high definition texture. Thanks to the targets previously set as reference points and thanks to the acquisition of their measures (reciprocal distances), the model has been scaled, rotated, and translated in the correct way. Thus, it was possible to export an orthorectified image with the mosaic design in true size. On the basis of these drawings, it was possible to obtain the exact geometry of each element. Following an in-depth study of the unit of measurement and comparisons with other known references, appropriate considerations have been made for the digital reconstruction of the mosaic.

Inside Masada's Western Palace, there are mosaics in the opus tassellatum technique which evidence the strong Roman influence that is present in the Herodian architecture (Netzer 1991:249-263). Analyzing compositions and geometric motifs, it is evident that the canons of the Greek-Roman tradition are perfectly followed. In antiquity, linear measures were related to the human body and in the Near East the fundamental unit was the "cubit" which remained the most used measurement system in the Mediterranean throughout the ancient period until the Roman era when it was replaced by the "foot." The cubit is an ancient unit based on the forearm length from the tip of the middle finger to the bottom of the elbow.

The geometries of the mosaic at the entrance of the Hall of the Throne of the Western Palace were analyzed for the "measure" that was supposed to regulate the composition. It turned out that the module used seems to be the 52 cm "Egyptian Royal Cubic." The mosaic is 6.5 cubits by 6.5 cubits, and concentric frames and individual geometric decorations continue to follow the original form (Figure 8). Before proceeding with the digital reconstruction of the mosaics, the group was concentrated on the materials, the colours, and the comparison with other "peb-

for exposure and white balance using software that supports the format.

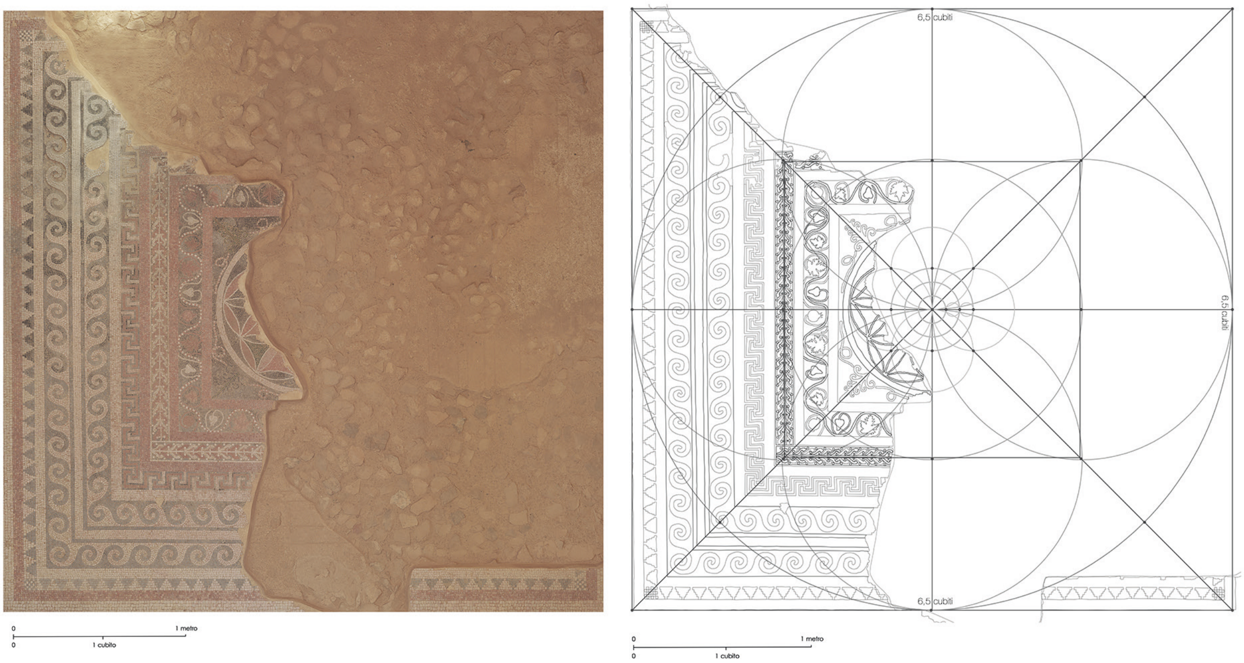

Figure 8. Figure shows the mosaic in the orthorectified view. From here, it was possible to proceed with the study of geometry and measurement in order to reconstruct its original drawing.

