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Original article

Proposition for the graphic representation, interpretation and evaluation of the degree of terrain resolution in virtual reconstructions

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ABSTRACT

The Seville Principles gather in their definitions the 3D representation of heritage assets in their context, that is, elements such as the surroundings and landscape, for both virtual reconstructions and virtual recreations. Currently, there are few virtual reconstructions that implement the historical-archaeological evidence scale to show the veracity of the work that has been carried out. Moreover, none of the existing propositions of historical-archaeological evidence scales consider the veracity of the represented terrain. Authors assign a neutral colour to the terrain, different from those applied to the evidence levels, in order to differentiate the former from the latter.

The present study proposes the development of a methodology to implement a resolution scale that graphically represents, interprets and evaluates the setting of the terrain associated with virtual reconstructions. To this end, a literature review was conducted on the existing methodologies for the creation of Digital Terrain Models (DTM). The evaluation of the analysed information was key for the selection of the resolution levels, which was followed by the selection of the colours associated with each resolution level, taking into account the subjective connotations of colours.

Introduction

Archaeology involves the construction of a historical discourse based on past societies. In other words, this discipline analyses history through Material Culture, that is, the material remains that are preserved [1]. In addition to understanding the social and cultural meaning of these materials, it is fundamental to situate them in space and time. Therefore, this science requires multidisciplinary work with cartography, topography, Geographic Information Systems (GIS), Global Positioning System (GPS), georeferencing and Digital Terrain Models (DTM).

The Seville Principles, in the third section of Principle 5 “Historical rigour” [2], state that: “The surroundings, context or landscape associated with an archaeological remain is as important as the remain itself. Anthracological, paleobotanical, paleozoological and physical palaeoanthropological studies must be used as reference for the development of rigorous virtual recreations of the landscape and context. Lifeless cities, lone buildings or dead landscapes cannot be systematically shown, as these represent false history.”

Similarly, the Seville Principles gather in their definitions the visual recovery of heritage alongside elements such as the surrounding and the landscape in virtual recreations [2]. A large number of 3D representations consist of material culture, surroundings and landscape, and the authors themselves classify their works as virtual reconstructions. Therefore, it can be deduced that it is very difficult to differentiate virtual reconstructions from virtual recreations.

Not all virtual reconstructions of a heritage asset incorporate the surroundings, context or landscape [3–5]. Although the most recent studies incorporate them, they do not explain the method they used to obtain these elements [6–10], and only some of them describe the way in which they acquired them [11,12].

A scientific traceability tool used in some virtual reconstructions is the historical-archaeological evidence scale. It consists in the implementation of colours in the virtual reconstruction to show its veracity. All the propositions of historical-archaeological evidence scale consist of a colour scale in which the different evidence levels determine the veracity of the reconstructed archae-

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ological remains [13–16]. None of the existing scales consider the terrain or surroundings. Aparicio and Figueiredo [14] established that, since the terrain did not have a corresponding evidence level, it would be appropriate to apply a colour different from those used for the evidence levels.

Research aim

The aim of the present study was to develop a proposition of resolution scale to graphically represent, interpret and evaluate the terrain associated with virtual reconstructions, addressing the need to provide virtual reconstructions with elements of the surroundings, landscape and context in line with the topography, as this information shows real evidence that has persisted for centuries. The proposition was developed in the terrain associated with Carcabuey Castle (Cordoba, Spain), where its suitability was verified. Subsequently, the proposition was implemented in the virtual reconstruction of the Baker's House at the archaeological site of Torreparedones (Spain) [17], and in the reconstruction of the historic district of Priego de Cordoba (Spain) [18].

Methodology

To attain the main objective of this study (the development of a proposition of terrain resolution scale in virtual reconstruction), a thorough literature review was carried out in the scope of Digital Terrain Model (DTM) creation. This literature review allowed identifying the existing methodologies for the creation of DTM. Likewise, we searched for the evaluation of point density and horizontal and vertical precision of each methodology. These data are gathered in Table 1: source; description; point density; horizontal precision; vertical precision.

The first technique identified for the creation of DTM is the use of Google Earth [19,20]. Through a GIS application, such as Blender GIS, it is possible to upload global mapping through Google Earth, selecting the image of the area of interest; thus, the relief is obtained, creating the 3D view of the area [12].

In Spain, the Spanish Institute of Geography (IGN) plays a fundamental role as a source of geographic data. This institution is considered a Geographic DataBase (GDB), where the data are organised for the realisation of analyses and the management of territory through GIS software. This GDB includes DTM, which are considered as the set of layers that represent different characteristics of the Earth's surface derived from a Digital Elevation Model (DEM). In the Download Centre of the IGN there are four DTM, which depend on the point density marked in the data capture:

- Digital Terrain Model – DTM02: digital terrain model 1st Coverage (2015-present) with 2 m mesh pitch.
- Digital Terrain Model – DTM05: digital terrain model 1st Coverage (2015-present) with 5 m mesh pitch.
- Digital Terrain Model – DTM25: digital terrain model 1st Coverage (2015-present) with 25 m mesh pitch.
- Digital Terrain Model – DTM200: digital terrain model 1st Coverage (2015-present) with 200 m mesh pitch.

The mesh pitch of each model indicates its precision. The smaller the mesh, the greater the DTM precision and reliability. Therefore, DTM02 presents greater precision and reliability than DTM05, and so on. The QGIS software can be used to manipulate the DTM and to obtain the 3D terrain file.

A DTM can be created using three different techniques. The first technique is the use of unmanned aerial vehicles (UAV) [21]. In this case, it is important to consider the target GSD (Ground Sample Distance), which directly depends on the quality criteria of the CCD (Charge-Coupled Device), the pixel size of the camera, orientation, and flight height, amongst other aspects [22]. Prior planning of the flight is essential, and this should include the planning of the overlapping, flight direction, flight speed, and the distribution of points and control marks for the correct georeferencing of the terrain [23–25]. Once the field work is carried out, the georeferenced images are obtained, which, after being processed with a suitable software, such as Agisoft Metashape, provide the 3D model of the terrain [22,26,27].

The second technique for the generation of DEM and DTM is land-based or airborne laser scanning [28–33]. The information gathered by the laser consists of a set of points, represented by XYZ coordinates of the scanned surface with respect to the reference system of the scanner [34]. The result is a set of points called “point cloud”, which must be georeferenced for the subsequent generation of the three-dimensional model [34,35], in photogrammetry programs such as Agisoft Metashape. This georeferencing is achieved by establishing certain control points (homogeneously distributed over the area both planimetrically and altimetrically), to which precise global coordinates are assigned through topographic methods. Point density in this method is defined by the user; depending on the extension of the surface to be scanned, the amount of points to be obtained by the scanner are established [18].

