New approach for optimizing the interpretation and representation of the degree of historical-archaeological evidence in the virtual reconstructions

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Abstract

Virtual reconstruction is defined as the visual recovery of a building or object through the creation of a three-dimensional model of the asset to be reconstructed, in a historical context. To provide the degree of veracity to the virtual reconstructions performed in the scope of heritage, the so-called historical-archaeological evidence scale emerged. Some authors have already used this methodology to provide their reconstructions with the degree of evidence, although none of the current propositions of evidence scales have been standardised to date. Moreover, it is still important to disseminate such scales as much as possible, since it has been shown that neither experts in this field of knowledge nor common users know about this methodology.

The aim of this study was to design and create a new proposition of historical-archaeological evidence scale based on the achromatism and implement it in the 'Baker´s House' at the archaeological site of Torreparedones (Baena, Córdoba, Spain). To carry out this investigation, it was essential to compare and analyse each proposition of historical-archaeological evidence scale. The qualitative and quantitative studies about the existing scale propositions also played a fundamental role in the realisation of this work. These results, in addition to the chromatic study, support the creation of a new proposition of historical-archaeological evidence scale, designed for any type of viewer. Each phase of the study met the quality standards established for this type of research.

Keywords Baker's House · virtual reconstruction · historical-archaeological evidence scale · quantitative-qualitative study

1 Introduction

In the archaeological scope, virtual reconstruction plays a fundamental role as a research tool (Machete et al. 2021; Moskvin et al. 2021; Rebec et al. 2022). Regarding the interpretation of heritage, the historical-archaeological evidence scale designates the representation of the degree of veracity of virtual reconstructions through the use of colour. To date, three historical-archaeological evidence scales have been used in the scientific literature: 1) the pioneering proposition, i.e., the historical-archaeological evidence scale developed in the Byzantium 1200 project (Byzantium 1200); 2) the proposition of P. Aparicio and C. Figueiredo (Aparicio and Figueiredo 2017); and 3) the more recent proposition used for the reconstruction of the Mosque-Cathedral and river landscape of Córdoba (Spain) (Ortiz et al. 2018).

The first two propositions of historical-archaeological evidence scale are distinguished by the fact that their evidence levels (10 levels in total for both) are inverted with respect to each other. For the proposition developed in the Byzantium project, the evidence levels are ordered from greater to lower veracity (Byzantium 1200), whereas the scale proposed by Aparicio and Figueiredo is ordered from lower to greater levels of historical-archaeological evidence (Aparicio and Figueiredo 2017; Aparicio 2016; Aparicio et al. 2021). Although the levels were inverted, their colours were not modified, and thus they have a very similar colour range of warm and cool colours. However, the third proposition uses a colour range from dark greens to browns, with eight levels of historical-archaeological evidence (Ortiz et al. 2018).

Table 1 shows the bibliometric study conducted on the implementation of the historical-archaeological evidence scales throughout history.

Table 1 Bibliometric study on the implementation of the existing historical-archaeological evidence scales.

Reference	Applied scale	Item	Levels	Chromatic gradation
http://www.byzantium1200.com/ (Byzantium 1200)	Byzantium 1200 project	Byzantium city around 1200	10	From warm to cool colours (greater evidence-lower evidence)

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Aparicio 2016	Aparicio & Figueiredo	The crenellated tower of San García, Algeciras (Spain) (17th-18th century). Virtual recovery of a military structure using technology	10	From cool to warm colours (lower evidence-greater evidence)
Aparicio and Figueiredo 2017	Aparicio & Figueiredo	The historical-archaeological evidence degree of virtual reconstructions: toward a graphic representation scale	10	From cool to warm colours (lower evidence-greater evidence)
De Mota and Valle 2018	Aparicio & Figueiredo	Archaeology of the military orders in Castilla-La Mancha and the virtual reconstruction of its heritage	10	From cool to warm colours (lower evidence-greater evidence)
Ortiz et al. 2018	COR_16	Proposal for the improvement and modification of the scale of evidence for the virtual reconstruction of cultural heritage: A first approach to the Mosque-Cathedral and the river landscape of Córdoba (Spain)	8	Colour range from greens to browns
Rodríguez-Hernández et al. 2021	Aparicio & Figueiredo	Virtual 3D reconstruction of the "Fortified tower" of the Ulaca Oppidum (Solosancho, Ávila, Spain): much more than an image	10	From cool to warm colours (lower evidence-greater evidence)
Aparicio et al. 2021	Aparicio & Figueiredo	Virtual 3D reconstruction of Gauzón Castle (Castrillón, Principado de Asturias, Spain)	10	From cool to warm colours (lower evidence-greater evidence)
Cáceres-Criado et al. 2022	Aparicio & Figueiredo	Graphic representation of the degree of historical-archaeological evidence: the 3D reconstruction of the "Baker's House"	10	From cool to warm colours (lower evidence-greater evidence)

Each of the existing propositions of representation scales uses specific colours. Behavioural scientists have reported that colour affects the reactions of the human organism, produces certain physiological reactions, creates emotional states and draws attention (Sierra et al. 2000).

Most experts agree that it is ideal to reflect the degree of historical-archaeological evidence in the virtual representation of a heritage asset, for the sake of clarity and authenticity. The graphic representation of the degree of historical-archaeological veracity, with a new proposition of evidence scale, considers the objectives set in projects conducted in the scope of virtual archaeology (López Menchero and Grande 2011; SEAV 2011; The London Charter).

1.1 Literature review

Previous studies have carried out the virtual reconstruction of the Baker´s House, at the archaeological site of Torreparedones (Baena, Córdoba, Spain) (Cáceres-Criado et al. 2022). This heritage asset, as is indicated by its name, is characterised by the presence of the base of a Roman bread oven, as well as the foundation of what could have been a rotatory mill (Morena et al. 2016; Morena et al. 2019). It has three constructive phases: late Republican Roman phase; late Imperial Roman phase; and Modern-Medieval phase. The virtual reconstruction is focused on the second phase (late Imperial Roman phase).

For the correct dissemination of the scientific work performed in this Roman house, the historical-archaeological evidence scale was considered a key element. The debate was about which of the propositions of historical-archaeological evidence scales would be the most suitable for the graphic representation of the archaeological remains found. The existing propositions were compared by implementing them in a specific area of the Baker's House (Cáceres-Criado et al. Pending to be published in lectures Notes in Mechanical Engineering). Based on the amount of reconstructive units presented by the virtual reconstruction, the results of such study showed that the best option was the proposition of Pablo Aparicio and César Figueiredo (Cáceres-Criado et al. 2022).

At this point, a question emerged, which motivated the present study. The scientific character of the evidence scale raises doubts about its objective: Is the evidence scale designed only for experts in the field of archaeology or is it aimed at the viewers of the archaeological sites?

The creation of a new proposition of evidence scale is considered appropriate to attain a visual representation scale that can be easily employed and understood by any type of

viewer. To this end, it is fundamental to reduce the evidence levels and the modification of their colours. Moreover, previous studies provide data that support the creation of the new proposition.

Furthermore, one step further would be to understand evidence scaling as a technique for evaluating virtual reality systems. The virtual reconstruction of a heritage asset together with the infographic of the scale of evidence helps with the visual interpretation of the veracity of the work carried out. This topic could be included in the so-called "Museums of the 21st century", where users would learn about the heritage asset and the 3D reconstruction work, for example, with virtual reality screens (Puig et al. 2020; Baradaran-Rahimi et al. 2022; Scavarelli et al. 2021; Hammady et al. 2021).

1.2 Research aim

The present study aims to disseminate archaeological work through the use of a new proposition of historical-archaeological evidence scale. This proposition is supported by a quantitative and qualitative analysis made for the 'Baker´s House' at the archaeological site of Torreparedones.

The main objective of this study was to generate a proposition of historical-archaeological evidence scale for the virtual reconstructions as a universal, understandable and applicable criterion for both experts and viewers in general. The aim is to provide the public with greater understanding of both the archaeological heritage and the scientific work conducted in the heritage assets.

2 Methodology

The present work was conducted in three methodological phases (Fig. 1): comparison of the existing historical-archaeological evidence scales; creation of the new historical-archaeological evidence scale; and implementation of the new proposition of historical-archaeological evidence scale.

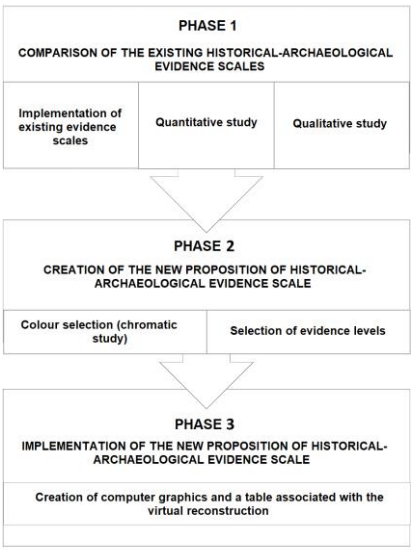


Fig. 1 Methodological phases.

Regarding the first phase of the study, it is important to take into account that the creation of a new proposition of historical-archaeological evidence scale is based on the existing historical-archaeological evidence scales. After knowing these, they are compared with each other in order to establish common criteria and differences. As was previously mentioned, the building in question already has a virtual 3D reconstruction (Cáceres-Criado et al. 2022), in which the evidence scale proposed by Pablo Aparicio and César Figueiredo (Cáceres-Criado et al. 2022) was implemented (Fig. 2). The comparison of the existing evidence scales required the attainment of computer graphics of the heritage asset from each of the propositions. To this end, the rest of the scales were implemented in the Baker´s House at the archaeological site of Torreparedones (Fig. 3 and 4).

