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# *AUGMENTED REALITY APPLIED TO THE RESTORATION OF HISTORICAL HERITAGE*

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*ABSTRACT:*

*Spain occupies a prominent position among the countries with the most UNESCO World Heritage Sites. The possibilities offered by the application of AR-VR technologies for some of these elements' virtual reconstruction brings a great opportunity to give visibility and support the transmission of cultural heritage, especially in those cases where physical restoration is not possible. It is increasingly common to find virtual reconstructions of monuments, since these do not damage either put at risk the element being represented. In this work, the process of modelling and reconstructing the Castillo de la Estrella, located in the town of Teba (Malaga), as well as the subsequent development of an Augmented Reality application is presented. This allows the Castillo de la Estrella reconstruction to be displayed virtually on mobile devices such as smartphones or tablets, and might potentially be implemented in the museum that houses the castle itself, providing a tool that improves the visitor experience and completes the range of cultural activities carried out in the monument.*

*Keywords: Augmented Reality, Virtual Reality, Historical Heritage, 3D Modelling*

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## 1. - INTRODUCTION

Until recent years, two-dimensional graphic representation provided the means to represent an architectural element through elevations, floors and sections, that is to say, blueprints in general. However, advances in technology in this respect have led to the current use of virtual reconstructions, that is, the three-dimensional design of the architectural structure, along with the possibility of applying realistic finishes. This enables going from regarding objects or elements as incomplete images in two dimensions to appreciate them at their full three-dimensional complexity showing both, their geometry and materiality.

In recent years, the concurrence of a number of technical and academic advances has made virtual reconstruction a reliable and tangible reality. Among its most widespread applications medicine is found, including the treatment of phobias and trauma, surgical operations, and pain management [1]. It is also used in the training of military professionals [2-3] and manufacturing and fabrication processes [4], whilst the possibilities for education are infinite [5-6]. In the field of tourism and museums it facilitates the possibility of travelling to any part of the world or showing objects or customs of the past that no longer exist [7-10]. Today, there are variety of

tools and techniques that can be used to obtain and generate reliable three-dimensional models [11]. Photogrammetry is a technique that is able to obtain very accurate and close to reality 3D models from a set of detailed photographs [12-14]. Augmented Reality (AR) complements the perception and interaction of the virtual world in a real environment. The possibilities offered by the application of AR-VR technologies for virtual reconstructions of these kind of elements are an opportunity to give visibility and facilitate the dissemination of lesser-known cultural heritage, especially when material restoration is not possible [15-16]. It is increasingly common to find virtual reconstructions of monuments, since these do not damage or put at risk the represented element [17], offering new possibilities for developing the market of tourist services [18].

Digitization is a means of preserving — in an exhaustive, easy, and completely innocuous way — the knowledge of the past while allowing the user to transport themselves to past times and visit buildings that no longer exist (either completely or partially). The REGINA, TRImálaga [19] and Revipán [20] projects were developed in the last few years with this purpose.

In this sense, the work presented here deals with the reconstruction of a fortress called "Castillo de la Estrella", a defensive space with over 1000 years of history that is located in Teba, Malaga.

The “Castillo de la Estrella” is listed as an asset of cultural interest (aka. BIC – Bien de Interés Cultural) since 1985 by the Andalusian Institute of Historical Heritage (IAPH – Instituto Andaluz de Patrimonio Histórico) with BIC code: 01290890004 published in BOE dated 29/06/1985.

The Castillo de la Estrella occupies an area of approximately 25000 $m^2$ and stands at a height of 600 m. The original fortress was built by the Arabs, although over the years it was occupied by different cultures that modified and extended the construction.

The castle is enclosed by a first belt of walls on the north side. The second belt, made of carved stone, is more solid and higher, outstanding four towers. The fortress is flanked by different towers all along the top of the hill, showing entrances to the underground galleries leading outside that are now blocked off. In the centre of what once was the main square, the main tower or homage tower stands. Its four edges are made of quadrilateral stone blocks. Inside de tower, at ground level, cisterns and stone channels that allowed rainwater to enter the building existed. In addition, vaulted ceiling and passages leading to the rooms could still be seen by the 80’s [21-22].