Lastly, the third technique is topographic elevation, which consists in a series of activities aimed at gathering information for the graphic representation of the terrain [36]. The traditional topographic elevation process is conducted through a total station or GPS, which are instruments of reliable measurement for topography [22]. With these measurement instruments placed, levelled, and geolocalised in a precise manner, a global positioning system is obtained. Then, the elevation points that are described by the topography of the area are radiated. Subsequently, back in the office, the obtained data are downloaded and exported to the software, AutoCAD 3D for example, to obtain the shape of the terrain and the DEM [22]. Point density in this technique would be on demand, that is, at the user's choice depending on the area and scale.

Table 1
Compilation of existing methodologies for the creation of DTM.

Source	Methodology description	Point density	Horizontal precision	Vertical precision
Google	Google Earth		>3 m	>2 m
SIG	MDT200	200 m	0.3 m	0.4 m
SIG	MDT25	25 m	0.3 m	0.4 m
SIG	MDT05	5 m	0.3 m	0.4 m
SIG	MDT02	2 m	0.3 m	0.2 m
Independent production	Unmanned aerial vehicle flights	Defined by user	On demand depending on the scale (>10 cm)	On demand depending on the scale (>10 cm)
Independent production	Land-based laser scanning – Airborne laser scanning	Defined by user	On demand depending on the scale (>10 cm)	On demand depending on the scale (>10 cm)
Independent production	Topographic survey	On demand depend in on the area and scale	On demand depending on the scale (>10 cm)	On demand depending on the scale (>10 cm)

It is worth mentioning that there are two sources that were not considered in the current methodologies for obtaining DTMs: historical cartography and aerial photography. Obtaining a DTM from historical cartography involves manual digital modelling or sculpting, as the cartography would be used as a reference for manual modelling. Therefore, the level of accuracy would depend on the person doing the work. For aerial photography, the IGN has aerial photographs or orthophotographs of the entire national territory, as well as their corresponding DTM. Thus, this information could be downloaded directly without the need to personally take the aerial photograph, thereby reducing the workload for obtaining the DTM.

Once the existing methodologies were documented for the creation of a DTM, the following step was to develop the proposition of a terrain-associated resolution scale. To this end, we designed a terrain-associated resolution scale that allows identifying the veracity of the terrain. The terrain resolution scale is implicit to the historical-archaeological evidence scale; therefore, the need to implement one of them would also imply the implementation of the other. Consequently, virtual representation studies must explain how the terrain associated with the virtual reconstruction was obtained.

Results and discussion

Creation of the proposition of a terrain-associated resolution scale

The first step in the creation of the new proposition was to select the classification criterion for the degree of veracity of the DTM. The DTM obtained through our own and external data sources are reliable, although, depending on their precision, they could be classified from greater to lower veracity or vice versa. With a good planning of support points, we could obtain the greatest precision, as long as the distribution and quantity requirements are met. The classification by precision depends both on the scale and on the instrumentation. Precision depends on the scale, since, based on the proximity to the reconstructed 3D model, greater or lower tolerance will be required. The lower the scale, the greater the proximity to the points that make up the 3D model and, therefore, the greater the precision. The greater the scale, the lower the proximity to the points that make up the 3D model and, therefore, the lower the precision. The Andalusian Institute of Historical Heritage has technical recommendations for the geometric documentation of heritage entities.[1] Such document gathers the acceptable precision tolerance according to the working scale. Moreover, the maximum pixel size as a function of the scale is recommended; for instance, for a 1:1 scale, the pixel size must be equal to or under 0.05 mm. Regarding instrumentation, it is usually quite precise, as there are good instruments in the market. However, such instruments are not expected to improve, that is, they are not likely to be more precise in the future. Thus, it is not considered viable to establish a classification methodology as a function of precision.

Taking precision into account, we decided to classify the models as a function of the data sources used for each methodology. The best data are those of lower precision, that is, those obtained through Google (Google Earth). The next data in the classification are those obtained from the SIG; in this case, we decided to group the four data available (MDT02; MDT05; MDT25; MDT200) into the same resolution level. When extrapolating this proposition to the international scope, the data of the SIG would be replaced with those provided by the country in which the study is conducted. Lastly, the data obtained appear as user's production, from manual to mechanical, whose precision is established by the scale and instruments used: topographic elevation; land-based or airborne laser scanning; drone flights.

Although the mentioned data are all reliable, it is necessary to think of another possibility, such as the terrain being created by the user. This implies that, through a digital modelling software, the terrain would be sculpted manually, which entails the addition of a new resolution level associated.

To sum up, the proposition of terrain-associated resolution scale for virtual reconstructions would have six classification levels:

- Topographic elevation
- Land-based laser scanning – Airborne laser scanning
- Drone flights
- SIG – Digital Terrain Model (MDT02; MDT05; MDT25; MDT200)
- Google
- Digital manual sculpting

Using the terrain-associated resolution scale implies selecting, for the terrain proposition, colours that are different from all those implemented in the historical-archaeological propositions. The selection of colours for the terrain-associated proposition is difficult, due to the chromatic variety amongst the historical-archaeological propositions. For instance, a chromatic variety of blue colours would work in the last two propositions [15,16], but not in [13] and [37]. On the other hand, a variety of brown colours would work for all the propositions, except for [15], and so on.

The above mentioned indicates that any chromatic spectrum selected for the terrain resolution scale will have colours similar to those of some of the existing propositions of historical-archaeological evidence scales. Therefore, this study advocates for the implementation of defined colours used for the representation of terrains by contour lines. The subjective connotations of colours also play an important role in this sense, due to the meanings that are associated by society to the colours in a conventional and generalised manner [38–41].

Verifying the effectiveness of the resolution levels proposed, as well as the colours selected, required their implementation in a DTM. To date, all works have been conducted in the Baker's House at the archaeological site of Torreparedones. However, the points that make up the DTM of this site do not show great differences in terms of mesh, thus they do not have a marked relief. Consequently, another terrain was selected, in which research is currently being carried out. This terrain corresponds to Carcabuey Castle (Cordoba), and it has greater topographic characteristics.

The DTM obtained for Carcabuey Castle was generated through the implementation of four methodologies (Fig. 1): unmanned aerial vehicle (UAV); Digital Terrain Model – DTM05; Digital Terrain Model – DTM25; Google Earth. These methodologies were selected for the precision obtained from each of them. In this case, the aim was to achieve greater precision in the natural rock on which the castle is located; therefore, the delimited terrain was obtained through unmanned aerial vehicle flight. For the terrains that make up the rest of the surroundings, the further away they are from the castle, the lower the precision they require; thus, less precise methodologies were implemented.

In a previous study based on the creation of a new proposition of historical-archaeological evidence scale [16], it was important to convert the chromatic scale to achromatism for the selection of colours of different intensities. Achromatism consists in modifying the attribute "colour value" [42,43], transforming the chromatic scale into an achromatic scale, where a scale of values is obtained, in which the intensity of each colour can be observed.

