



VIRTUAL MUSEUM ENRICHED BY GIS DATA TO SHARE SCIENCE AND CULTURE. CHURCH OF SAINT STEPHEN IN UMM AR-RASAS (JORDAN)

MUSEO VIRTUAL ENRIQUECIDO CON DATOS GIS PARA COMPARTIR CIENCIA Y CULTURA. LA IGLESIA DE SAN ESTEBAN EN UMM ER-RASAS (JORDANIA)

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Highlights:

- Definition of a complete pipeline ranging from data acquisition to visualization in multi-channel multimedia applications.
- Management of heterogeneous data in Geographic Information Systems (GIS) and their exploitation in Augmented and Virtual Reality (AR/VR).
- GIS applied to the archaeological domain for expert and non-expert users.

Abstract:

Umm ar-Rasas is a Jordan archaeological site, located 30 km southeast of the city of Madaba, in the northern part of Wadi Mujib. It preserves findings dating back the period from the end of 3rd to the 9th century AD and, since 2004, it belongs to the world heritage list of UNESCO. In 2015 a multidisciplinary work was undertaken over the archaeological site, mainly focusing on the Church of Saint Stephen, with the main purpose of enhancing the knowledge and documenting the conservation state of the polychrome mosaic floor, which covers the entire surface of the hall and presbytery. A huge amount of data has been collected, coming from archaeological and historical investigations, geophysics and geodetic inspections and geomatics surveying, which produced also a true orthophoto of the mosaic floor. Data has been organized in a geo-database, facilitating the exchange of information between different actors. Moreover, the management of data within a dedicated Geographic Information System (GIS), has allowed in-depth analysis for understanding the evolution of the iconographic repertoire that, over the centuries, has undergone several disfigurements due to the iconoclastic age. The knowledge of the mosaic has also been vital for the implementation of multimedia applications and for the creation of virtual experiences, in which the information can be conveyed and visualized directly on the virtual reconstruction of the whole archaeological site. The innovation of the proposed work, is therefore in the management of a data flow that can be exploited by different actors through different platforms: experts, thanks to the use of GIS, and visitors with the use of multimedia applications (such as Augmented Reality (AR) or high-resolution web visualization) for dissemination purposes, in order to preserve this priceless mankind heritage.

Keywords: virtual archaeology; digital archaeology; geo-database; cultural heritage; documentation; 3D reconstruction

Resumen:

Umm er-Rasas es un sitio arqueológico de Jordania, ubicado a 30 km al sureste de la ciudad de Madaba, en la parte norte de Wadi Mujib. Conserva hallazgos que datan del período comprendido entre finales del siglo III y IX d.C. y, desde 2004, pertenece a la lista del patrimonio mundial de la UNESCO. En 2015, se realizó un trabajo multidisciplinar en el sitio arqueológico, que se centró principalmente en la Iglesia de San Esteban, con el propósito principal de mejorar el conocimiento y la documentación del estado de conservación del suelo con el mosaico policromado que cubre toda la superficie de la sala y el presbiterio. Se ha recopilado una gran cantidad de datos provenientes de investigaciones arqueológicas e históricas, inspecciones geofísicas y geodésicas y levantamientos geomáticos, que produjeron también una ortofoto verdadera del suelo con el mosaico. Los datos se han organizado en una geodatabase, facilitando el intercambio de información entre diferentes actores. Además, la gestión de los datos en un Sistema de Información Geográfica (SIG) dedicado, ha permitido un análisis profundo que facilita la comprensión de la evolución del repertorio iconográfico que, a lo largo de los siglos, ha sufrido varias desfiguraciones debido a la era iconoclasta. El conocimiento del mosaico también ha sido vital en la implementación de aplicaciones multimedia y en la creación de experiencias virtuales, en las que la información se puede transmitir y visualizar directamente en la reconstrucción virtual de todo el sitio arqueológico. La innovación del trabajo propuesto está, por lo tanto, en la gestión del flujo de datos que puede ser

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explotado por diferentes actores a través de diferentes plataformas: expertos, gracias al uso del SIG, y visitantes con el uso de las aplicaciones multimedia (como son la Realidad Aumentada (AR) o la visualización web de alta resolución) para fines de divulgación, con el fin de preservar este patrimonio incalculable de la humanidad.