At present, considering the two walled enclosures that once composed the whole fortress, only certain traces of its past remain since the entire area within the defences is completely barren. In the central area, a small fortress belonging to the homage tower and the count’s palace can still be seen: a four storey residential tower and some sections of the wall have been preserved intact, although in general, these constructions have gradually disappeared as a result of their progressive abandonment. The higher levels in the tower cannot be visited since there is no trace of the staircase leading to them.

## 2. - MATERIAL & METHODS

The methodology employed in this work presents the process of modelling and reconstructing the Castillo de la Estrella, located in the town of Teba (Malaga). The first work stage begins by pursuing the approval and consent of the local administration of the municipality of Teba together with identifying and collecting all the available information on the monument, paying special attention to the documentation contained in the report "Revision of the master plan for Castillo de la Estrella" [23]. Then, before starting the three-dimensional model of the various elements composing the whole monument, 2D ground plans from the terrain and the fortress are developed and obtained considering all collected data. AutoCAD Software is employed at this stage. Besides the 2D ground plans, elevations need to be defined. They are obtained from applying photogrammetry techniques on every fortress face in order to ascertain their current state. This is done using Adobe Photoshop software. By the end of this phase, the work arrives at the starting point of the 3D modelling, counting on the complete blueprints of the castle surroundings, topographical survey, historical photographs, photogrammetric elevations and the archive and library collections containing sources and reviews of works and restorations carried out on the walls. The work process followed is shown in Fig. 1:


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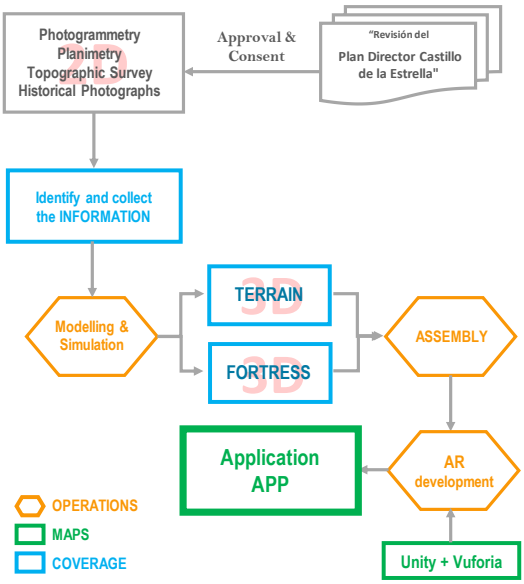


*Fig. 1. Diagram of operations developed during modelling (Source: authors' own)*

For the 3D modelling, three different software/tools are employed: 3ds Max for the sake of accuracy in measurements and shapes, Unity for the sake of realism and Vuforia in order to generate de AR application.

## 2.1. - DATA PREPARATION AND MANAGEMENT

Since the same amount of information is not available for each element that makes up the monument, three different stages of action were established:

- **Terrain:** the fortress is strategically adapted to the surrounding terrain, therefore, increasing the size and complexity of the element and requiring an accurate representation. Initially, an editable grid is generated from the contour lines. This grid can be modelled and become very realistic through the application of real textures.
- **Fortress:** For the modelling process of the fortress, the monument is divided into three different areas:
  - Homage Tower
  - Alcázar
  - Exterior walls

Each element of the castle was modelled in 3D, generating editable grids from the reconstruction of all existing elements positioned in their exact location. From the photometry obtained of each of the elevations, it has been possible both, to establish their real dimensions and to identify elements such as windows, doors, and pathologies, as well as to generate the exact textures of the monument itself. Due to the irregularity of the terrain and considering the real height of each, the lower part of all the elements of the fortress was oversized to facilitate the subsequent assembly process.