As was previously mentioned, the colours selected for the new proposition of terrain-associated scale were based on a sienna

[1] Technical recommendations for the geometric documentation of heritage entities provided by the Andalusian Institute of Historical Heritage (Culture Department) (v1.0 23/11/2011) https://www.iaph.es/export/sites/default/galerias/patrimonio-cultural/documentos/gestion-informacion/recomendaciones_tecnicas_documentacipm_geometrica.pdf.

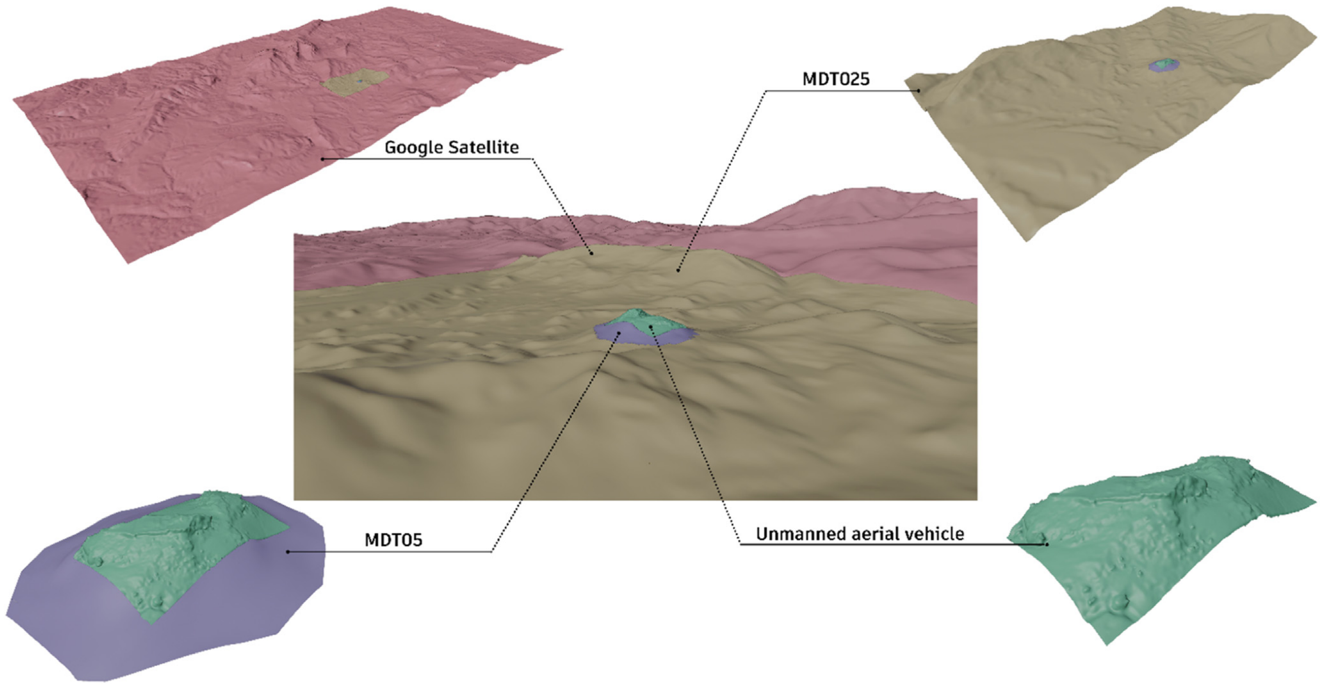

Fig. 1. Differentiation by colours of the methodologies used to obtain the terrain: Green: UAV; Violet: MDT05; Yellow: MDT25; Pink: Google Earth). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Scale of greys of the veracity levels of the proposition of terrain-associated scale.

Level of resolution	Definition	Colour
1	Digital manual sculpting	
2	Google	
3	SIG –Digital Terrain Model (DTM02; DTM05; DTM25; DTM200)	
4	Drone flights	
5	Land-based laser scanning; Airborne laser scanning	
6	Topographic elevation	

spectrum. For its adjustment, achromatism was considered, which allowed adapting the intensity of each colour. Before establishing as optimal the colours selected for the proposition, they were implemented in the DTM of Carcabuey Castle (Table 2).

After verifying the dissimilarity of the values that make up the achromatic scale, we obtained a scale of colours with different intensities amongst them. This scale consists of six veracity levels associated with the existing methodologies for the generation of a DTM as a function of precision, ordered from lower to greater precision (Table 3; Fig. 2).

Once the resolution levels and the colours associated with them were established, a more complex aspect was addressed: the reconstructive units. These are understood as a record system that allows for a better identification of each of the elements of the reconstruction [14]. A reconstructive unit is constituted by a reconstructed element, for example, walls, windows, floors, etc. Likewise, an element can have several reconstructive units, as it can be composed of one part reconstructed based on what is preserved and another part reconstructed from comparative architecture [44]. Furthermore, each reconstructive unit is associated with an evidence level and, therefore, with a colour. This entails that different reconstructive units can have the same evidence level, which means that their reconstruction was conducted under the same criterion (comparative architecture, archaeological hypothesis, etc.), although referring to different elements [44].

The record system with reconstructive units was designed to be used in the historical-archaeological evidence scale [14]. This system could contain the terrain if this were identified with such scale; however, as this is not the case, it was necessary to establish a new system for the terrain. Since the terrain-associated resolution scale was created based on the methodology used to obtain it, for its similarity with the proposition, it was decided to identify the terrain resolution levels with methodological units (MU). These would have the same theoretical basis as reconstructive units, but they would identify the units that correspond to the terrain-associated resolution scale.

In the case of the terrain of Carcabuey Castle, since it contains four methodologies for its generation, there would be four MUs (Fig. 3). The first MU (MU1) would correspond to resolution level 4 (UAV), followed by the MUs of the DTM of SIG, DTM05 and DTM25. Although both DTM05 (MU2) and DTM25 (MU3) correspond to the same resolution level (3), they are different MUs, since the data used for the generation of each terrain are different. Finally, the last MU (MU4) corresponds to resolution level 2, since it was obtained using data from Google Earth.

Implementation of the new proposition in a virtual reconstruction

The Baker's House (Torreparedones, Baena, Spain)

The Baker's House is located in the archaeological site of Torreparedones (Baena, Cordoba, Spain) [44]. It is a Roman *domus* with occupation from the Late Republican, Early Imperial and Medieval–Modern Ages [17]. After performing the virtual reconstruction of the building and analysing the existing propositions of evidence

Table 3
Resolution scale proposed for the terrain associated with virtual reconstructions.