Fig. 2 Application of the evidence scale proposed by P. Aparicio and C. Figueiredo in the Baker´s House virtual reconstruction.

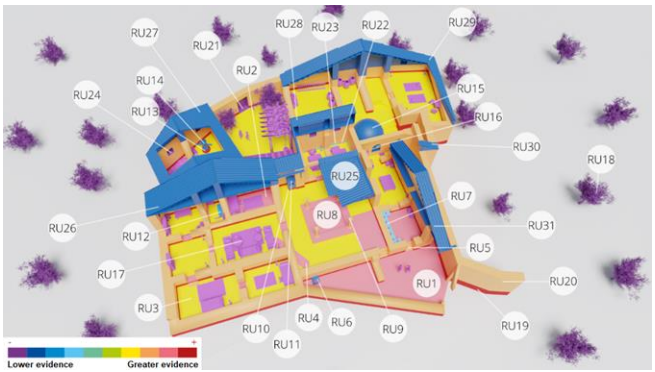


Fig. 3 Application of the evidence scale proposed in the Byzantium 1200 project in the Baker´s House virtual reconstruction.

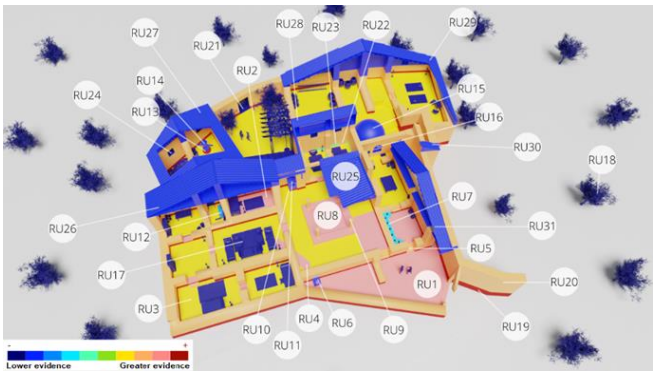
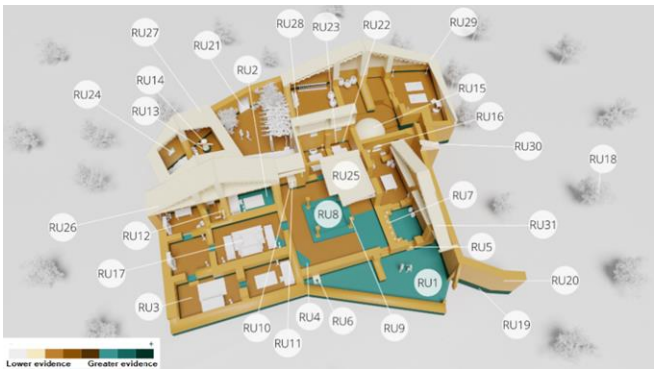


Fig. 4 Application of the evidence scale proposed by Ortiz et al. in the Baker's House virtual reconstruction.



In the first phase of this study, and based on the existing propositions of historical-archaeological evidence scales, a quantitative study was performed as a result of the Topical Seminar 'Scientific Representation in Archaeology through the Use of Digital Technologies': Implementation of evidence scales in the Mosque-Cathedral of Córdoba and in Gauzón Castle', which was held on March 4th 2022 at the University of Córdoba. This totally anonymous study was carried out on-line and face-to-face, depending on the modality chosen by each attendee. The questionnaire consisted of 18 closed questions (In Table 2 "Appendix"), which were answered after

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receiving the information presented by Pablo Aparicio and Rafael Ortiz.

Table 2 Quantitative study presented in the Topical Seminar held in the University of Córdoba.

Questions	Response options
1. What is your gender?	• Man; • Woman
2. What is your age?	• 20-30 years; • 30-40 years; • Over 40 years
3. What is your academic training?	• Arts and Humanities; • Science; • Heatlh Sciences; • Social and Legal Science; • Engineering and Architecture. • Other
4. Is this the first time you heard about the historical-archaeological evidence scale?	• Yes; • No
5. Why do you think you did not know about the historical-archaeological evidence scale?	• Its lack of dissemination; • Virtual reconstructions are not usually accompanied by an evidence scale; • I am not interested in this topic; • Lack of training in the Degree of Archaeology
6. How many virtual reconstructions do you know?	• 0; • 1-5; • 5-10; • Over 10
7. How many of these virtual reconstructions are accompanied by a historical-archaeological evidence scale?	• 0; • 1-5; • 5-10; • Over 10
8. In your opinion, what kind of audience receives the information presented in the historical-archaeological evidence scale?	• Experts in the field; • The general public; • Both
9. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you think that the use of a historical-archaeological evidence scale is a good option to accompany a virtual reconstruction?	• Likert scale*

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10. As is proposed by P. Aparicio and C. Figueiredo in one of their studies, the historical-archaeological evidence scale contributes to the creation of a language for all professionals of the field. Do you agree with this? — Likert scale*

11. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, is the name "historical-archaeological evidence scale" descriptive? — Likert scale*

12. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you consider that the historical-archaeological evidence scale helps to disseminate and correctly interpret not only the heritage asset but also the archaeological work conducted? — Likert scale*

13. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, if it were compulsory to accompany virtual reconstructions with historical-archaeological evidence scales, do you think this would help the general public to understand the archaeological remains? — Likert scale*

14. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you think it is convenient for the tourist to accompany the information presented in the explanatory panels of archaeological sites with the historical-archaeological evidence scale of the virtual reconstruction? — Likert scale*

15. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the evidence levels proposed by P. Aparicio? — Likert scale*

16. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the evidence levels proposed by R. Ortiz? — Likert scale*

17. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the colours used in the proposition of P. Aparicio? — Likert scale*

18. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the colours used in the proposition of R. Ortiz? — Likert scale*

* Likert scale composed of the following options: Strongly Agree; Agree; Neither Agree nor Disagree; Disagree; Strongly Disagree.

The answers obtained in the questionnaire were statistically analysed, which is why information about gender, age and education was gathered. The mean of these answers was calculated and an analysis of variance (ANOVA) was performed to compare the variances between the means of the 'gender', 'age' and 'education' categories in each of the questions proposed in the questionnaire.

Moreover, before the Topical Seminar, a meeting was held with professionals of this professional category (archaeologists) with the aim of solving doubts about the propositions of historical-archaeological evidence scales. After explaining the propositions, since many of the attendees did not know about their existence, questions were asked to Pablo Aparicio and Rafael Ortiz in an interview at the mentioned seminar (In Table 3 "Appendix").:

1. Everyone agrees that the evidence scale, in addition to its scientific value, has an educational and informational purpose, but what is the target audience? Experts in the discipline, common viewers or both?

P.A: "Exactly, both. I think it is very important that the scale does not lose its educational character and that looking at the caption with the warmer or cooler gradation along with the image of the virtual reconstruction should be enough for anyone to understand which areas have a greater or lower level of evidence. Subsequently, we could expand them with further information for the study".

R.O: "From my point of view, I think that the evidence scale is useful for all audiences, and it grants transparency to the virtual reconstructions, for both technicians and the general public. In our case, when we started working with the scale, we saw that it had to be reduced, and the change of colour was due to the work we began, where we made several propositions and talked to all the technicians involved".

2. What did you consider for the selection of colours?

P.A: "In this sense, since we based our work on the proposition developed in the Byzantium 1200 project, considering the need for standardising the scale, we believed it would be most interesting to keep using colours similar to those used in the Byzantium project, basically because we understood that they worked very well. We made small changes in the colours, that is, we adjusted the colours in a way that they could be distinguished. However, as was previously commented, purple may be a bit confusing, and it should be recalculated a little".

R.O: "Solving the problem related to the work we were doing and also in the colours that were used in geographic information systems. We attempted to create a scale of colours that solved the problems regarding the consideration of warm colours — cool colours that existed in the previous propositions".

3. Do you think that your proposition is the most appropriate one for any virtual reconstruction regardless of the number of reconstructive units?

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— P.A: "It should be. The aim is to make this proposition useful for any kind of virtual reconstruction. I was able to apply it to all virtual reconstructions that I have carried out to date. There was not one virtual reconstruction in which I said 'it's impossible here'. However, in some cases, it is necessary to reduce a little, such as the number of reconstructive units, otherwise, it can be difficult. In other cases, it is necessary to merge reconstructive units into a single unit. The case of Elephantine City is paradigmatic; it was possible to apply it to the entire city, and I believe that it allows the viewer to clearly see the evidence level of each area. We must also be aware that the evidence scale must be flexible and that its use depends on the excavation team or scientific team. It is important to understand that this is a tool that shows the evidence level and that we must apply it in each case as clearly as possible".

— R.O: "Unlike Pablo Aparicio, we always work in the same scope, so I cannot really answer that question. Since we always work on the same thing, the Mosque-Cathedral, we cannot export this information to other virtual reconstructions".

4. As has been previously mentioned, many of the archaeologists who attended this seminar did not know the historical-archaeological evidence scale. What do you think this is due to?