- **Assembly:** in order to place the fortress on the terrain rightfully, each modelled area was imported and inserted in the terrain independently of each other. In addition, the modelling of the exterior walls was also divided into several sections, taking references on the fortress' oversized walls that allow each element to be embedded in the terrain at its corresponding level, therefore hiding the re-mains beneath.

The following figures show the development of the working stages.

First, a 2D plan reconstruction of all defensive elements of the fortress was developed according to all data collected in the preceding research. This was done through AutoCAD software. Then, 2D ground plans of the fortress and topography were imported to 3DS Max where the 3D model was obtained (Fig. 2).


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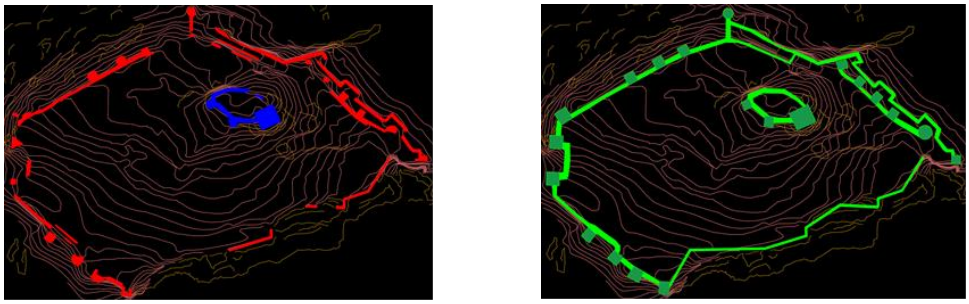

*Fig. 2. Plan reconstruction of the outer walls based on the location and current remains of Castillo de la Estrella. (Source: authors' own)*

Since the height at which each element is located is different to one another, placing each piece at its right height can become a complex task; that is the reason why every wall was modelled larger than needed as explained before.

The final assembly was performed by means of Unity Software and Vuforia, where final textures are applied in order to be able to proceed with the Augmented Reality model generation (Fig. 3).

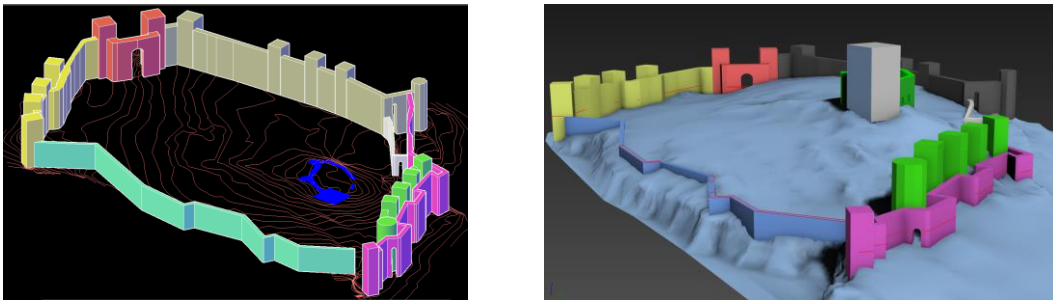

*Fig. 3. General view of the outer walls reconstruction and each 3D-modelled element location on the terrain (Source: authors' own).*

Textures generation was carried out as precisely as possible by employing different images for the recreation. In Fig.4, a detailed view of one the textures created from the photometric elevations together with the results of the final texture can be appreciated.

*Fig. 4. Texture recreation from NW elevation orthophotography (Source: authors' own).*

A ground plan model oversizing heights was performed so that afterwards, the photogrammetry could be attached based on reference points that allow placing each element at the point of maximum height. This results in a visualization of each of the faces involved in the fortress (Fig. 5).