Palabras clave: arqueología virtual; arqueología digital; geodatabase; patrimonio cultural; documentación; reconstrucción 3D

1. Introduction

The use of digital technologies makes the application of information technology unavoidable, also in archaeology (Saygi & Remondino, 2013). State-of-the-art workflows proved to be sustainable and affordable enough to manage heterogeneous data, coming from different sources. In archaeology, this aspect is tremendously important, and the exponential growth of digital tools for data registration, acquisition and management, has become mandatory at each level and essential to preserve and protect cultural heritage (Anichini *et al.*, 2012). For the preservation and conservation of archaeological data findings, Geographical Information Systems (GIS) has demonstrated to be the more versatile computerized method (Salonia & Negri, 2003; Colosi *et al.*, 2009). Despite 3D information is not thoroughly integrated, the management of complex data is possible, allowing to store information coming from different players and stakeholders (Baik, Yaagoubi & Boehm, 2015; d'Annibale, Tassetti & Malinverni, 2014). GIS functionalities are more and more interesting; however, what is still missing is a real integration between digital data. For the archaeology domain, this integration might be a turnkey, given the huge amount of data that are very difficult to be stored into a complex structure.

This issue arises due to the data heterogeneities in terms of source information, chronological parameters dissimilarity and findings classification (Anichini, Fabiani, Gattiglia, & Gualandi, 2012). There is thus the necessity to satisfy both internal (cataloguing, documentation, preservation, management of archaeological heritage) and external (communication through the web portal) purposes. In fact, from this approach, two kinds of users can take advantage: the first ones are the insiders, such as archaeologists, experts and conservators (Malinverni, Pierdicca, Giuliano, & Mariano, 2018). The second ones are the visitors, who can exploit the potentials of new ways of communication to improve their knowledge. Dealing with these latter, nowadays there is a need to provide immersive and multimedia solutions to improve the cultural experience, making culture accessible,

tangible, communicative, pursuing the goal of an "edutainment" experience (Pierdicca, Malinverni, Frontoni, Colosi, & Orazi, 2016). Given the above, the workflow proposed in this paper has been set up in order to range from data gathering toward the management system with the aim of providing information for different kind of users, from insiders/public administration, dealing with technical information, to the wide public and advanced tourism. A schematic representation of the pipeline of work is reported in (Fig. 1). This study is backed by the "Kastrum Project"¹ (Gabrielli & Greco, 2018). The main objectives of the project are:

- survey and documentation of the archaeological site;
- documentation of the state of decay of the most relevant and high-risk structures;
- creation and development of a geodatabase for the enhancement and availability of data by a wider range of users; and finally,
- creation of a permanent training school addressed to local staff and focused on new technologies for Cultural Heritage with the aim of increasing tourism quality.

Within its framework, we concentrated our efforts studying the mosaic of the Church of St Stephen, briefly described in the following. The management of data within a dedicated GIS has allowed in-depth analysis for understanding the evolution of the iconographic repertoire that, over the centuries, has undergone several disfigurements due to the iconoclastic age. The knowledge of the mosaic has also been vital for the implementation of multimedia applications and for the creation of virtual experiences, in which the information can be conveyed and visualized directly on the virtual reconstruction of the whole site. The integrated management of the various information levels makes the extraction of information extremely easy and streamlined, facilitating the development of digital

¹ <https://it-it.facebook.com/kastrumproject>

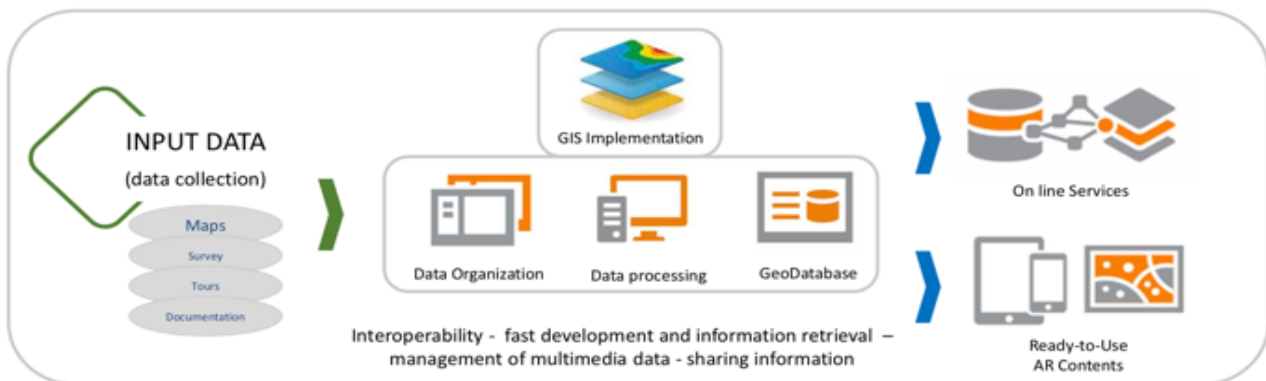


Figure 1: General workflow of the research. After the data collection phase, data is made interoperable due to the management in GIS, and then used for multimedia experiences.

applications. The innovation of the proposed work is, therefore, the management of a data flow that can be enjoyed by different actors through different platforms: experts in GIS and visitors by means of the help of applications. On the other side, it can be used for multimedia applications (i.e. AR application or high-resolution web visualization) for dissemination purposes, to spread with the mankind this priceless heritage.