— P.A: "I get emails from Italy, UK, etc., and I see that it use in virtual reconstructions is increasing. Moreover, I teach in the MSc of Virtual Heritage and in the education platform of Koré, and there we aim to disseminate the use of the evidence scale, also through seminars like this. It is important to use it in our workplace to increase its dissemination, as well as to modify it if necessary, although it would be good to modify it in a consensuated manner in order to achieve its standardisation".

— R.O: "As Pablo Aparicio says, the use of the historical-archaeological evidence scale is increasing, in Spain and in other countries, such as Portugal, Italy, etc., so a greater number of people will surely know it soon".

5. One of the attending archaeologists proposed the following: "The main disadvantage is the scarce training given to archaeology students. Greater dissemination and analysis of this system would considerably help in this matter". Do you think that it would be possible, from research, to show the relevance of the evidence scale, even teaching it as part of a subject in the university?

— P.A: "Education is essential for the application of knowledge. I think it would be very good to explain this scale in universities, since, as has been explained, it can be applied not only to virtual reconstructions, but also to traditional historical drawings, and it allows providing a scientific section. To date, when virtual reconstructions were performed, if you were very lucky you could find an article that explained how it had been done, but their veracity was never addressed. Therefore, I think it is a very important tool that came here to stay".

— R.O: "Yes, but it is important to highlight that there are still archaeologists who do not understand digital technologies, so universities should start changing some things to highlight the relevance of this scope, which is widespread".

The aim of the second phase of the study was to assign colours and evidence levels for the new proposition, which required a thorough search for bibliographic material related to the symbology of the colour associated with people. From this bibliographic search regarding colour assignment for the new scale proposition, it was observed that colours with greater wave length (e.g., red and orange) cause a greater physiological activation than green (Díez et al. 2000; Wilson 1966). This is frequently described as a stimulating, energetic and vital colour. On its part, yellow is less exciting than red (Schaie and Heiss 1988), being associated with vitality, mirth and fun (Sharpe 1974). In regard to the colour green, its excitation potential is more limited (Schaie and Heiss 1988), being associated with safety, comfort, calmness, quietness, youth and freshness. The coolest colour of the chromatic wheel is blue, and the preference for it is thought to indicate good control over emotions and behaviours (Díez et al. 2000).

A recent study conducted in Spain about the emotional connection with colour shows the concepts associated with each colour (Bazán 2018; Corbin), including the following:

- Blue: tranquility, calmness, peace, serenity, stillness, relaxation, quietness, harmony and well-being.
- Green: mirth and life, tranquility, serenity, relaxation, quietness, calmness, peace and hope.
- Red: strength, passion, mirth, life, energy, love, heat, intensity, vitality, optimism, beauty, emotion, power, fire, dynamism, self-esteem, action, revolution and struggle, effort and excitement.
- Purple: serenity, tranquility, peace, relaxation, calmness, mirth and happiness, balance, harmony, well-being, women, femininity, freedom, beauty, profoundness, transformation and spirituality.
- Yellow: mirth, fun, light, luminosity, life, liveliness, energy, positivity, good vibes, heat, warmth, tranquility, peace, optimism and happiness.
- Orange: mirth, optimism, fun, energy, strength, vitality, life, liveliness, spark, creativity, warmth, heat, showy, intensity, cheerfulness and sympathy.

In addition to the meaning of the colours, several studies show that the preferences for them change throughout life (Dittmar 2001; Mohebbi 2014; Terwogt and Hoeksma 1995). This could be attributed to the alterations in the discrimination of colours and also to the decrease of the functions of the mechanisms present in sight with ageing (Dittmar 2001).

The change in colour preferences in older people could be attributed to the alterations in the discrimination of colours and in visual images, the yellowing of the lens and the decrease of the function of the blue cone mechanism with ageing.

After selecting the colours and evidence levels for the new proposition, the last phase of the study was conducted. These colours and evidence levels were implemented in the virtual 3D

reconstruction of the Baker's House, obtaining computer graphics of the virtual model and a table associated with such graphics presenting information of the evidence levels that correspond to each reconstructive unit.

3 Results and discussion

The representation of the degree of historical-archaeological evidence of the 'Baker´s House' through a new scale proposition required the comparison of the existing evidence scales. Their implementation in the Baker´s House provided results of their use in this heritage asset (Table 43). On the one hand, the scale proposed in the Byzantium 1200 project (Byzantium 1200) is closer to the proposition of Aparicio and Figueiredo (2017) than to that of Ortiz et al. (2018). It could be said that the second proposition is more recent than the first proposition and, thus, it is an improved version of it. Their colour range is quite similar and, in both scales, warm colours represent greater historical-archaeological evidence, whereas cool colours represent lower evidence. Both scales are very visual, and each of the evidence levels are easily identified. Regarding the third proposition (Ortiz et al. 2018), it is visually very different from the other two propositions. The colour range is different, and the reduction of the evidence levels is observed in the computer graphics, showing less colours. Visually, the evidence levels are not so easily distinguishable, due to the similarity between their colours, unlike in the other two propositions.

Table 43 Identification of the evidence levels, colours and definition of the propositions of historical-archaeological evidence scales.

Level of evidence	Colour Byzantium 1200	Definition Byzantium 1200	Colour Aparicio and Figueiredo (2017)	Definition Aparicio and Figueiredo (2017)	Colour Ortiz et al. (2018)	Definition Ortiz et al. (2018)
1		Exists in its original form		Imagination		Still existing in its original form
2		Partially or with modifications		Conjecture based on similar structures		Still existing with modifications
3		Photographs or plans available		Basic textual reference		Detailed graphical evidence
4		Archaeological information		Descriptive textual reference		Slight graphical evidence
5		Detailed graphical evidence		Simple graphical reference		Archaeological hypothesis
6		Simple graphical evidence		Detailed graphical reference		Textual evidence
7		Textual and comparative evidence		Basic archaeological information or simple base plans		Based on similar structures
8		Textual evidence		Strong archaeological and documental evidence in photographs and detailed plans		Based on historical context, nature and culture
9		Based on similar structures		Still existing (or partially existing) with modifications		
10		Imagination		Still existing in its original form		

Regarding the colours used in the pioneer scale (Byzantium 1200) and in the proposition of Aparicio and Figueiredo (2017), several observations emerged. Firstly, the colours selected are not pure, that is, their value and intensity are altered as they are mixed with achromatic colours (white and black). These colours identified as pastel colours stand out less, despite corresponding to warmer colours. For instance, by mixing orange with white, this colour loses purity and thus yellow stands out over orange, in spite of the fact that the latter is warmer. Likewise, the use of pink in the historical-archaeological evidence scale would alter the colour range, since pink results from modifying the intensity of the colour red. Lastly, regarding the proposition of Aparicio and Figueiredo (2017), the colour purple does not allow the proposed evidence scale to go from cool to warm colours, since purple is not a cool colour. Purple results from mixing the primary colours blue and red, which would imply inverting the chromatic circle, obtaining a scale of warm to cool colours.

Moreover, from the proposition of Ortiz et al. (2018), it is worth mentioning that the colour palette used is too large and difficult to understand for the users who are not familiarised with colour theory. By modifying the attributes of the colours, the proposition of evidence scale is little intuitive, since it uses atypical colours that result from the mixture of primary and

secondary colours. To sum up, it is a much personalised palette and, thus, it is poorly universal.

The evidence levels also show differences between the propositions. Firstly, the evidence levels of the pioneer proposition (Byzantium 1200) and the proposition of Aparicio and Figueiredo (2017) are quite similar. The difference lies in the fact that the Byzantium project orders the levels from higher to lower veracity, whereas the second proposition orders them from lower to higher evidence level. Although the levels are ordered in the opposite manner, the colours associated with them are the same for both propositions, with the warmer colours corresponding to greater evidence and the cooler colours corresponding to lower evidence. Regarding the evidence levels proposed by Ortiz et al. (2018), there are significant differences with respect to the previous propositions. In this case, the author reduced the levels from 10 to 8, ordering them from greater to lower historical-archaeological evidence. Moreover, another difference lies in the veracity levels aimed at the archaeological hypotheses. Ortiz et al. (2018) associate them with lower veracity compared to the graphic evidence, whereas the two previous propositions associate the archaeological hypotheses with greater veracity compared to the graphic evidence.

As was previously mentioned, and as a result of the Topical Seminar held in the University of Córdoba, a live interview was carried out with Pablo Aparicio and Rafael Ortiz. Different aspects are worth highlighting from such interview. Firstly, Aparicio and Ortiz consider each other's propositions to be correct, and they answered most of the questions with similar answers. They both thought about the same type of audience when they created their propositions of evidence scales, i.e., both experts of the discipline and the general public. This is different from the selection of colours, since, although both of them considered all types of audience, the interpretation of the colours from all viewers is different for each proposition. While the colours used by Pablo Aparicio are focused on the use of the chromatic wheel, Ortiz et al. (2018) use a more difficult palette in terms of colour theory. Furthermore, according to Pablo Aparicio, the works that implement their proposition of evidence scale and its corresponding colours show its validity for any type of reconstruction, whereas Rafael Ortiz could not carry out independent studies in the Mosque-Cathedral, thus they could only validate the evidence levels and the corresponding colours of their proposition in said heritage asset. Although each author has implemented the scale in a larger or smaller number of scopes, they both agree that their scales are being used with increasing frequency to support virtual reconstructions, and they also know that they are being used in other countries. Lastly, it is worth highlighting that they both agree that this research field should be taught in subjects at universities, and they are doing everything they can to disseminate it, both in their workplace and through teaching.