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Geometric accuracy in large surface reconstructions depends on the technology and techniques employed [24-27]. In this sense, the geometric accuracy of the model presented here responds to the aforementioned reference points that were taken from two different sources and then employed in the CAD model: on the one hand, they were measured from real images taken on site. On the other hand, the same reference points were drawn from the photogrammetry developed and enclosed in the review of the Master Plan of "Castillo de la Estrella" provided by the town council.

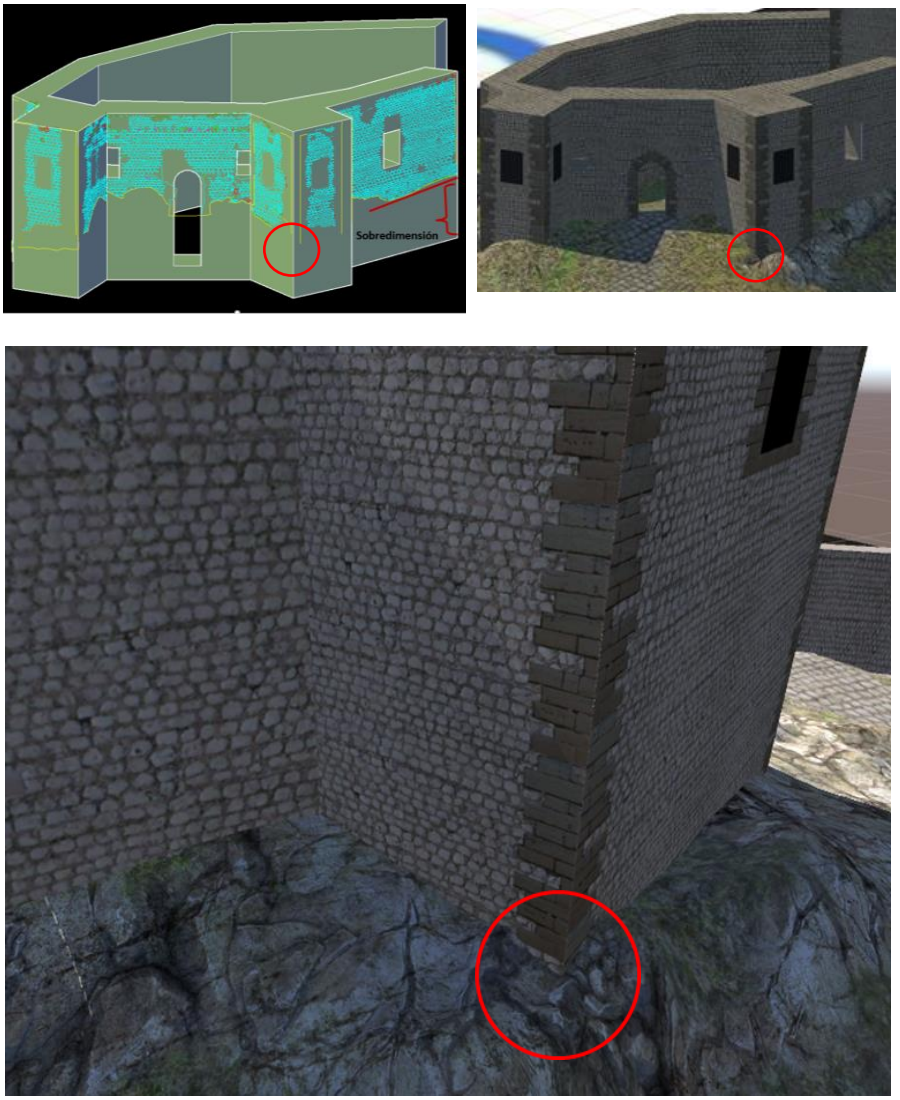


*Fig. 5. 3D Modelling of the Alcázar (Source: authors' own)*

In order to give each element its own corresponding texture (Fig. 6), splitting all faces so that each of them could be identified as an editable mesh becomes essential. So it is, the hierarchy and naming process of each of these elements. Once textures were placed, reference points previously chosen will grant the rightful location of the modelled elements at its precise height.