2. Related work

Technologically advanced interactive systems, settled in modern-day museums, is a streamlined research domain, that is very important to offer a positive experience to the visitors and encourage them to return (Bruno et al., 2010). To this objective, museums and archaeological sites are developing modern communication and learning tools. An increasing body of research explores the application of Virtual Reality (VR) and Augmented Reality (AR) in the context of cultural tourism (Dilek, Doğan & Kozbe, 2019). While previous studies outline VR and AR as promising technologies to positively influence the visitor experience, these typically do not focus on how such technologies should be built to suit the context or add value to tourists and/or insiders. For a better evaluation of the workflow proposed in this article, a brief exploration of the recent literature is needed. (Han, Weber, Bastiaansen, Mitas & Lub, 2019) investigates elements affecting the tourist experience in the cultural tourism context from a theoretical perspective by discussing the impact of VR and AR technology on the visitor's learning experience. So, museums are using AR technology to their advantage. With AR, museums are superimposing their virtual world right over what is in front of the visitor, bringing exhibits and artefacts to life in new ways. Like QR codes, mobile phone guided audio tours, and smartphone apps have become widely used mobile features in museums all over the world, some museums are starting to explore ways to weave in more interactive and customized features that can enhance the visitor experience. There is a growing interest in virtual museum exhibitions that make use of Web3D and AR techniques (Blanco-Pons, Carrión-Ruiz, Lerma & Villaverde, 2019). The latter presents an AR app developed to ease understanding and visualisation of faint rock art painted scenes on site through smartphones, using feature-based tracking. The AR app has been implemented in Unity with the ARToolKit library. A usability evaluation has been carried out through a questionnaire to a group of visitors in order to validate the app, as well as the method to identify the performance and user's satisfaction with the developed AR app. Another similar approach is described by (Kyriakou & Hermon, 2019) whereby means of a smartphone in Head Mounted Display (HMD), the Leap Motion and software created in Unity3D, the authors have implemented an AR application, which facilitates natural interaction with specific geometric models from the museum's collection. The study presented by (Barrile, Fotia, Bilotta & De Carlo, 2019) compares the results of two different methods (instrumentation and processing methods) for 3D acquisition through laser scanner and for Ground Penetrating Radar (GPR) localisation of any buried archaeological remain.

The results were integrated into WebGIS, and/or made available through Android apps, for smartphones and tablets. In addition, VR and AR can be used to integrate the real world with information of different origins enriched with graphics, textual and multimedia contents. The workflow illustrated by (Rahaman, Champion, & Bekele, 2019) starts with digitising 3D artefacts based on image-based photo modelling (photogrammetry), converting a 3D point cloud to a 3D mesh, saving and sharing the geometric model to an online repository, viewing the model in VR/AR, and finally deploying the 3D content to a Mixed Reality environment (MS HoloLens) and interacting with the virtual content.

Researchers at the Australian Centre for Visual Technologies have developed methods of generating geometric models from archival sources demonstrating that it has utility in the interpretation of the 'life history' of watercraft. Further, the technique can be a useful analytical tool in the archaeological investigation of wrecked and abandoned vessels (Hunter, Jateff & van den Hengel, 2019). In line with these research trends, following is showed our approach.

3. Case of study: Umm ar-Rasas archaeological site

It sounds fair to acquaint the reader about the study area object of this work; so, a brief explanation of the archaeological site is presented, with the specific focus over the mosaic in which the GIS and the multimedia experience has been developed.