Additionally, as a result of said Topical Seminar, the questionnaire was administered and completed, with the participation of 30 people. To obtain the results of this questionnaire, the mean of each of the questions (except for the first three: gender, age and education) was statistically analysed. Moreover, the variance of the means of the 'gender', 'age' and 'education' categories with each of the questions was also explored. Next, Table 54 shows the results of the analyses.

Table 54 Statistical results obtained from the questionnaire.

Question	Mean	ANOVA ('Gender' variable)	ANOVA ('Age' variable)	ANOVA ('Education' variable)
4	1.37	Pr(>F): 0.271	Pr(>F): 0.74	Pr(>F): 0.0746
5	2.07	Pr(>F): 0.546	Pr(>F): 0.866	Pr(>F): 0.71
6	2.50	Pr(>F): 0.184	Pr(>F): 0.69	Pr(>F): 0.0885
7	1.90	Pr(>F): 0.491	Pr(>F): 0.848	Pr(>F): 0.0757
8	2.27	Pr(>F): 0.64	Pr(>F): 0.118	Pr(>F): 0.854
9	1.73	Pr(>F): 0.101	Pr(>F): 0.236	Pr(>F): 0.298
10	1.90	Pr(>F): 0.00375	Pr(>F): 0.213	Pr(>F): 0.0568
11	1.23	Pr(>F): 0.489	Pr(>F):0.147	Pr(>F): 0.706
12	1.20	Pr(>F): 0.253	Pr(>F): 0.708	Pr(>F): 0.0233
13	1.43	Pr(>F): 0.607	Pr(>F): 0.0361	Pr(>F): 0.705
14	1.20	Pr(>F): 0.346	Pr(>F): 0.119	Pr(>F): 0.959
15	1.83	Pr(>F): 0.345	Pr(>F): 0.466	Pr(>F): 0.00863
16	1.86	Pr(>F): 0.626	Pr(>F): 0.312	Pr(>F): 0.208
17	1.80	Pr(>F): 0.279	Pr(>F): 0.596	Pr(>F): 0.726
18	2.59	Pr(>F):0.412	Pr(>F): 0.0086	Pr(>F): 0.00539

For the correct interpretation of the results of the means, it is important to take into account that not all questions have the same number of response options. Question 1, 2 and 3 are not focused on the historical-archaeological evidence scale, as they were used to characterise the respondents.

Focusing on the most interesting results for the creation of a new proposition of historical-archaeological evidence scale, it is important to highlight that, regardless of gender, age and education, the mean value in question 4 was 1.367. This indicates that over half of the respondents (maximum mean value: 2) had heard about the evidence scale for the first time. In question 5, half of the respondents agree that this is due to the fact that virtual reconstructions are not usually accompanied by an evidence scale (mean value: 2.07). For questions 6 and 7 (maximum mean value: 4), the respondents answered that they knew between 1-5 and 5-10 virtual reconstructions, and that, among these, between 0 and 1 were accompanied by a historical-archaeological evidence scale. Regarding question 8 (maximum mean value: 3), the respondents stated that the information presented in the evidence scale reached the general public (mean value: 2.27).

The rest of the questions (9-18) belong to the Likert scale on the level of agreement or disagreement (maximum mean value: 5). As can be observed in Table 54, except for question 18, none of them exceeded the mean value of 2. This indicates that, from question 9 to 17, the respondents 'strongly agreed' with some of the questions being close to 'agree'. However, question 18 obtained a mean value of 2.59, being close to 'neither agree nor disagree' regarding the opinion about the colours used in the proposition of Ortiz et al (2018).

After the analysis of variance (ANOVA) carried out for the 'gender', 'age' and 'education' categories with each of the questions, the following results were obtained:

- With respect to the 'gender' category, for all questions, except question 10, the p value was over 0.05, exceeding the 5% significance level, which shows that gender did not influence the responses at 95% confidence level. For question 10, the p value was below 0.05, which indicates that gender did influence the responses given to this question, thus the null hypothesis was accepted.
- For the 'age' category, for all questions, except for questions 13 and 18, the p value was over 0.05, exceeding the 5% significance level, thus age did not influence the responses at 95% confidence level. Regarding questions 13 and 18, the p value was below 0.05, thus age did influence the responses given in these questions, and the null hypothesis was thereby accepted.
- In the 'education' category, except for questions 12 and 18, the p value was over the 5% significance level, showing that education did not influence the responses at 95% confidence level. For questions 12 and 18, the p value was not over 0.05, indicating that the null hypothesis was accepted since education did influence the responses given in these questions.

Based on the fact that this project pursues a proposition focused on the common viewer, without losing its scientific character, we firstly evaluated the historical-archaeological evidence levels to be shown. The aim was to obtain a very visual scale, without excessive information, that can be understood by any person regardless of their age or education.

Since virtual reconstructions are created to show how a heritage asset was in a specific time (López-Menchero and Grande 2011), we believe that, visually, the archaeological remains that require highlighting the least are those that are preserved, as, due to the fact that they can be personally observed, their intensity should not be highlighted in the evidence scale implemented in the virtual reconstruction. Therefore, this would imply ordering the evidence levels from lower to greater historical-archaeological veracity, with the former being associated with a greater visual colour intensity.

Furthermore, it is important to consider that not all visitors of archaeological sites are experts of the discipline, thus, the greater the number and information of evidence levels, the greater the difficulty to interpret them. To solve this, it was decided to reduce the historical-archaeological evidence levels, in order to omit information of these which not all users know how to interpret. Based on the existing propositions of evidence scales, six historical-archaeological veracity levels are proposed:

1. Elements of the historical and natural context. Elements close to the historical and natural context.
2. Representation through compared architecture. Structure or object represented by compared architecture or similar contemporary elements.
3. Archaeological hypotheses. Information based on the result of the archaeological excavations.
4. Textual references. Textual description of elements.
5. Graphic references. References of elements in drawings, prints or paintings.
6. Preserved archaeological remains. Structure or object preserved in the present.

As was previously mentioned, the intensity of the colours is fundamental in the present proposition. Some studies show that one of the attributes of colour is value (Edwards 2004; De Grandis 1985). By transforming the chromatic scale to achromatism, the value scale can be observed (Fig. 5), which shows the darker and brighter colours of the chromatic wheel. In other words, the intensity of each colour can be observed.

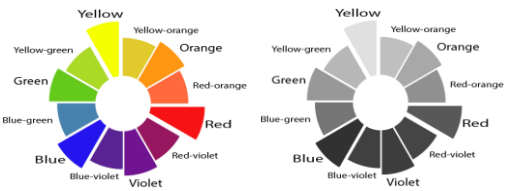

Fig. 5 Transformation of the chromatic wheel to achromatism.

As was previously mentioned, the discrimination of colours can be affected by age (Dittmar 2001; Mohebbi 2014; Terwogt and Hoeksma 1995; therefore, it is important to use colours that can be distinguished from each other by their intensity. The new proposition of historical-archaeological evidence scale aims to denote the levels of lower veracity with darker and more intense colours, while associating the greater veracity

levels with clearer and less intense colours. To this end, it was fundamental to transform the chromatic wheel to achromatism, thus observing the intensity of the colours. Moreover, the 3D model was essential to apply the different groups of colours and verify how they worked in it. After several colour tests performed in the 3D model, it was decided to select a scale composed of warm colours, from greater to lower intensity (Table 65). Analog colours were used to create a warm colour scale. The discrimination of the primary colour blue and the secondary colour green is due to the pursuit for a gradation without leaps in the chromatic wheel, thus creating a visually harmonious scale.

Table 65 Evidence levels and their associated colours of the new proposition of historical-archaeological evidence scale.

Level of evidence for virtual reconstructions	Definition	Colour	RGB	HEX
1	Elements of the historical and natural context		67 128 _ 0 85 2	43005280 0034
2	Representation through comparative architecture		134243 _303 4 57	86002DF 3212F
3	Archaeological hypotheses		22741 2778 36 7	E31B24F 14E25
4	Textual references		2439 84153 4733	F3542F99 921
5	Graphic references		25539 24506 55 4	EA9F4EF CE04
6	Preserved archaeological remains		255 24534 5515	FFF53730 F

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In order to accurately evaluate the intensity (brightness or darkness of the colours used), the scale of greys associated with the colours used was created. Additionally, this scale was used to calibrate the degrees of value of the selected colours (Edwards 2004). As can be observed in Table 76, the scale of greys corresponding to the selected colours shows different intensities among them, with the levels of lower historical-archaeological evidence being more intense than those of greater veracity.

Table 76 Scale of greys of the veracity levels of the new proposition of historical-archaeological evidence scale.

Level of evidence for virtual reconstructions	Definition	Colour
1	Elements of the historical and natural context	
2	Representation through comparative architecture	
3	Archaeological hypotheses	
4	Textual references	
5	Graphic references	
6	Preserved archaeological remains	

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The 3D model played a fundamental role in the selection of colours, as it was used with different colour values until it was appropriately adjusted. In the scale of greys, it was confirmed that the selected colours were optimal to show the evidence scale from greater to lower intensity. This was also tested in the 3D model to verify that the same effect was obtained (Fig. 6). Lastly, the outer terrain of the Baker´s House, which is not part of the veracity of the heritage asset, is associated with a neutral colour, which does not stand out among the colours that correspond to the evidence levels.