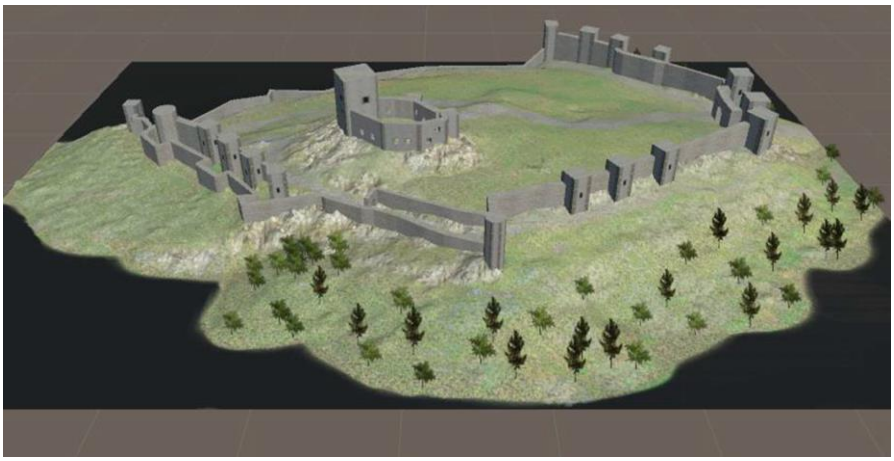

*Fig. 6. Reconstruction and final assembly details (Source: authors' own).*

## 3. - RESULTS

Once the modelling phase was completed, having placed all the elements of the fortress in their final position on the ground, the final model was obtained. Then, it must be implemented in the software of a multiplatform game engine to generate an Augmented Reality application for mobile devices or tablets that can potentially be implemented in the museum housed in the castle itself, providing a tool that improves the visitor experience. AR technology allows virtual elements to be superimposed on the reality we capture with our eyes by employing an electronic device such a smartphone or tablet. It can take an infinite number of means to place these virtual elements, whether it be an image, an object or a certain environment or space. Along with this process, a marker needs to be generated to trigger the representation of the virtual model. Fig. 7 displays the result of the final application on a device.

- Digital 3D model: which is perceptible of modification if new information becomes known about the monument.
- AR application: any user owning an Android or iOs device can run the application and enjoy it. The results obtained are as follows:

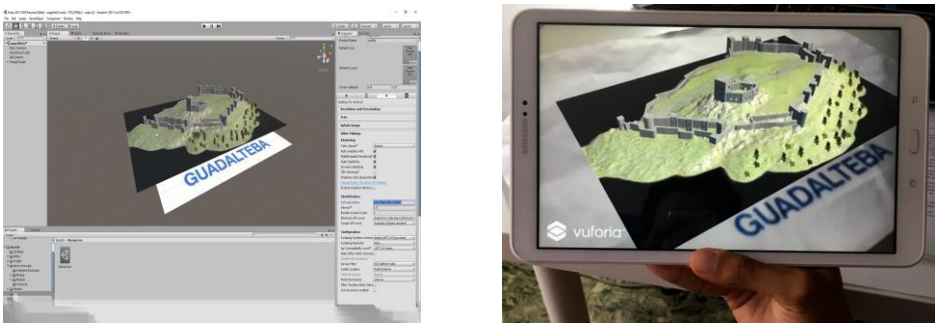


*Fig. 7. View of the AR application on an Android device (Source: author's own)*

## 4. - CONCLUSION


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Given that many of the constructions that constitute our historical heritage have reached a terrible state of abandonment in modern times, and even are at potential risk of permanent ruin, the possibilities offered by their digital restoration allow us to preserve and transmit this cultural knowledge, presenting its contents in a more attractive and comprehensive way.