The archaeological site Umm ar-Rasas – Kastron Mefaa, located on the East of the Dead Sea, 70 km south from Amman and 30 km southeast of the city of Madaba (Fig. 2), in the northern part of Wadi Mujib. Between 1986 and 2004 the site Umm ar-Rasas has been subjected to several scientific surveys made by Padre Michele Piccirillo with the Studium Biblicum Franciscanum, supported by the Department of Antiquities of Jordan. It was Padre Piccirillo who identified the ruins of Umm ar-Rasas and the ancient Kastron Mefaa, already known from sources after the discovery of the mosaic inscriptions inside the two churches. These inscriptions allowed to set two important dates helping for the chronological timeline of the ecclesiastical complex and other useful information for the historical reconstruction of different aspects of the Christian population's life of Kastron Mefaa (Ognibene, 2002; Piccirillo & Alliata, 1994; Piccirillo, 1991, 2008). The ruins cover an extension of almost 10 hectares and belong to a Roman castrum, characterized by a majestic fortified wall with its dimensions of 158 x 140 m and by many civil and religious buildings rising both inside and outside the castrum and dated back to the Byzantine - first Islamic period and the 9th century. In the northern part of the site, it arises an architectural complex called "St. Stephen's complex", from the name of the Protodeacon and protomartyr to who it was named after the major church (Fig. 3). This ecclesiastical complex is composed by four churches: the church of Saint Stephen to the east and the church of Bishop Sergius to the north, the 3rd church is called the Courtyard church, and the 4th is the Aedicula church. This complex developed from the 6th century, preserving its Christian identity until the end of the 8th century under the Arabic Caliphate.



Figure 2: General overview of the archaeological site by satellite image.



(a)



(b)



(c)

Figure 3: Pictures of the St. Stephen complex: a) Main entrance to the mosaic findings; b) Shelter covering the archaeological site; c) Internal view of the archaeological site.

4. Materials and methods

This section is devoted to the description of data collected among the years for the documentation of the archaeological site. Moreover, since their management is a fundamental part of the project, besides being the backbone for the development of the virtual experience, the GIS deserves a clearer explanation, given in the following sections.

4.1. Data acquisition

From 2013 to 2016 the actions of documentation and surveying were focused on the two Byzantine churches of Saint Stephen and Bishop Sergius and on Stylite Tower. The research group used different survey techniques, such as laser scanner and digital photogrammetry, and tried to integrate each other allowing the creation of geometric models with the aim of data interpretation concerning the walls and the floor surfaces. For implementing the so-called “Multi-View Stereo” method, a huge amount of shots (ca 4000 in total) were captured; as results, we obtained the best radiometric quality of the surfaces and higher geometrical detail of the floors of the two churches. This acquisition was carried out by a reflex camera Canon EOS 5D Mark II with a full frame sensor with 21,1 MP and a 28 mm camera lens. The camera was arranged on the top of a pole and constantly held at the highness of 170 cm. Choice justified getting the best compromise between the photo accuracy and the suitable dimension of the acquired area (2 m² for each shot). Combining with the point cloud model made by the terrestrial laser scanner (TLS), it was possible to obtain a 3D metric model of both buildings. The scans were performed with a TLS instrument, the Faro Focus3D 120. The integration of the two survey techniques, georeferencing with local coordinates, generated a metric orthomosaic in 1:1 scale of the mosaic surface of both churches, characterized by the descriptive accuracy of colours, the details of the detected surfaces, the Digital Elevation Model (DEM) of the walls and the floors with an accurate representation (margins of few millimeters) of the geometric floor deformations (Gabrielli, Portarena & Franceschinis, 2017). The results of this process are shown in Fig. 4.