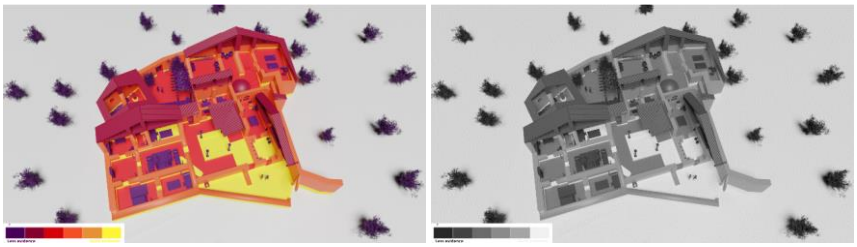

Fig. 6 Render with the implementation of the new scale proposition in the Baker´s House in colour and in scale of greys.

Therefore, the new proposition of historical-archaeological evidence scale has six levels of veracity (Table 65). The colours of greater intensity show the levels of lower historical-archaeological evidence, whereas the brighter colours (less intense) represent greater veracity. The implementation of the new proposition of evidence scale produced computer graphics with 31 reconstructive units (Fig. 7). Next, we present the table associated with the historical-archaeological evidence scale of the 'Baker´s House' (Table 87). This table identifies the number of the reconstructive unit, the evidence level, a brief description of the element or structure, the chronology and the corresponding bibliography.

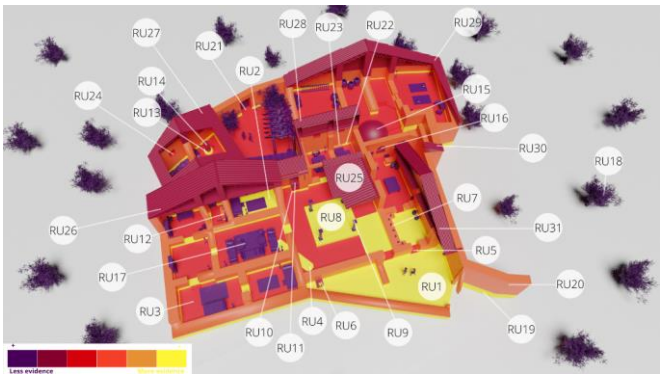

Fig. 7 Computer graphics of the new proposition of historical-archaeological scale for the digital reconstruction of the *domus*.

Table ~~87~~ Identification of the RUs, evidence levels, name, description, chronology and bibliography of the new proposition of historical-archaeological evidence scale of the virtual reconstruction of the Baker´s House of Torreparedones.

RU	Evidence level	Name	Description	Chronology	Bibliography
1	6	Pavement made of large stone slates	This building technique consisted in extending a bed of *opus incertum* and irregular flagstone paving, being a parallel technique to the one used in the paving of the streets of the city of Torreparedones.	Early Roman Empire	(Moreno 2015)
2	6	Pavement of *opus signinum*	Pavement of *opus* signinum in the room identified as *cubiculum*.	Early Roman Empire	(Morena et al. 2016; Morena et al. 2019)
3	3	Non-preserved pavement	Pavements of the *domus* that are not preserved.		
4	6	"*A bagnarola*" water tank	Supplied with rainwater gathered in the roofs, given its location in one of the corners of the *atrium*.	Late Roman Republic	(Morena et al. 2016; Morena et al. 2019)
5	3	Stairs	Stairs proposed for bridging the different levels of the rooms.		
6	2	Latrine	The presence of a limestone slate that stands out in size in all the pavement could be an indication of the location of the latrine hole.		(Morena et al. 2019)
7	4	Structure designed for the sale of bakery products	Garret made of large 20cm-high slates, located in the southern half of the space.		(Morena et al. 2019)

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8	6	*Impluvium*	Square pond that gathers rainwater and discharges to the street through a canalisation system connected to a larger canalisation system.	Early Roman Empire	(Morena et al. 2016; Morena et al. 2019)
9	3	*Impluvium columns*	First building phase of the *atrium*.		(Morena et al. 2016; Morena et al. 2019)
10	6	Base of the *lararium*	Square structure that could correspond to the base of the recess that held the figurines for domestic worship.	Early Roman Empire	(Morena et al. 2019)
11	2	*Lararium*	Due to its chronology and location, it seems to correspond to a variant of the aediculae type, pseudoaedicular, characterised for being made of walls or a solid block, with an inner recess-like cavity, where domestic worship figurines would be placed, crowned by a gable.		(González 2003; Corrales et al. 2016)
12	4	Kitchen structure	Masonry structure		(Morena et al. 2019)
13	6	Circular base associated with the rotatory mill	Circular base of slightly over 1 m in diameter that seems to correspond to the base of a rotatory mill.	Early Roman Empire	(Morena et al. 2016; Morena et al. 2019)
14	2	Roman rotatory mill	Formed by two hollow cones placed upside down, one over the other, with the grain remaining between the two cones and being milled by the friction between the two cones.		(Flores 1993; Morales 2008)
15	2	Oven vault	In Augusta Emerita, an oven was recovered, which presented an access similar to the one in the *domus* of Torreparedones, consisting of a small passable entrance up to the very mouth of the oven, embedded in a square structure. Similarly, the floor of the oven preserved in Torreparedones is typologically identical to that of the bread oven of the 'Birds' House' and that of the *domus* of the Planetarium (Itálica, Seville, Spain).	Early Roman Empire	(Bustamante and Salido 2014; Luzón 1975)
16	2	Oven mouth	It has a diameter of 4 m and it would have been covered by a vault, being embedded, at least in the upper part by a wall, with side openings for putting in and taking out the products to be baked and the fire wood.	Early Roman Empire	(Morena et al. 2019)
17	1	Roman furniture	Roman furniture associated with each space.		
18	1	Vegetation	Contemporary vegetation in time and space.		
19	6	Skewback of the walls of the *domus*	The walls were built with rammed earth and *opus incertum* for the plinths, resorting to irregular bonds of limestone, which is the natural local rock, applying plaster as the final layer.	Early Roman Empire	(Morena et al. 2019)
20	4	Elevation of the walls of the *domus*	Since the total height of the walls of the *domus* is not preserved, the work of Vitrubius was selected. It is important to take into account that the ratio relationships established by Vitrubius are approximate.		(Díaz 2014)
21	3	Access to the western area	Without archaeological evidence, it was decided to create an open door to the *hortus*, since there must have been an access in the production area to introduce the elements for their use.		(Cáceres-Criado et al. 2022; Cáceres-Criado et al. 2022)
22	6	Preserved parietal decoration	Ornamental technique in which a mortar coating is repeatedly hit with a mold containing the embossed decoration. Then, the coating is covered with pure lime or mortar.	Early Roman Empire	(Morena et al. 2016; Morena et al. 2019)
23	5	Parietal decoration	This type of decoration has also been found in other Roman sites. The archaeological work conducted in Beatas Street (Cartagena, Spain)		(Fernández et al. 2005)

			recovered panels decorated with embossed motifs.	
24	3	Windows	In the Villa de las Musas (Arellano, Navarra, Spain), a window grill was discovered. The preservation of this type of elements helps in their 3D reconstruction, as well as in the calculation of the size of the hollows.	(Mezquíriz 2004)
25	2	*Atrium* cover	*Compluvium* / *impluvium* system	(Díaz 2014; Adam 1996)
26	2	Cover of the southern rooms	Large gabled cover that discharges the rainwater into the *atrium* and into the street located south of the *domus*.	(Díaz 2014; Adam 1996)
27	2	Cover of the storage and milling area	Spaces E-37 and E-38 consist of a hip roof that discharges rainwater into three areas: the northern area (*hortus*), the street located south of the *domus* and the street located west of the *domus*.	(Díaz 2014; Adam 1996)
28	2	Cover of the *tablinum* and *cubiculum*	The *tablinum* (E-11) and the *cubiculum* located in the northern area (E-12) consist of a shed roof that also discharges into the *atrium*, since, otherwise, the rainwater would go to the open corridor of the western area of the *domus*, where there are no canalisations or storage structures.	(Díaz 2014; Adam 1996)
29	2	Cover of the service area	The other cover is the one that covers spaces E-22, E-23, E-24, E-26, E-28, E-31 and E-46, with a gable roof, which discharges the rainwater into the *hortus* and into the northern area of the *domus*.	(Díaz 2014; Adam 1996)
30	2	Cover of the woodshed	Shed roof proposed for the closing of space E-32, identified as woodshed.	(Díaz 2014; Adam 1996)
31	2	Cover of the commercial area, redistribution area and latrine	Spaces E-15 and E-16 are composed of a gable roof, discharging, on the one hand, into the western area of the *domus*, and, on the other hand, into the eastern area. The closing of spaces E-36 and E-13 consists of a shed roof that would be the continuation of the previous cover, discharging the rainwater into the 'porch'.	(Díaz 2014; Adam 1996)

4 Conclusions

The application of a colour scale in virtual reconstructions is a valid tool to show the degree of veracity of the work conducted. Therefore, the existing propositions of each historical-archaeological evidence scale are considered optimal for such purpose. However, the selection of the evidence levels and colours is key for their easy and unequivocal understanding.