Level of resolution	Definition	Colour	RGB	HEX
1	Digital manual sculpting		53 36 13	35240D
2	Google		93 63 25	5D3F19
3	SIG –Digital Terrain Model (DTM02; DTM05; DTM25; DTM200)		124 87 37	7C5725
4	Drone flights		150 115 69	967345
5	Land-based laser scanning; Airborne laser scanning		169 144 112	A99070
6	Topographic elevation		233 218 177	E9DAB1

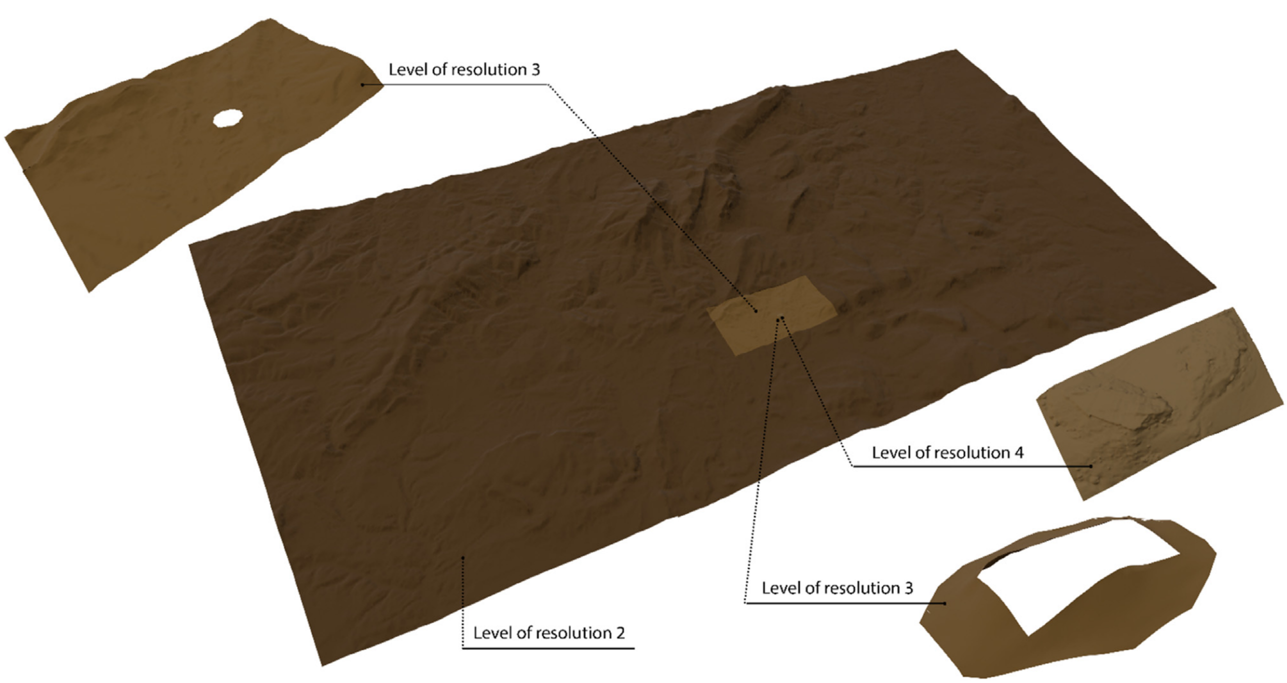

Fig. 2. Implementation of the terrain-associated resolution scale in Carcabuey Castle.

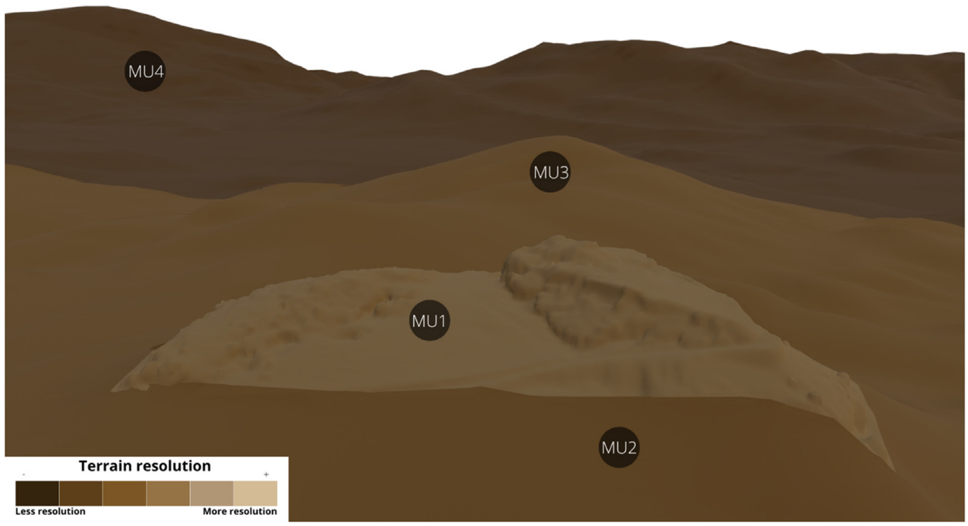

Fig. 3. Final infogram of the terrain-associated resolution scale of Carcabuey Castle.