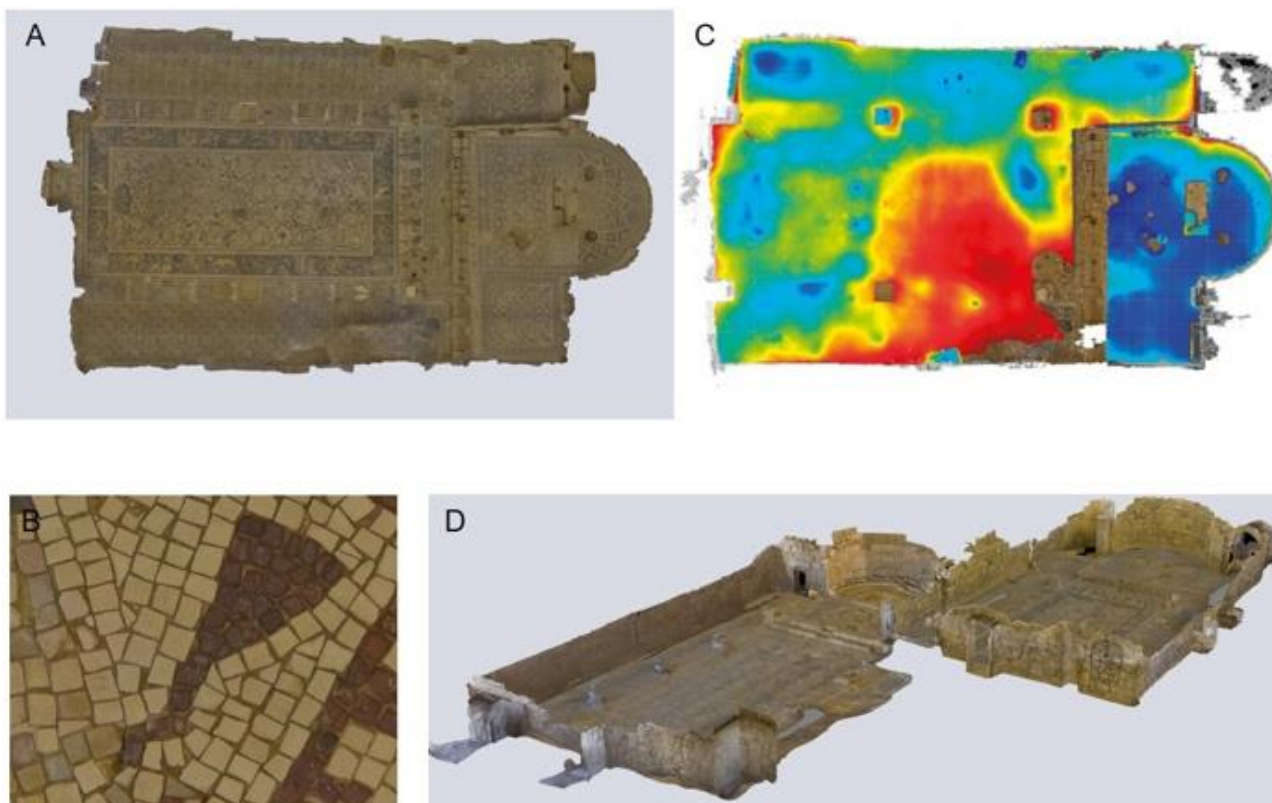


Figure 4: Results of the data processing phase: A) Ortho-image of the mosaic; B) A detail of the mosaic; C) DEM of the floor deformation; D) 3D model of the church.

4.2. Data organization

The known data related to the mosaic floor of the church of Santo Stefano were used to build a GIS that would represent a model for the computerized management and interdisciplinary analysis of data obtained from different research methods (e.g. laser scanner, photogrammetry, GPR, etc.).

The GIS is a valid system to support the planning of future restoration activities thanks to the management of information on the state of conservation of the floor surface (e.g. recording of different types of deterioration, information on maintenance operations, restoration and protection of the mosaic). Moreover, it is the basis for innovative tools such as AR or web GIS, aimed at enhancing and using the site thanks to the rational recording of historical, artistic and archaeological information of the floor mosaic in particular and the building in general. The logical structure of the geodatabase (depicted in Fig. 5) has been developed thinking of the mosaic floor as a territory. Just as a territory, in fact, the floor surface presents a variegated morphology (DEM) with an altimetric profile dictated in part also by the presence of probable underlying structures and shows traces of anthropic actions (damage of anthropic origin such as disfigurative interventions that characterize almost all representations of living subjects) and natural actions (damage of natural origin such as moisture, wind or animals) that have followed one another over time. The mosaic tile is the key element. Within the geodatabase, the tiles are considered as simple features and are distinguished from each other according to some qualitative characteristics; at the same time, the tiles are merged with respect to their geographical characteristics (position of the one with respect to the other and with

respect to the floor) in the corresponding panel feature within the whole mosaic.

Within the GIS, the tiles that make up the mosaic and the areas without them (damaged and restored sectors), described by polygon, are inserted into vector layers while the archaeological, historical-artistic and restoration data are organized into descriptive tables closely linked together by logical connections. Each table is structured in rows (or tuples) and columns (properties or attributes). Each row represents an entity to be stored in the database, while the characteristics of each entity are defined by the attributes. The scheme of a database is given in the conceptual model following an ER (Entity-Relationships) system, by the set of tables and the way in which they are related to each other (Fig. 5). The digitization of each tile and the logical connection of each with the tables of attributes and with the other vector levels created allows obtaining quantitative and qualitative information on the mosaic (Fig. 6).

The degree of detail of the information depends on the tiles within the GIS. To date, 54,828 mosaic floor tiles have been digitized by the human operator, which is time-consuming. An automated approach based on deep learning (Felicetti, et al., 2018) is currently being studied with the aim of obtaining an instrument that digitizes the tiles with high precision, calculating their inhomogeneity from a morphological point of view.