The software employed was not a hazardous election but a thoughtful choice regarding several aspects. The original contour lines of the terrain were obtained in AutoCAD, therefore, the 2D ground floor of the fortress was developed in the same software; Although the 3D modelling could have been performed in the same software, 3DS Max was used seeking for the maximum precision in shapes and geometries while Unity offered better realism in textures. In addition, the edition and composition of each wall texture was developed in Adobe Photoshop by means of photogrammetric techniques. Finally, Vuforia was needed to create the AR application together with Unity. The versatile selection of software involved in the process made the virtual reconstruction quite exhaustive and successful.

Broadly speaking, the modelling and reconstruction of the Castillo de la Estrella allows us to make progress regarding the widespread knowledge of the monument. Supporting this kind of technologies, especially considering their application in this type of cultural spaces turns into a great way to enhance the value of historical elements. Moreover, bringing it to life in a tangible project through the development of an AR application that enables the users and visitors to become involved in the monument will bring the consequent benefit to tourism activity in the area.

Furthermore, the data and information offered in the AR application can always be updated, which allows us to have an open tool to facilitate and encourage the transmission of cultural knowledge, promoting its use in other heritage elements with preservation needs.

## REFERENCES

[1] G. S. Letterie, «How virtual reality may enhance training in obstetrics and gynecology», Am. J. Obstet. Gynecol., vol. 187, n.o 3, S, pp. S37-S40, sep. 2002.

[2] S. Ilnicki et al., «Our Experiences in the Use of VR Technology in Therapy and Prevention of Combat Related Stress Disorders in the Polish Army», en NEW TOOLS TO ENHANCE POSTTRAUMATIC STRESS DISORDER DIAGNOSIS AND TREATMENT: INVISIBLE WOUNDS OF WAR, 2013, vol. 108, pp. 139-148.

[3] P. Figueroa, C. Francisco Rodriguez, J. Tiberio Hernandez, J. Camilo Blanco, R. Oses, y L. Ballesteros, «A Shooting Simulator from Boats», en 2014 PROCEEDINGS OF THE 9TH INTERNATIONAL CONFERENCE ON COMPUTER GRAPHICS THEORY AND APPLICATIONS (GRAPP 2014), 2014, pp. 88-95.

[4] A. Vergnano, G. Berselli, y M. Pellicciari, «Interactive simulation-based-training tools for manufacturing systems operators: an industrial case study», Int. J. Interact. Des. Manuf., vol. 11, n.o 4, pp. 785-797, 2017.

[5] D. Kaminska, T. Sapinski, N. Aitken, A. Della Rocca, M. Baranska, y R. Wietsma, «Virtual reality as a tool in mechatronics education», en 2017 18th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering, ISEF 2017, 2017.

[6] C. M. Huttar y K. BrintzenhofeSzoc, «Virtual Reality and Computer Simulation in Social Work Education: A Systematic Review», J. Soc. Work Educ., vol. 56, n.o 1, pp. 131-141, 2020.

[7] J. Alabau-Montoya y M.-E. Ruiz-Molina, «Enhancing visitor experience with war heritage tourism through information and communication technologies: evidence from Spanish Civil War museums and sites», J. Herit. Tour. doi: 10.1080/1743873X.2019.1692853

[8] K. Yoo y N. Gold, «Emotion evoking art exhibition in VR», en Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST, 2019. doi: 10.1145/3359996.3365028.

[9] J. Häkkilä et al., «Visiting a virtual graveyard - Designing virtual reality cultural heritage experiences», en ACM International Conference Proceeding Series, 2019. doi: 10.1145/3365610.3368425

[10] M. K. Bekele, «Walkable Mixed Reality Map as interaction interface for Virtual Heritage», Digit. Appl. Archaeol. Cult. Herit., vol. 15, 2019. doi: 10.1016/j.daach.2019.e00127

[11] Y. Alshawabkeh, M. El-Khalili, E. Almasri, F. Bala'awi, and A. Al-Massarweh, "Heritage documentation using laser scanner and photogrammetry. The case study of Qasr Al-Abidit, Jordan," Digit. Appl. Archaeol. Cult. Herit., vol. 16, 2020, doi: 10.1016/j.daach.2019.e00133.