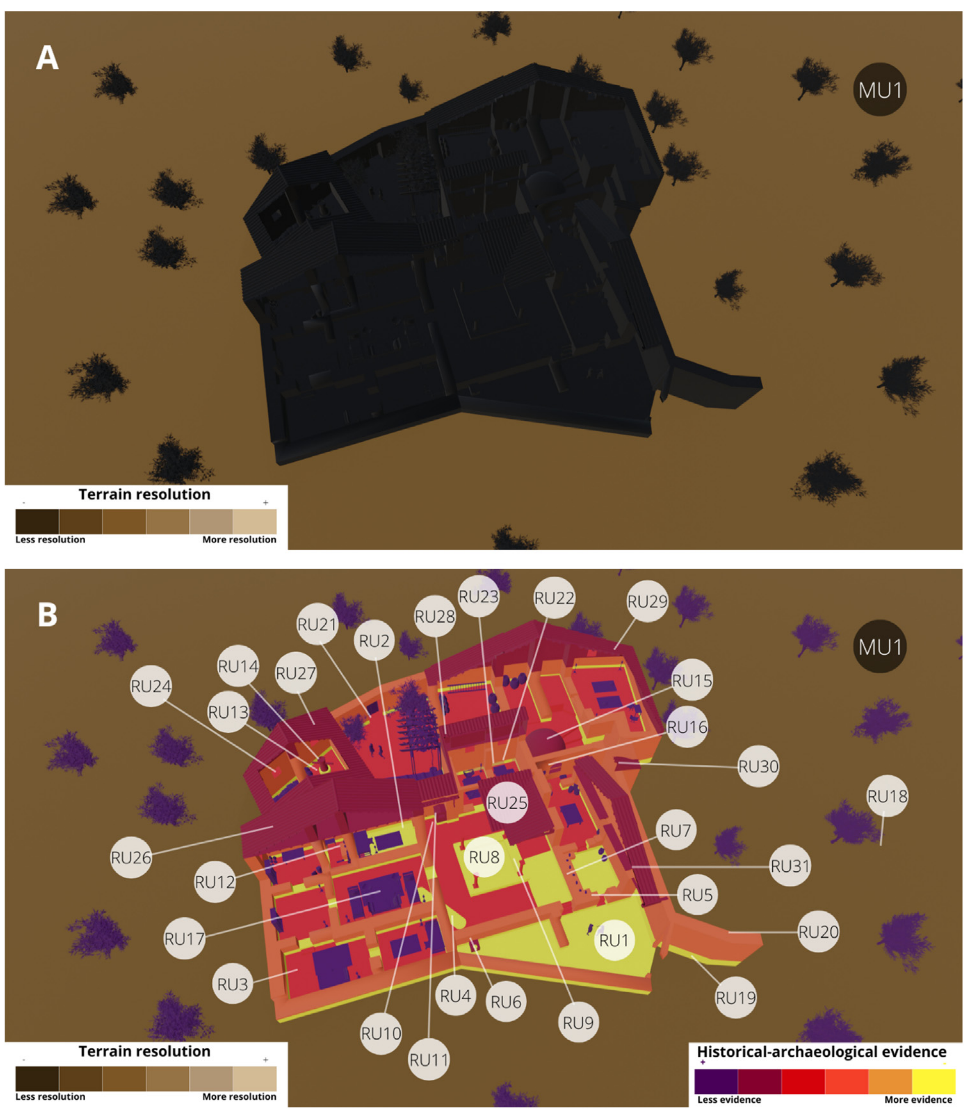

Fig. 4. Final infogram of the Baker's House: A. Terrain-associated resolution scale; B. Terrain-associated resolution scale and historical-archaeological evidence scale.

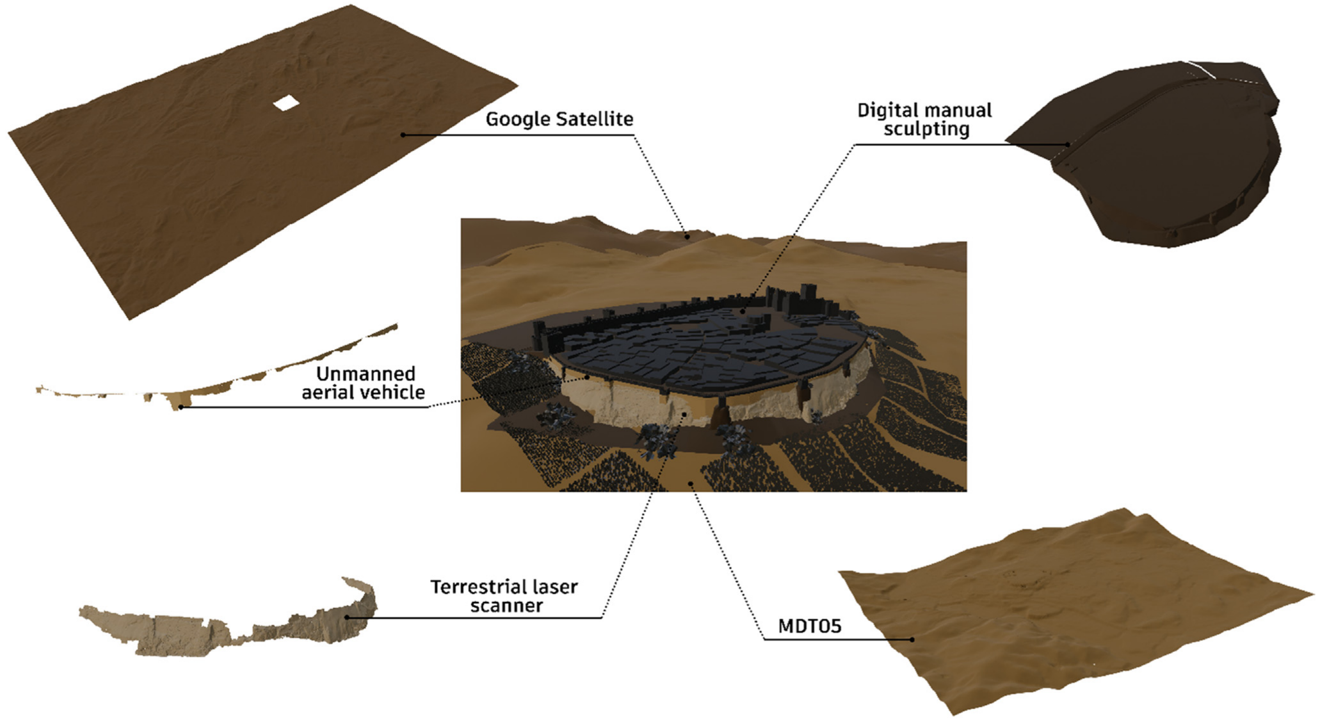

Fig. 5. Identification of the methodologies used to obtain the terrain associated with the historic district of Priego de Cordoba.

scales [45,46], a new proposition of historical-archaeological evidence scale was conducted by Cáceres-Criado [16]. As in the previous propositions, the most recent proposition does not consider the terrain in the historical-archaeological evidence scale. In other words, to date, the virtual reconstructions generated with an associated historical-archaeological evidence scale do not take the terrain into account.

At this point, we implemented the terrain-associated resolution scale for the virtual reconstruction of the Baker's House. To this end, it is important to consider the methodology that was previously used to create the terrain associated with the *domus* of Torreparedones. In this case, we used data from the Spanish Institute of Geography, specifically, the Digital Terrain Model of 1st Coverage with 5 m mesh pitch (DTM05) [12]. Therefore, this terrain is associated with resolution level 3.

The MUs of the terrain were represented in a similar way as in the case of the reconstructive units, except for the inversion of colours, in order to better differentiate them. The final result would be the generation of an infogram that shows two captions: 1) the one corresponding to the historical-archaeological evidence scale; and 2) the one corresponding to the terrain-associated resolution scale (Fig. 4). Moreover, this infogram must also show the reconstructive units associated with each reconstructed element of the heritage asset, as well as the MUs associated with the terrain.

All the information gathered in the image would be linked to an explanatory table, which would provide detailed information, focusing on aspects such as [16]: the number of reconstructive units/methodological units; evidence/resolution level; name; description; chronology; bibliographic references. Including the MUs in the explanatory table guarantees necessary information in the long term. For instance, the MU1 of the Baker's House shows the year of the DTM used. This information could be renewed in the future after updating the data of the SIG. Moreover, if the DTM is modified with more recent data, this could lead to new studies on the terrain and potential variations in time.

The terrain obtained for the Baker's House does not have great elevation differences in its topography. Therefore, in the final infogram of the implementation of the scales (Fig. 4), a flat terrain with no relief is observed. Next, we present another example of the terrain obtained for a virtual 3D reconstruction, a terrain obtained with different methodologies that has greater topographic elevations.