5. Results

Now, that the framework of the project has been presented, as well as the data structure behind the complexity of data, the virtualization of such information will be shown, with particular focus on two kind of

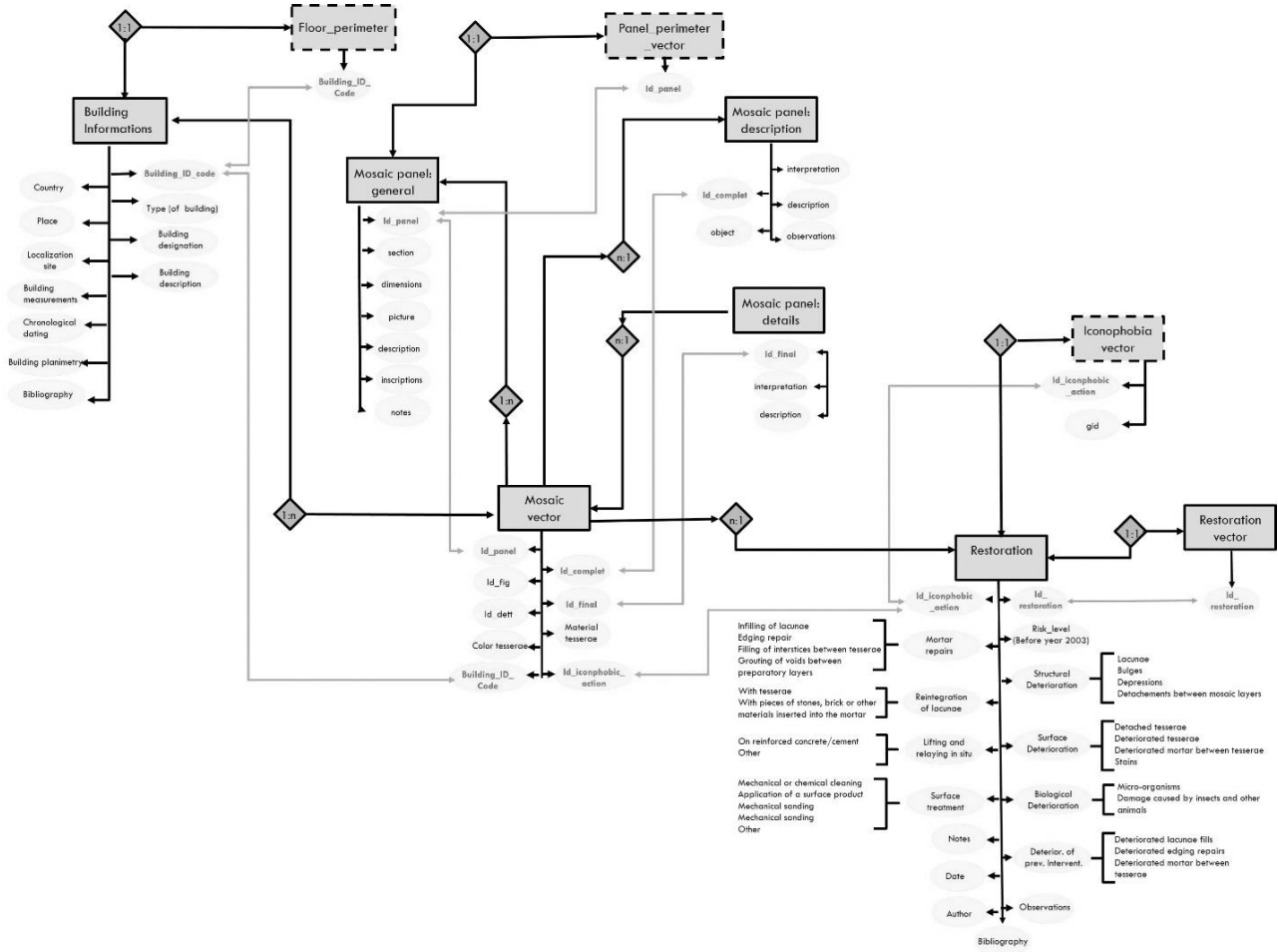


Figure 5: Structure of the relational database which follows the conceptual model of data management.