Although no negative results were obtained in the questions about the existing propositions of historical-archaeological evidence scales, the open debate in the Topic Seminar showed aspects that needed to be addressed. Thus, we decided to create a new proposition that encompasses such aspects and which can reach the general public, regardless of their education with respect to the topic.

The achromatic wheel is fundamental to show a scale where the order of the colours is important. The colourless scale in this study was used to adjust the degree of value of each colour and thus obtain a scale of greater to lower visual colour intensity. To increase the understanding of the evidence scale for any type of viewer, regardless of their age or education, it was decided to reduce the evidence levels. It was observed that the presentation of very detailed information in the evidence levels may lead to mistakes in terms of their visual understanding, since the evidence levels increase, with the consequent increase of visual fatigue in the identification of each colour.

As is shown by the results of the questionnaire, there is still a great percentage of people who do not know the historical-archaeological evidence scale. To solve this issue, it is fundamental to disseminate the scale, highlighting its value in research studies and in the sites of the heritage assets. The historical-archaeological evidence scale for virtual reconstructions is a useful tool to systematise the existing information about the assets, further disseminate them, and finally, assess the virtual reconstruction creation process. In addition to facilitating the correct interpretation of the archaeological work, this scale would help to correctly interpret heritage assets, presenting them in explanatory panels of the archaeological sites, in mockups, museums..., etc. Therefore, its use should be encouraged, which is the best way of

disseminating it, to pursue the creation of a universal and unique language.

Appendix

See Table 2 and Table 3.

Table 2 Quantitative study presented in the Topical Seminar held in the University of Córdoba.

Questions	~~Response~~ Opoptions responses
1. What is your gender?	• Man; • Woman
2. What is your age?	• 20-30 years; • 30-40 years; • Over 40 years
3. What is your academic training?	• Arts and Humanities; • Science; • Heatlh Sciences; • Social and Legal Science; • Engineering and Architecture. • Other
4. Is this the first time you heard about the historical-archaeological evidence scale?	• Yes; • No
5. Why do you think you did not know about the historical-archaeological evidence scale?	• ~~Its l~~Lack of dissemination; • Virtual reconstructions are not usually accompanied by an evidence scale; • I am not interested in this topic; • Lack of training in the Degree of Archaeology
6. How many virtual reconstructions do you know?	• 0; • 1-5; • 5-10; • Over 10
7. How many of these virtual reconstructions are accompanied by a historical-archaeological evidence scale?	• 0; • 1-5; • 5-10; • Over 10
8. In your opinion, what kind of audience receives the information presented in the historical-archaeological evidence scale?	• Experts in the field; • General public; • Both

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9. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you think that the use of a historical-archaeological evidence scale is a good option to accompany a virtual reconstruction?	• Likert scale*
10. As is proposed by P. Aparicio and C. Figueiredo in one of their studies, the historical-archaeological evidence scale contributes to the creation of a language for all professionals of the field. Do you agree with this?	• Likert scale*
11. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, is the name "historical-archaeological evidence scale" descriptive?	• Likert scale*
12. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you consider that the historical-archaeological evidence scale helps to disseminate and correctly interpret not only the heritage asset but also the archaeological work conducted?	• Likert scale*
13. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, if it were compulsory to accompany virtual reconstructions with historical-archaeological evidence scales, do you think this would help the general public to understand the archaeological remains?	• Likert scale*
14. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you think it is convenient for the tourist to accompany the information presented in the explanatory panels of archaeological sites with the historical-archaeological evidence scale of the virtual reconstruction?	• Likert scale*
15. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the evidence levels proposed by P. Aparicio?	• Likert scale*
16. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the evidence levels proposed by R. Ortiz?	• Likert scale*
17. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the colours used in the proposition of P. Aparicio?	• Likert scale*
18. In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the colours used in the proposition of R. Ortiz?	• Likert scale*

* Likert scale composed of the following options: Strongly Agree; Agree; Neither Agree nor Disagree; Disagree; Strongly Disagree.

Table 3 Qualitative study ~~carried out with~~conducted to Pablo Aparicio and Rafael Ortiz

Questions	Response Pablo Aparicio	Response Rafael Ortiz
1. Everyone agrees that the evidence scale, in addition to its scientific value, has an educational and informational purpose, but what is the target audience? Experts in the discipline, common viewers or both?	"Exactly, both. I think it is very important that the scale does not lose its educational character and that looking at the caption with the warmer or cooler gradation along with the image of the virtual reconstruction should be enough for anyone to understand which areas have a greater or lower level of evidence. Subsequently, we could expand them with further information for the study".	"From my point of view, I think that the evidence scale is useful for all audiences, and it grants transparency to the virtual reconstructions, for both technicians and the general public. In our case, when we started working with the scale, we saw that it had to be reduced, and the change of colour was due to the work we began, where we made several propositions and talked to all the technicians involved".
2. What did you consider for the selection of colours?	"In this sense, since we based our work on the proposition developed in the Byzantium 1200 project, considering the need for standardising the scale, we believed it would be most interesting to keep using colours similar to those used in the Byzantium project, basically because we understood that they worked very well. We made small changes in the colours, that is, we adjusted the colours in a way that they could be distinguished. However, as was previously commented, purple may be a bit confusing, and it should be recalculated a little".	"Solving the problem related to the work we were doing and also in the colours that were used in geographic information systems. We attempted to create a scale of colours that solved the problems regarding the consideration of warm colours – cool colours that existed in the previous propositions"

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3.	Do you think that your proposition is the most appropriate one for any virtual reconstruction regardless of the number of reconstructive units	"It should be. The aim is to make this proposition useful for any kind of virtual reconstruction. I was able to apply it to all virtual reconstructions that I have carried out to date. There was not one virtual reconstruction in which I said 'it's impossible here'. However, in some cases, it is necessary to reduce a little, such as the number of reconstructive units; otherwise, it can be difficult. In other cases, it is necessary to merge reconstructive units into a single unit. The case of Elephantine City is paradigmatic; it was possible to apply it to the entire city, and I believe that it allows the viewer to clearly see the evidence level of each area. We must also be aware that the evidence scale must be flexible and that its use depends on the excavation team or scientific team. It is important to understand that this is a tool that shows the evidence level and that we must apply it in each case as clearly as possible"	"Unlike Pablo Aparicio, we always work in the same scope, so I cannot really answer that question. Since we always work on the same thing, the Mosque-Cathedral, we cannot export this information to other virtual reconstructions"
4.	As has been previously mentioned, many of the archaeologists who attended this seminar did not know the historical-archaeological evidence scale. What do you think this is due to?	"I get emails from Italy, UK, etc., and I see that its use in virtual reconstructions is increasing. Moreover, I teach in the MSc of Virtual Heritage and in the education platform of Koré, and there we aim to disseminate the use of the evidence scale, also through seminars like this. It is important to use it in our workplace to increase its dissemination, as well as to modify it if necessary, although it would be good to modify it in a ~~consensuated~~consensual manner in order to achieve its standardisation"	"As Pablo Aparicio says, the use of the historical-archaeological evidence scale is increasing, in Spain and in other countries, such as Portugal, Italy, etc., so a greater number of people will surely know it soon".
5.	One of the attending archaeologists proposed the following: "The main disadvantage is the scarce training given to archaeology students. Greater dissemination and analysis of this system would considerably help in this matter". Do you think that it would be possible, from research, to show the relevance of the evidence scale, even teaching it as part of a subject in the university?	"Education is essential for the application of knowledge. I think it would be very good to explain this tool in universities, since, as has been explained, it can be applied not only to virtual reconstructions, but also to traditional historical drawings, and it allows providing a scientific section. To date, when virtual reconstructions were performed, if you were very lucky you could find an article that explained how it had been done, but their veracity was never addressed. Therefore, I think it is a very important tool that came here to stay".	"Yes, but it is important to highlight that there are still archaeologists who do not understand digital technologies, so universities should start changing some things to highlight the relevance of this scope, which is widespread"

Acknowledgements The authors would like to thank Pablo Aparicio and Rafael Ortiz for their participation in the Topical Seminar supporting the dissemination of the historical-archaeological evidence scales. The authors would also like to thank them for solving the doubts that emerged from the questions asked in this study. Lastly, the authors would also like to thank Irene Ferrer, BSc in Fine Arts, for helping us with her knowledge on colour theory.

Conflicts of interest

The authors declare no conflict of interest.

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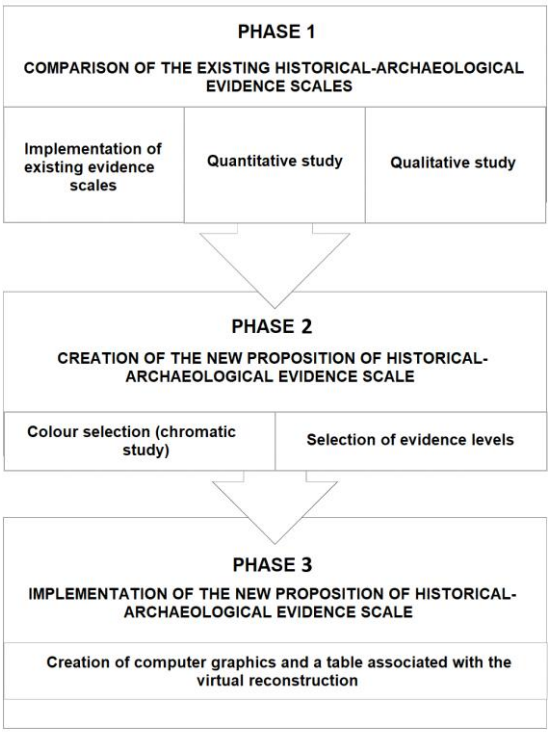

Fig. 1. Methodological phases.