Historic district of Priego de Cordoba

The virtual 3D reconstruction of the walled enclosure and the town of Priego de Córdoba, at the time of its greatest splendour (15th century), was previously carried out by Diego F. García Molina as part of his doctoral thesis [18]. In the search to implement the resolution scale of the terrain associated with a virtual reconstruction, this site was chosen based on the methodological possibilities for its creation, as well as for showing greater differences in topographic levels compared to the previously mentioned terrain.

A fundamental characteristic of this site is its natural ditch, also known as the walkway ditch. It is set as a natural wall that, along with man-made walls and towers, enclosed and defended the neighbourhood of the town in the Middle Ages [47].

For the creation of the terrain associated with the historic district of Priego de Cordoba, five methodologies were used (Fig. 5). Firstly, the neighbourhood of the town was reconstructed by digital manual sculpting, using orthophotographs. Over this model, the ditch was placed, which was obtained through two methodologies. One of these methodologies was land-based laser scanning, which allowed generating the natural rock that makes up said ditch; the other methodology, i.e., traditional topographic elevation, was used to obtain the model that would join the natural rock of the ditch with the medieval walkway. The surroundings of the historic district were created with data from the SIG, specifically DTM02. Lastly, for the terrain that corresponds to the horizon, we used data from Google Earth.

The five methodologies implemented to create the terrain are associated with five terrain resolution levels: 1) Neighbourhood of the town: resolution level 1; 2) horizon terrain: resolution level

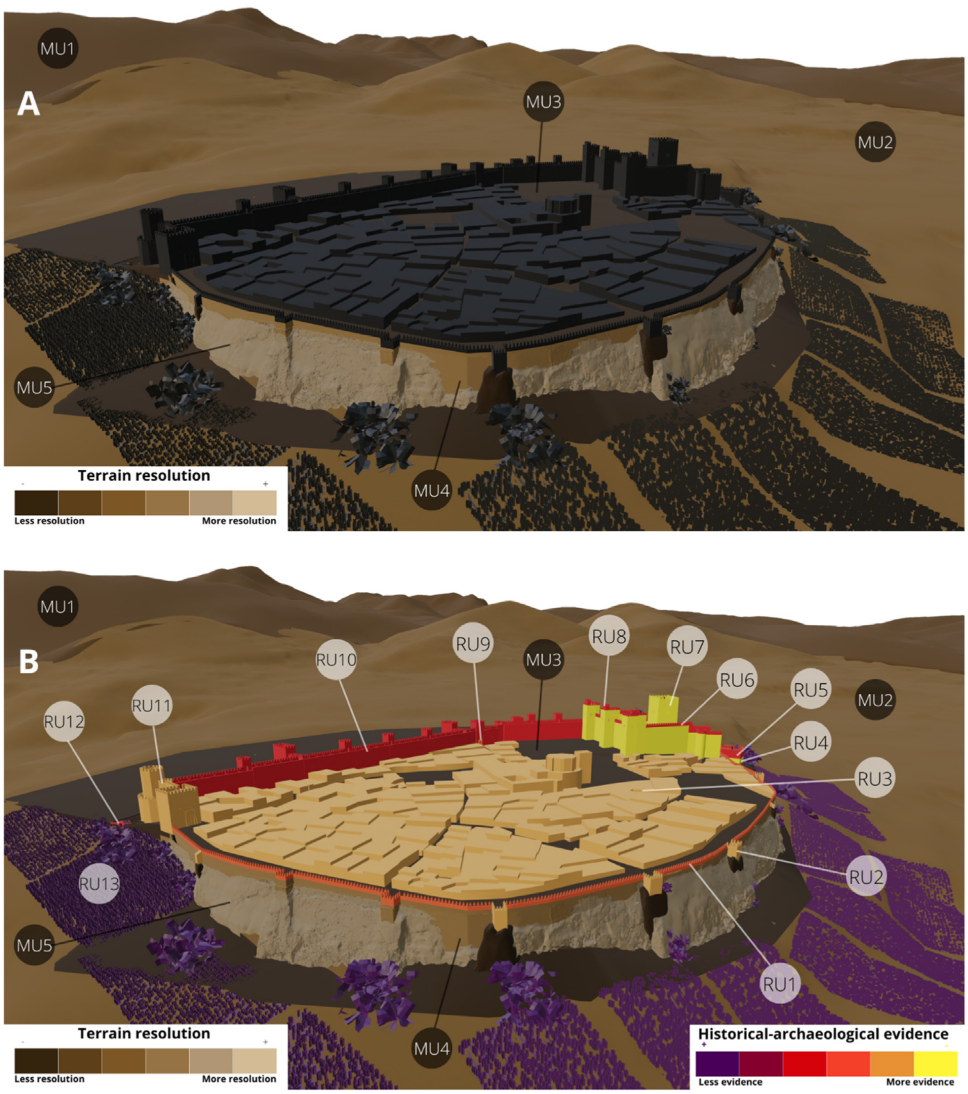

Fig. 6. Final infogram of the virtual reconstruction of the walled enclosure and the town of Priego de Córdoba: A) terrain-associated resolution scale; B) terrain-associated resolution scale and historic-archaeological evidence scale.

2; 3) detail terrain: resolution level 3; 4) natural ditch: resolution level 5; 5) ditch-walkway joint: resolution level 4. Regarding the record of the methodologies used to create the terrain, five methodological units were established, one per level of veracity: MU1 (resolution level 2); MU2 (resolution level 3); MU3 (resolution level 1); MU4 (resolution level 5); and MU5 (resolution level 4). As a final result, we obtained an infogram that shows the terrain-associated resolution level (MU) and the historical-archaeological evidence scale of the reconstructed heritage asset (Fig. 6).

The altimetric differences in the historic district of Priego de Cordoba make up an optimal infogram to visualise the relief of the terrain.

Conclusions

The implementation of propositions of historical-archaeological evidence scales in virtual reconstructions help to interpret and disseminate the heritage. The implementation of the terrain resolution scale alongside the historical-archaeological evidence scale can be used to represent the quality levels of virtual reconstructions, and it contributes to the dissemination of the archaeological heritage. Furthermore, it paves the road for the application of a digital research methodology in this field, and, with its use, it is intended to encourage the expert community in the construction of a common language. The creation of a proposition of terrain-associated resolution scale adds precision and greater veracity to the reconstruction of the physical surroundings.

The reconstructive units and methodological units imply the study and construction of the historical discourse shown in a single graphic image. The final infogram obtained, in which both scales are implemented, along with the explanatory table associated, highlight the virtual archaeological work conducted, for both the heritage asset and its surroundings.

The terrain-associated resolution scale proposed and described in this study poses the first creation of a criterion that can be understood and applied by the expert community. Furthermore, it helps the observers to understand and visualise the landscape represented in virtual reconstructions. To sum up, the terrain-associated resolution scale meets the principles established in the Seville Principles.