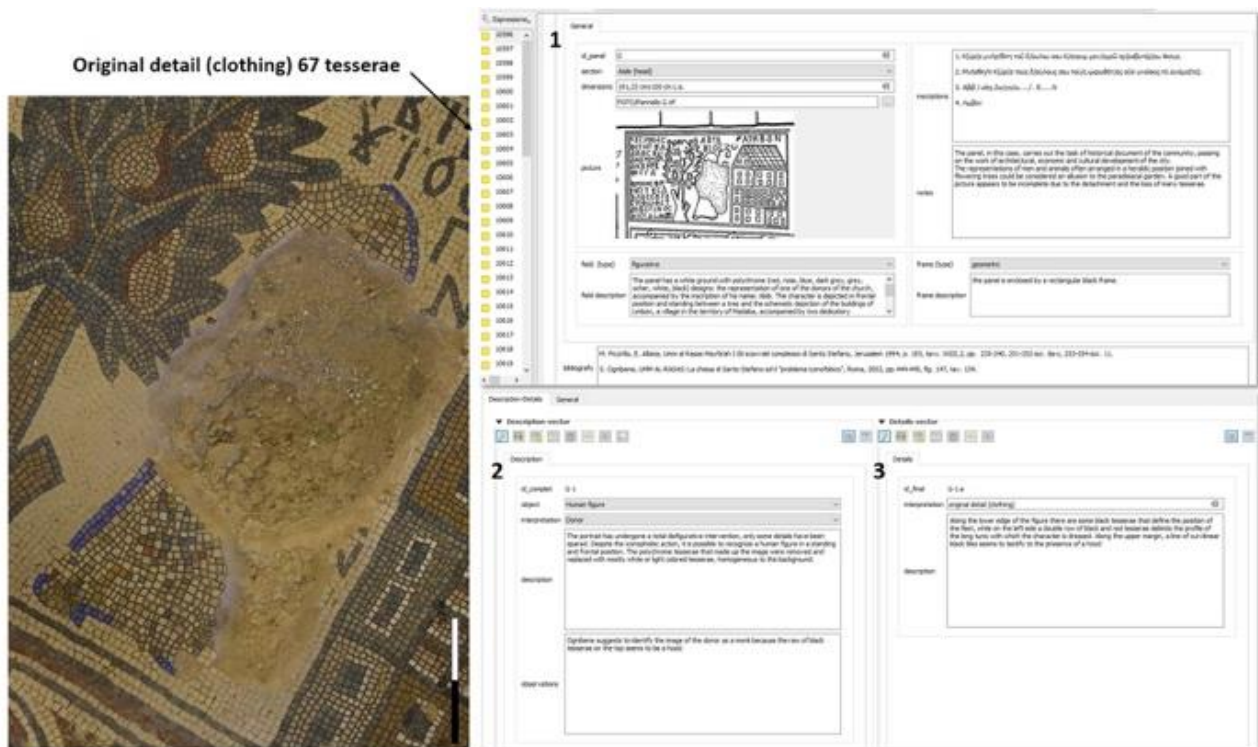


Figure 6: Example of a link between the geometrical data and the descriptive information about a portion of the mosaic.

experiences: AR based on mobile devices and VR based on a web solution for the High Definition (HD) visualization of the mosaic. Nowadays, virtual reproduction represents a consolidated approach towards a complete diffusion and enhancement of cultural heritage. Archaeology, precisely because of the complexity of its contents and the limitations of the heritage to be exploited, can also benefit from the use of new media (Pierdicca, Frontoni, Malinverni, Colosi, & Orazi, 2016). As seen above, information archiving is a key process for insiders; archaeologists, experts and conservators have access to innovative organisational techniques that allow rapid and low-cost data collection. However, these data too often remain disposable only for experts, while policies should be adopted to facilitate visitors, who can exploit the potential of new ways of communicating to improve their knowledge.

5.1. High definition visualization

As mentioned before, digital media should be considered a tool to solve a specific issue. In the case of the floor, to allow the general public to perceive the details even without visiting the site, it was necessary to design a web interface that could show, at a very high level of detail, the particulars of the ortho-images described above. The limitation of this kind of images is certainly represented by its large size, which does not allow easy use on all devices. In this regard, we have chosen to implement an .HTML page that uses a technique of virtual texturing to allow the use of huge images for visualization purposes. The technique combines classic mapping and loading of only the necessary cards at the request of the user. For each zoom level appears the set of tiles corresponding to the observed texture (2D + LoD / scale coordinates). This method allows visualizing with a common browser the survey at the maximum acquisition resolution. An example of a display is shown in Fig. 7.