ble mosaics." The mosaic discovered is adorned with a geometric motif, very common in the Hellenistic world and which was mainly common on the island of Delos in the first half of the first century BC. In the center there is a decorative motif particularly associated with Jewish art, such as stylized branches of olive, pomegranate, fig leaves, vine leaves, and other natural themes (Yadin 1968:119-120).

Thanks to these studies and the procedures described above, it was possible to proceed with the hypothetical reconstruction of the mosaic, continuing the geometric design and completing the representation by coloring the "tiles" (Figure 9). In the end, the reconstructed 3D model was inserted in a virtual 3D environment to be displayed digitally in its original (albeit reconstructed) form.

Conclusions: The Possibilities of Using the Database

Nowadays, 3D models are increasingly used in the field of Cultural Heritage, even if they are constantly supported by traditional 2D graphic systems. 3D models, as well as providing design support, are important for permanently recording the shape of existing architectural works and artifacts, in order to achieve those for future generations. 3D models, therefore, have become an important 'tool' of the discipline for representation, useful for the construction of virtual scenarios, as well as for the valorization and dissemination of the heritage-related data.

In the case of architectural or archaeological complexes of a certain size, virtual models and related information become part of a museum system that are set up as real museums where the visitor is driven to become part of the narrative itself. The range of products through which you can configure a 3D digital system (video games, 3D model prints, web sites, AR applications, etc…) allows different approaches to representation, re-evaluating their limits, goals, and expressive potential. Virtual representative systems allow one to develop a more participatory and knowledgeable learning pathway and are able to increase the interaction between the user and the heritage-related information. In the case of the Masada fortress, the intention is to reproduce "virtually" the archaeological site in its entirety, exploiting the potential of VR and AR so that it can create multimedia content that can be viewed directly on the archaeological site through various devices, and at the same time can be accessed through PCs remotely. The appealing look and appearance of interactive 3D models and content, in this case, is more important than the metric accuracy of the work. Here is an example of the display of the Western Palace mosaic, accu-

Figure 9. The drawing of the mosaic cad geometry has been reconstructed and colored using a palette of colors derived from the study of the colour of the existing mosaic portion, comparing the colors of the other mosaics of Western Palace.

Figure 10. In the image, a rendering of the current status of the mosaic is observed. You can import the 3D model into software such as Unity 3D or Unreal Engine to make it interactive and associate extra content with some sensitive points to interact.

rately detected from material point of view, and its reconstruction (Figure 10). The greatest challenge in the development of a procedural way for the realization of effective virtual platforms is to seek representative way to understand and at the same time valorize and communicate the Heritage.

Acknowledgements

The results presented in this paper are part of a wider ongoing research carried out in collaboration between the Shenkar College of Ramat Gan (Tel Aviv) and the University of Pavia.

Professors: Stefano Bertocci, Maria Teresa Grassi, Sandro Parrinello, Rebeka Vital.

Collaborators: Maria Bazzicalupo, Marco Benedetti, Monica Bercigli, Benedetta Bertoglio, Daniele Bursich, Sara Bua, Niccolò Centrone, Anastasia Cottini, Filippo Fantini, Giulia Loddi, Eleonora Mariotti, Francesca Picchio, Sara Porzilli, Andrea Scalabrelli, Mattia Ventimiglia.

Credits

The author of paragraphs 1, 3 and 4 is Stefano Bertocci; the author of paragraphs 2, 5, 6 and 7 is Monica Bercigli.

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