Through this research work, it was possible to represent the terrain associated with the virtual reconstructions of heritage assets based on a graphic scale. This fact can be transferred to other scientific disciplines, such as topography and engineering, amongst others. Any expert of another scientific discipline who obtains Digital Terrain Models in their research may implement the terrain resolution scale to show their veracity, that is, the methodology used for the generation of the Digital Terrain Models.

Author contributions

D-FG-M and IC-C contributed to the conceptualization; ICC, PT-T and J-MV-Z were involved in the methodology; PTT and D-FG-M contributed to the validation; IC-C, D-FG-M, PT-T and J-MV-Z were involved in the investigation; D-FGM contributed to the resources; IC-C contributed to the data curation; IC-C and PT-T contributed to the writing—original draft preparation; IC-C, PT-T and D-FG-M were involved in the writing—review and editing; IC-C and PT-T contributed to the supervision. All authors have read and agreed to the published version of the manuscript.

Availability of data and materials

The data and material can be provided upon request from Paula Triviño-Tarradas (ig2trtap@uco.es).

References

[1] L. Caballero-Zoreda, El dibujo arqueológico: Notas sobre el registro gráfico en arqueología, Papeles Partal 3 (2006) 75–95.

[2] R. Castelo-Ruano, M. Aguado, M. Zamora, A. López, C. Sierra, Novedades En La Interpretación Arquitectonica De La Villa Bajoimperial De El Saucedo (Talavera La Nueva, Toledo) Y Su Reconstrucción Virtual. Anales de Prehistoria y Arqueología (2002). Available at: https://revistas.um.es/apa/article/view/60991. Accessed 9 December 2022.

[3] M.F. Gutiérrez, Á.R. Soria, J.M. García, S.F.R. Asensio, A.F. Díaz, Visualización virtual de la Quintilla, Virtual Archaeol. Rev. 4 (9) (2013) 143–147.

[4] V.M. López-Menchero, A. Grande, Hacia una carta internacional de arqueología virtual. El borrador SEAV, Virtual Archaeol. Rev. 2 (4) (2011) 71–75.

[5] C. Portalés, P. Alonso-Monasterio, M.J. Viñals, Reconstrucción virtual y visualización 3d del yacimiento arqueológico Castellet de Bernabé (Lliria, España), Virtual Archaeol. Rev. 8 (16) (2017) 75–82.

[6] D. Vizcaíno, J.J. Bienes, E. Bravo, J.M. Soler, La reconstrucción virtual del patrimonio arqueológico al servicio de la divulgación y puesta en valor de la Villa Romana de Liédena (Navarra, España), Virtual Archaeol. Rev. 4 (8) (2013) 104–108.

[7] J. García Carpintero López de Mota, D.Gallego Valle, La arqueología de órdenes militares en Castilla-La Mancha y la reconstrucción virtual de su patrimonio, Virtual Archaeol. Rev. 9 (19) (2018) 76–88.

[8] M. Cabezas-Expósito, F.D.P. Montes-Tubío, Reconstrucción virtual de la fortaleza bajomedieval de Aguilar de la Frontera. EGA, Rev. Expresión Gráfica Arquitectónica 24 (35) (2019) 236–247, doi:10.4995/ega.2019.10200.

[9] P. Valle, A. Fernández, A.A. Rodríguez, Lost archaeological heritage: virtual reconstruction of the medieval castle of San Salvador de Todea, Virtual Archaeol. Rev. 13 (26) (2022) 22–44.

[10] F.X. Hernàndez-Cardona, R. Sospedra-Roca, J.R. Casals-Ausió, Virtual and didactic approach to the defensive heritage of the 16th century Fort of the Trinitat (Roses, Girona), Virtual Archaeol. Rev. 13 (26) (2022) 103–115.

[11] P. Aparicio-Resco, A. García Álvarez-Busto, I. Muñiz-López, N. Fernández–Calderón, Reconstrucción virtual en 3D del castillo de Gauzón (Castrillón, Principado de Asturias), Virtual Archaeol. Rev. 12 (25) (2021) 158–176.

[12] P. Triviño-Tarradas, D.F. García-Molina, R. Hidalgo-Fernández, I. Cáceres-Criado, Digital Representation of the Terrain Associated with an Archaeological Site: case Study of the 'Baker's House'in Torreparedones, International conference on the Digital Transformation in the Graphic Engineering, Springer, Cham, 2021.

[13] Byzantium 1200. Available at: http://www.byzantium1200.com/. Accessed 27 November 2022.

[14] P. Aparicio, C. Figueiredo, El Grado De Evidencia Histórico-Arqueológica De Las Reconstrucciones Virtuales: Hacia Una Escala De Representación Gráfica, Revista Otarq: Otras arqueologías 1 (2016) 235–247, doi:10.23914/otarq.v0i1.96.

[15] R. Ortiz, E. León, R.E. Hidalgo, Proposal for the improvement and modification in the scale of evidence for virtual reconstruction of the cultural heritage: a first approach in the mosque-cathedral and the fluvial landscape of Cordoba, J. Cult. Herit. 30 (2018) 10–15, doi:10.1016/j.culher.2017.10.006.

[16] I. Cáceres-Criado, D.F. García-Molina, F.J. Mesas-Carrascosa, P. Triviño-Tarradas, New approach for optimizing the interpretation and representation of the degree of historical-archaeological evidence in the virtual reconstructions, Virtual Real 27 (2) (2022) 1–17.

[17] I. Cáceres-Criado, P. Triviño-Tarradas, J.M. Valderrama-Zafra, D.F. García-Molina, Digital preservation and virtual 3D reconstruction of" The Baker's house" in the archaeological site of Torreparedones (Baena, Cordoba-Spain), Digit. Appl. Archaeol. Cult. Herit. 24 (2022).

[18] D.F. García-Molina, Estudio Comparativo De Distintas Técnicas Para La Documentación y Puesta En Valor Del Patrimonio Ingeniero-Arquitectónico (Doctoral Dissertation, Universidad de Córdoba (ESP), 2017.

[19] S.C. Benker, R.P. Langford, T.L. Pavlis, Positional accuracy of the Google Earth terrain model derived from stratigraphic unconformities in the Big Bend region, Texas, USA, Geocarto Int. 26 (4) (2011) 291–303, doi:10.1080/10106049.2011.568125.

[20] J.U. Richard, C. Ogba, Analysis of accuracy of differential global positioning system (DGPS) and Google Earth digital terrain model (DTM) data using geographic information system techniques, J. Geodesy Geomat. Eng. 2 (2016) 52–61.

[21] W.S. Udin, A.F. Hassan, A. Ahmad, K.N. Tahar, Digital Terrain Model extraction using digital aerial imagery of Unmanned Aerial Vehicle, in: 2012 IEEE 8th International Colloquium on Signal Processing and Its Applications, 2012, pp. 272–275.