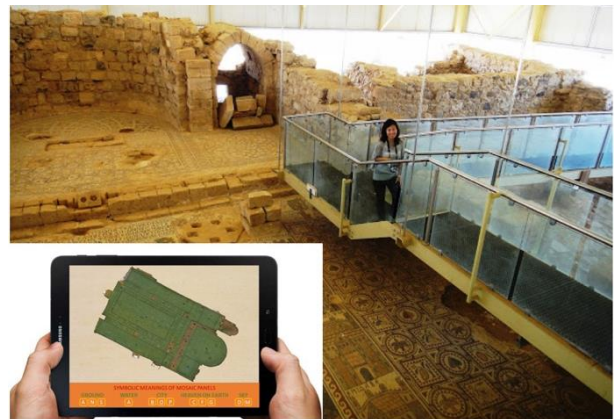


Figure 7: Example of a high-resolution display of the mosaic's orthoimage. At the left top, a navigator allows geolocating the detail of the mosaic.

5.2. AR application

While the use of the web can prove to be a decisive resource for sharing heritage, the new frontiers of the mobile world today make it possible to create increasingly interactive experiences, even directly at the place of visit. The information that can be conveyed during a visit, however, are of a more general nature and do not allow further investigation. In this case, the use of mobile applications and interaction techniques such as AR, can represent useful support to the visitor (Fig. 8a).

Still exploiting the information structured in the geodatabase, it was decided to extract some detail reports and to be able to make a visualization directly by framing, with the camera of a common smartphone, the mosaic. A tracking system based on images has therefore been adopted. Once the video stream of the integrated video camera is activated, the device can match the pre-loaded contents, looking for the key points associated with the images. The digital content is then superimposed on the screen from the camera's point of view, depending on the orientation of the device. The test was conducted on a 1:1 scale reproduction of the mosaic, but it proved to be an excellent solution for the use of the archaeological site. A reproduction of the AR experience is shown in Fig. 8b.



(a)



(b)

Figure 8: a) Example of AR application to show on site the description of the mosaic coming from the data selected in the GIS; b) A reproduction of the AR application.

6. Discussion and conclusion

In this paper, a complete workflow has been showed, specifically designed for the archaeological domain. As demonstrated by the recent literature, the collection of meaningful data, even heterogeneous as in this case, deserve more articulated management. In this way, not only expert and insiders can benefit from this knowledge but this system can really increase and share the knowledge of an archaeological site to the visitors, not only on the field but also in the museum.

In fact virtual technology can affect a very wide range of users and potential tourists, for example, who have difficulty walking, but also those who are not able to fully enjoy a cultural visit on site directly. It is essential to point out the accessibility, usability and pleasantness topic connected to the cultural experience, which must

allow anyone to live a satisfying experience in conditions of autonomy, comfort, safety.

Nowadays all these necessities can be satisfied through the use of innovative technological tools, so far used only in entertainment, but which, in recent years, they are increasingly useful for educational purposes and support to the disability. In recent years many VR and AR initiatives have given an improvement to overcome the barriers in relation to the people with disabilities. Thanks to applications of immersive reality the difficulty accessing of many disabled people, such as to natural landscapes or vast archaeological sites, can be reduced giving other audio-visual perceptions, being in a museum. Disabled people can also "travel through time", in the past, exploiting the reconstructions and documentation related to the history of ancient civilizations. It is also possible to "see the invisible", to observe what is hidden to the public after discovery, for reasons of conservation, material fragility or human neglect.

Through the integration of technologies, the reproduction of museum objects, "sensitive" to the touch, and the audio App guide the visually impaired or blind visitor through thematic paths designed on the principles of storytelling, generating an "augmented" experience.

However, the complexity of data produced requires a further step toward their full management by different actors. Geomatic techniques have become so mature, that the degree of detail and the accuracy make possible every kind of survey, even in hard conditions and give the possibilities to store a lot of 3D data. Depending on the level of interaction and communication that one wants to achieve, there is the need to use different multimedia approaches to retrieve this 3D data, enriched by descriptive information. In the specific case of the mosaic floor, having the collection and organization of these data into the geodatabase, it becomes also the source for the implementation of multimedia applications. In fact, the integrated management of the various information levels that make up the floor makes the extraction of information extremely easy and streamlined, facilitating the development of digital applications. The innovation of the proposed work is therefore in the management of a data flow that can be enjoyed by different actors through different platforms: experts in GIS and visitors with the help of applications, developing an advanced user interface for content exploration, according to different levels of user profiling. This way, information is not duplicated and, depending on the level of interaction required, every actor of the cultural heritage value chain can benefit from them.

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