[12] Babič, M., Petrovič, D., Sodnik, J., Soldo, B., Komac, M., Chernieva, O., ... & Calì, M. (2021). Modelado y clasificación de abanicos aluviales con DEM y métodos de aprendizaje automático: un estudio de caso de abanicos torrenciales eslovenos. Teledetección, 13(9), 1711.

[13] Martínez-Carricondo, P., Agüera-Vega, F., Carvajal-Ramírez, F., Mesas-Carrascosa, F. J., García-Ferrer, A., & Pérez-Porras, F. J. (2018). Evaluación de la precisión del mapeo fotogramétrico de UAV basado en la variación de los puntos de control en tierra. Revista internacional de observación de la tierra aplicada y geoinformación, 72, 1-10.

[14] Cali, M., & Ambu, R. (2018). Reconstrucción fotogramétrica 3D avanzada de la superficie de objetos extensos mediante la adquisición de imágenes de la cámara UAV. Sensores, 18(9), 2815.

[15] M. Trunfio, S. Campana, and A. Magnelli, "Measuring the impact of functional and experiential mixed reality elements on a museum visit," Curr. ISSUES Tour., doi: 10.1080/13683500.2019.1703914.

[16] D. Petrelli, "Making virtual reconstructions part of the visit: An exploratory study," Digit. Appl. Archaeol. Cult. Herit., vol. 15, 2019, doi: 10.1016/j.daach.2019.e00123.

[17] A. Marto and A. Gonçalves, "Mobile AR: User evaluation in a cultural heritage context," Appl. Sci., vol. 9, no. 24, 2019, doi: 10.3390/app9245454.


ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87 n.1 DOI: https://doi.org/10.6036/10651

[18] Madirov, E.; Absalyamova, S. The influence of Information Technologies on the Availability of Cultural Heritage. Procedia-Soc. Behav. Sci. 2015, 188, 255–258.

[19] «TRImálaga», Universidad de Málaga, 2010. [En línea]. Disponible en: http://www.trimalaga.uma. es/. [Accedido: 20-ene-2020].

[20] F. Gutiérrez, «Los Baños del Carmen, en todo su esplendor», Diario SUR, Málaga, may-2013.

[21] B. Ruiz González, "Castillo de Teba," Arqueología, vol. 83, 1985.

[22] A. Vallejo Triano, "Actuación arqueológica en el Castillo de Teba, Málaga," 1985.

[23] YamurArqueología&Arquitectura, «Revisión del plan director del Castillo de la Estrella de Teba, Málaga». Rincón de la Victoria, 2017.

[24] Ferwati, M. S., & El Menshawy, S. (2021). Virtual reconstruction of the historic city of Al-Zubarah in Qatar. Digital Applications in Archaeology and Cultural Heritage, 21, e00177. https://doi.org/10.1016/j.daach.2021.e00177

[25] Banfi, F., Brumana, R., Roascio, S., Previtali, M., Roncoroni, F., Mandelli, A., & Stanga, C. (2022). 3D HERITAGE RECONSTRUCTION AND SCAN-TO-HBIM-TO-XR PROJECT OF THE TOMB OF CAECILIA METELLA AND CAETANI CASTLE, ROME, ITALY. https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-49-2022

[26] Vital, R., & Sylaiou, S. (2022). Digital survey: How it can change the way we perceive and understand heritage sites. Digital Applications in Archaeology and Cultural Heritage, 24, e00212. https://doi.org/10.1016/j.daach.2022.e00212

[27] López, J. A. B., Civantos, J. M. M., & Collazo, J. R. (2020). Architectural survey and archaeological analysis of the Píñar Castle as a starting point for its conservation. Virtual Archaeology Re-view, 11(22), 95-115. https://doi.org/10.4995/var.2020.12397


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