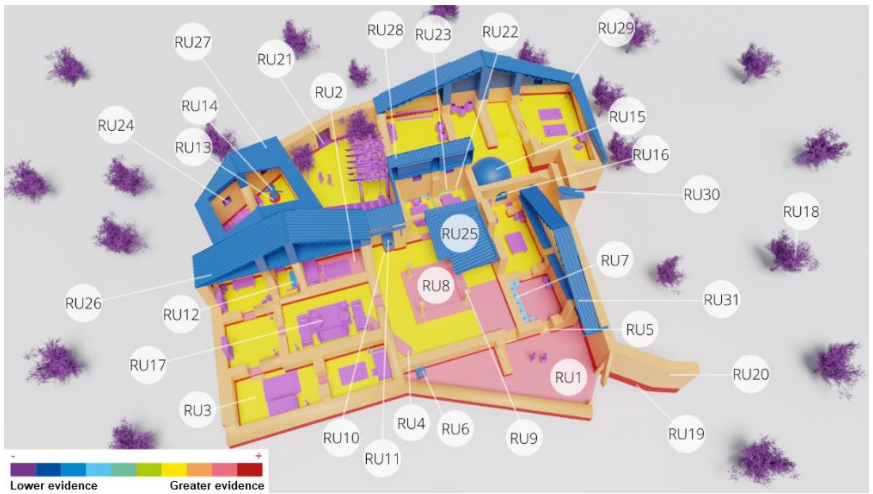

Fig. 2. Application of the evidence scale proposed by P. Aparicio and C. Figueiredo in the Baker´s House virtual reconstruction.

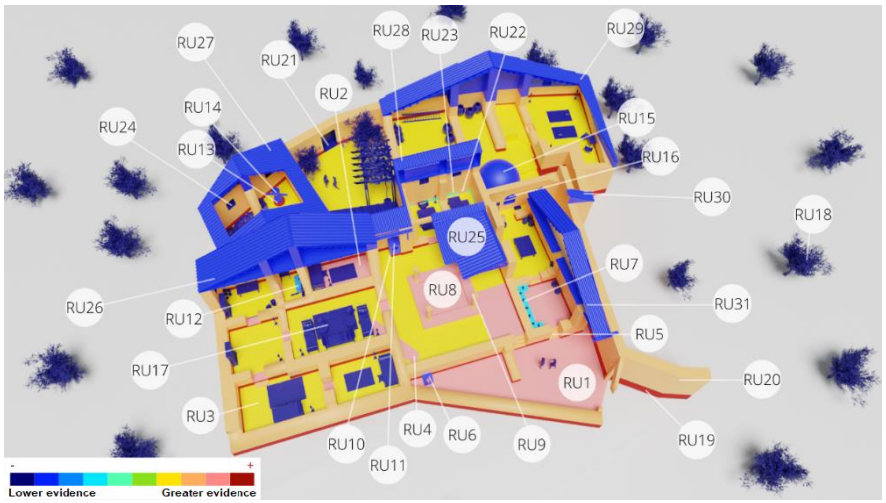

Fig. 3. Application of the evidence scale proposed in the Byzantium 1200 project in the Baker´s House virtual reconstruction.

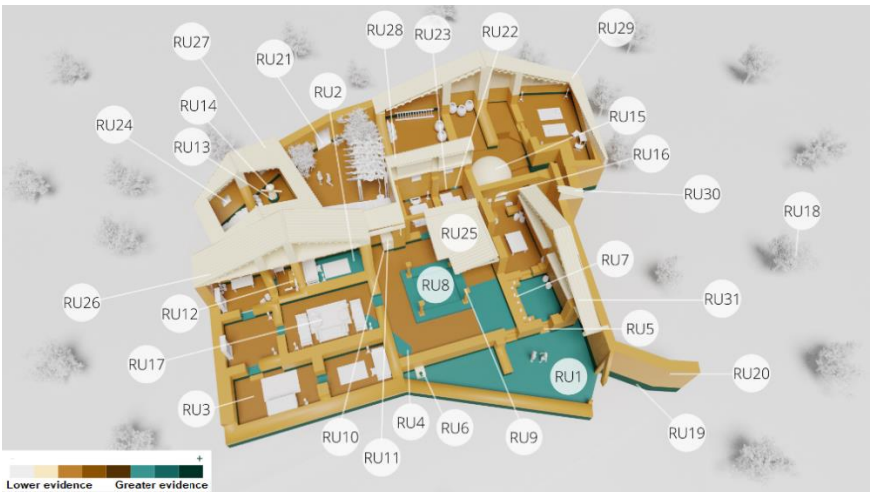

Fig. 4. Application of the evidence scale proposed by Ortiz et al. in the Baker's House virtual reconstruction.

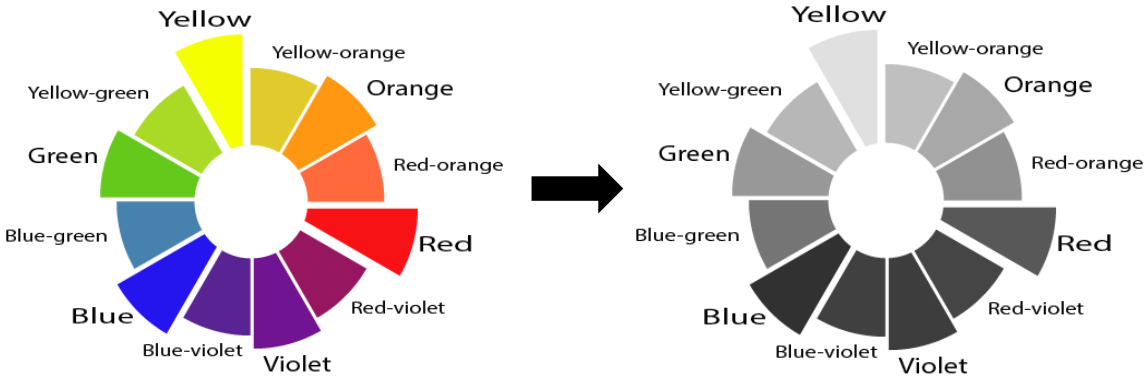

Fig. 5. Transformation of the chromatic wheel to achromatism.

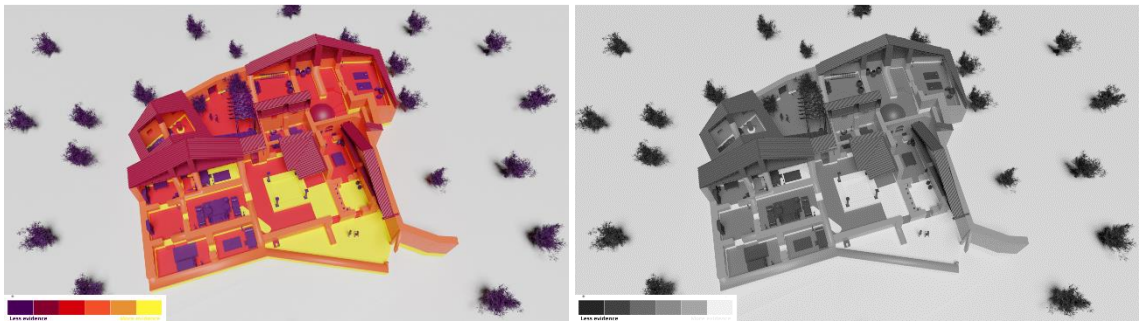

Fig. 6. Render with the implementation of the new scale proposition in the Baker´s House in colour and in scale of greys.

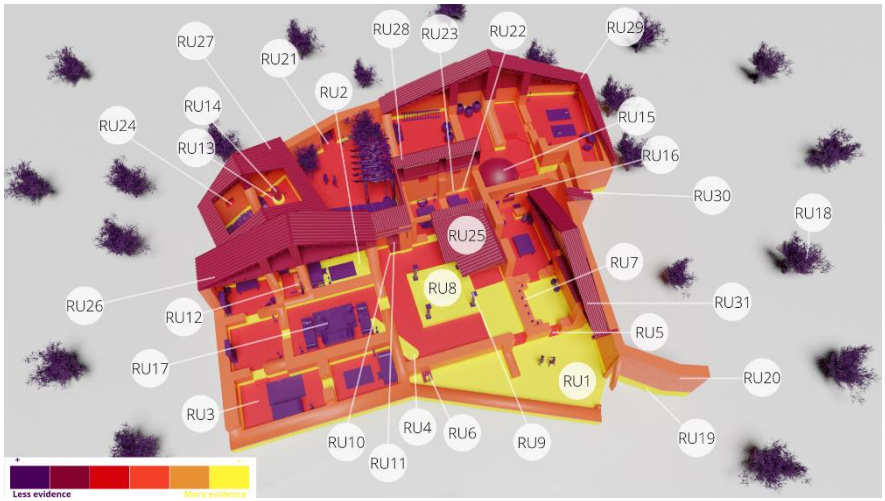

Fig. 7. Computer graphics of the new proposition of historical-archaeological scale for the digital reconstruction of the *domus*.