[22] J.J. Cabada Quiliche, Evaluación de precisión y costo en un levantamiento topográfico con estación total y aeronave pilotada remotamente (RPA-DRON) en el centro poblado Cashapampa–Cajamarca 2018 (2019).

[23] F.J. Mesas-Carrascosa, F. Pérez Porras, P. Triviño-Tarradas, J.E. Meroño de Larriva, A. García-Ferrer, Project-based learning applied to unmanned aerial systems and remote sensing, Remote Sens. 11 (20) (2019) 2413, doi:10.3390/rs11202413.

[24] F.J. Mesas-Carrascosa, A.I. de Castro, J. Torres-Sánchez, P. Triviño-Tarradas, F.M. Jiménez-Brenes, A. García-Ferrer, F. López-Granados, Classification of 3D point clouds using color vegetation indices for precision viticulture and digitizing applications, Remote Sens. 12 (2) (2020) 317, doi:10.3390/rs12020317.

[25] N. Lopes-Bento, G.A. Silva-Ferraz, R.A. Pena-Barata, L. Santos-Santana, B.D. Souza-Barbosa, L. Conti, V. Becciolini, G. Rossi, Overlap influence in images obtained by an unmanned aerial vehicle on a digital terrain model of altimetric precision, Eur. J. Remote Sens. 55 (1) (2022) 263–276.

[26] M. Govorčin, G.E. Geoinf, B. Pribičević, A. Đapo, Comparison and analysis of software solutions for creation of a digital terrain model using unmanned aerial vehicles, in: 14th International Multidisciplinary Scientific GeoConference SGEM, 2014, pp. 99–108.

[27] M.Fernández Díaz, La Profesión de Piloto de Drones en el ámbito del Patrimonio Cultural y la Arqueología: ciencia y divulgación desde el aire (2018).

[28] A. Kobler, N. Pfeifer, P. Ogrinc, L. Todorovski, K. Oštir, S. Džeroski, Repetitive interpolation: a robust algorithm for DTM generation from Aerial Laser Scanner Data in forested terrain, Remote Sens. Environ. 108 (1) (2007) 9–23.

[29] K.A. Razak, M. Santangelo, C.J. Van Westen, M.W. Straatsma, S.M. de Jong, Generating an optimal DTM from airborne laser scanning data for landslide mapping in a tropical forest environment, Geomorphology 190 (2013) 112–125, doi:10.1016/j.geomorph.2013.02.021.

[30] J.P. Resop, L. Lehmann, W.C. Hession, Drone laser scanning for modeling riverscape topography and vegetation: comparison with traditional aerial lidar, Drones 3 (2) (2019) 35, doi:10.3390/drones3020035.

[31] F. Marotta, S. Teruggi, C. Achille, G.P.M. Vassena, F. Fassi, Integrated laser scanner techniques to produce high-resolution DTM of vegetated territory, Remote Sens. 13 (13) (2021) 2504.

[32] G. Del Duca, C. Machado, Assessing the quality of static terrestrial and mobile laser scanning for a preliminary study of garden digital surveying (2022).

[33] S.K.P. Kushwaha, A. Singh, K. Jain, M. Mokros, Optimum number and positions of terrestrial laser scanner to derive DTM at forest plot level, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. (2022) 457–462 XLIII-B3-2022, doi:10.5194/isprs-archives-XLIII-B3-2022-457-2022.

[34] H. Porras, J.J. Cáceres, E.O. Gallo, Modelos urbanos tridimensionales generados a partir de nubes de puntos de un escáner láser terrestre, Tecnura: Tecnología y Cultura Afirmando el Conocimiento 18 (41) (2014) 134–153.

[35] J.M. Corso, Gestión y Explotación De La Información TLS De 3D a 2D y 2.5D: análisis, Selección y Síntesis a Partir De La Tecnología Escáner Láser Terrestre, Universitat Politècnica de Catalunya, 2015. Doctoral thesis Available at https://www.tdx.cat/handle/10803/321364#page=1. Accessed 5 December 2022.

[36] R. Pachas, El levantamiento topográfico: Uso del GPS y estación total, Academia 8 (16) (2009) 29–45.

[37] P. Aparicio, HAcia Una Nueva Versión De La Escala De Evidencia Histórico-Arqueológica Para Reconstrucciones Virtuales (2022). https://parpatrimonioytecnologia.wordpress.com/2022/06/06/hacia-una-nueva-version-de-la-escala-de-evidencia-historico-arqueologica/.

[38] L.C. Ou, M.R. Luo, A. Woodcock, A. Wright, A study of colour emotion and colour preference. Part III: colour preference modeling, Color Res. Appl. 29 (5) (2004) 381–389, doi:10.1002/col.20047.

[39] B. Bazán, La conexión emocional con el color. Los colores que más y menos gustan en España y sus significados, Rev. Sonda. Invest. Artes Letras (7) (2018) 275–290. Available at https://dialnet.unirioja.es/servlet/articulo?codigo=6797576. Accessed 29 November 2022.

[40] J.A. Corbin, Colores y emociones: ¿cómo se relacionan entre sí? Psicología y Mente, 2020. Available at https://psicologiaymente.com/psicologia/colores-emociones-relacionan. Accessed 3 December 2022.

[41] S. BytyÇi, Influence of colors as a key element in consumer marketing, Expert J. Market. 8 (2020) 41–47 Available at https://marketing.expertjournals.com/ark:/16759/EJM_803byty%C3%A7i41-47.pdf. Accessed 10 December 2022.

[42] B. Edwards, Color by Betty Edwards: A Course in Mastering the Art of Mixing Colors, TarcherPerigee, New York, USA, 2004.

[43] L. De Grandis, Teoría y Uso del Color, Ed. Cátedra, Madrid, 1985.

[44] A. Peñuela, A. Hayas, J. Infante-Amate, P. Ruiz-Montes, A. Temme, T. Reimann, A. Peña-Acebedo, T. Vanwalleghem, A multi-millennial reconstruction of gully erosion in two contrasting Mediterranean catchments, Catena 220 (2023) 106709.
[45] I. Cáceres-Criado, D.F. García-Molina, F.J. Mesas-Carrascosa, P. Triviño-Tarradas, Graphic representation of the degree of historical-archaeological evidence: the 3D reconstruction of the "Baker's House, Herit. Sci. 10 (1) (2022) 1–14.
[46] I. Cáceres-Criado, D.F. García-Molina, R.E. Hidalgo-Fernández, P. Triviño-Tarradas, Techniques for the representation of the application of historical-archaeological evidence scales in heritage assets, in: International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing, Springer, Cham, 2023, pp. 3–10.
[47] D.F. García-Molina, R. González-Merino, J. Rodero-Pérez, B. Carrasco-Hurtado, Documentación 3D para la conservación del patrimonio histórico: el castillo de Priego de Córdoba, Virtual Archaeol. Rev. 12 (24) (2021) 115–130.