Table 1
Bibliometric study on the implementation of the existing historical-archaeological evidence scales.

Reference	Applied scale	Item	Levels	Chromatic gradation
http://www.byzantium1200.com/ [4]	Byzantium 1200 project	Byzantium city around 1200	10	From warm to cool colours (greater evidence-lower evidence)
Aparicio 2016 [7]	Aparicio & Figueiredo	The crenellated tower of San García, Algeciras (Spain) (17th-18th century). Virtual recovery of a military structure using technology	10	From cool to warm colours (lower evidence-greater evidence)
Aparicio & Figueiredo 2017 [5]	Aparicio & Figueiredo	The historical-archaeological evidence degree of virtual reconstructions: toward a graphic representation scale	10	From cool to warm colours (lower evidence-greater evidence)
De Mota & Valle 2018 [9]	Aparicio & Figueiredo	Archaeology of the military orders in Castilla-La Mancha and the virtual reconstruction of its heritage	10	From cool to warm colours (lower evidence-greater evidence)
Ortiz-Cordero et al., 2018 [6]	COR_16	Proposal for the improvement and modification of the scale of evidence for the virtual reconstruction of cultural heritage: A first approach to the Mosque-Cathedral and the river landscape of Córdoba (Spain)	8	Colour range from greens to browns
Rodríguez-Hernández et al., 2021 [10]	Aparicio & Figueiredo	Virtual 3D reconstruction of the "Fortified tower" of the Ulaca Oppidum (Solosancho, Ávila, Spain): much more than an image	10	From cool to warm colours (lower evidence-greater evidence)
Aparicio-Resco et al., 2021 [8]	Aparicio & Figueiredo	Virtual 3D reconstruction of Gauzón Castle (Castrillón, Principado de Asturias, Spain)	10	From cool to warm colours (lower evidence-greater evidence)
Cáceres-Criado et al., 2022 [19]	Aparicio & Figueiredo	Graphic representation of the degree of historical-archaeological evidence: the 3D reconstruction of the "Baker's House"	10	From cool to warm colours (lower evidence-greater evidence)

Table 2
Quantitative study presented in the Topical Seminar held in the University of Córdoba.

Questions		Response options
1.	What is your gender?	• Man; • Woman
2.	What is your age?	• 20-30 years; • 30-40 years; • Over 40 years
3.	What is your academic training?	• Arts and Humanities; • Science; • Heatlh Sciences; • Social and Legal Science; • Engineering and Architecture. • Other
4.	Is this the first time you heard about the historical-archaeological evidence scale?	• Yes; • No
5.	Why do you think you did not know about the historical-archaeological evidence scale?	• Its lack of dissemination; • Virtual reconstructions are not usually accompanied by an evidence scale; • I am not interested in this topic; • Lack of training in the Degree of Archaeology
6.	How many virtual reconstructions do you know?	• 0; • 1-5; • 5-10; • Over 10
7.	How many of these virtual reconstructions are accompanied by a historical-archaeological evidence scale?	• 0; • 1-5; • 5-10; • Over 10
8.	In your opinion, what kind of audience receives the information presented in the historical-archaeological evidence scale?	• Experts in the field; • The general public; • Both
9.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you think that the use of a historical-archaeological evidence scale is a good option to accompany a virtual reconstruction?	• Likert scale*
10.	As is proposed by P. Aparicio and C. Figueiredo in one of their studies, the historical-archaeological evidence scale contributes to the creation of a language for all professionals of the field. Do you agree with this?	• Likert scale*
11.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, is the name "historical-archaeological evidence scale" descriptive?	• Likert scale*
12.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you consider that the historical-archaeological evidence scale helps to disseminate and correctly interpret not only the heritage asset but also the archaeological work conducted?	• Likert scale*
13.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, if it were compulsory to accompany virtual reconstructions with historical-archaeological evidence scales, do you think this would help the general public to understand the archaeological remains?	• Likert scale*
14.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, do you think it is convenient for the tourist to accompany the information presented in the explanatory panels of archaeological sites with the historical-archaeological evidence scale of the virtual reconstruction?	• Likert scale*
15.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the evidence levels proposed by P. Aparicio?	• Likert scale*
16.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the evidence levels proposed by R. Ortiz?	• Likert scale*
17.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the colours used in the proposition of P. Aparicio?	• Likert scale*
18.	In a scale of 1-5, with 1 being Strongly Agree and 5 being Strongly Disagree, what do you think about the colours used in the proposition of R. Ortiz?	• Likert scale*

* Likert scale composed of the following options: Strongly Agree; Agree; Neither Agree nor Disagree; Disagree; Strongly Disagree.

Table 3
Qualitative study conducted to Pablo Aparicio and Rafael Ortiz

Questions		Response - Pablo Aparicio	Response - Rafael Ortiz
1.	Everyone agrees that the evidence scale, in addition to its scientific value, has an educational and informational purpose, but what is the target audience? Experts in the discipline, common viewers or both?	"Exactly, both. I think it is very important that the scale does not lose its educational character and that looking at the caption with the warmer or cooler gradation along with the image of the virtual reconstruction should be enough for anyone to understand which areas have a greater or lower level of evidence. Subsequently, we could expand them with further information for the study".	"From my point of view, I think that the evidence scale is useful for all audiences, and it grants transparency to the virtual reconstructions, for both technicians and the general public. In our case, when we started working with the scale, we saw that it had to be reduced, and the change of colour was due to the work we began, where we made several propositions and talked to all the technicians involved".
2.	What did you consider for the selection of colours?	"In this sense, since we based our work on the proposition developed in the Byzantium 1200 project, considering the need for standardising the scale, we believed it would be most interesting to keep using colours similar to those used in the Byzantium project, basically because we understood that they worked very well. We made small changes in the colours, that is, we adjusted the colours in a way that they could be distinguished. However, as was previously commented, purple may be a bit confusing, and it should be recalculated a little".	"Solving the problem related to the work we were doing and also in the colours that were used in geographic information systems. We attempted to create a scale of colours that solved the problems regarding the consideration of warm colours – cool colours that existed in the previous propositions".
3.	Do you think that your proposition is the most appropriate one for any virtual reconstruction regardless of the number of reconstructive units	"It should be. The aim is to make this proposition useful for any kind of virtual reconstruction. I was able to apply it to all virtual reconstructions that I have carried out to date. There was not one virtual reconstruction in which I said 'it's impossible here'. However, in some cases, it is necessary to reduce a little, such as the number of reconstructive units; otherwise, it can be difficult. In other cases, it is necessary to merge reconstructive units into a single unit. The case of Elephantine City is paradigmatic; it was possible to apply it to the entire city, and I believe that it allows the viewer to clearly see the evidence level of each area. We must also be aware that the evidence scale must be flexible and that its use depends on the excavation team or scientific team. It is important to understand that this is a tool that shows the evidence level and that we must apply it in each case as clearly as possible".	"Unlike Pablo Aparicio, we always work in the same scope, so I cannot really answer that question. Since we always work on the same thing, the Mosque-Cathedral, we cannot export this information to other virtual reconstructions".
4.	As has been previously mentioned, many of the archaeologists who attended this seminar did not know the historical-archaeological evidence scale. What do you think this is due to?	"I get emails from Italy, UK, etc., and I see that its use in virtual reconstructions is increasing. Moreover, I teach in the MSc of Virtual Heritage and in the education platform of Koré, and there we aim to disseminate the use of the evidence scale, also through seminars like this. It is important to use it in our workplace to increase its dissemination, as well as to modify it if necessary, although it would be good to modify it in a consensual manner in order to achieve its standardisation".	"As Pablo Aparicio says, the use of the historical-archaeological evidence scale is increasing, in Spain and in other countries, such as Portugal, Italy, etc., so a greater number of people will surely know it soon".
5.	One of the attending archaeologists proposed the following: "The main disadvantage is the scarce training given to archaeology students. Greater dissemination and analysis of this system would considerably help in this matter". Do you think that it would be possible, from research, to show the relevance of the evidence scale, even teaching it as part of a subject in the university?	"Education is essential for the application of knowledge. I think it would be very good to explain this tool in universities, since, as has been explained, it can be applied not only to virtual reconstructions, but also to traditional historical drawings, and it allows providing a scientific section. To date, when virtual reconstructions were performed, if you were very lucky you could find an article that explained how it had been done, but their veracity was never addressed. Therefore, I think it is a very important tool that came here to stay".	"Yes, but it is important to highlight that there are still archaeologists who do not understand digital technologies, so universities should start changing some things to highlight the relevance of this scope, which is widespread".

Table 4
Identification of the evidence levels, colours and definition of the propositions of historical-archaeological evidence scales.

Level of evidence	Colour Byzantium	Definition Byzantium	Colour Aparicio and Figueiredo	Definition Aparicio and Figueiredo	Colour Ortiz et al.	Definition Ortiz et al.
1		Exists in its original form		Imagination		Still existing in its original form
2		Partially or with modifications		Conjecture based on similar structures		Still existing with modifications
3		Photographs or plans available		Basic textual reference		Detailed graphical evidence
4		Archaeological information		Descriptive textual reference		Slight graphical evidence
5		Detailed graphical evidence		Simple graphical reference		Archaeological hypothesis
6		Simple graphical evidence		Detailed graphical reference		Textual evidence
7		Textual and comparative evidence		Basic archaeological information or simple base plans		Based on similar structures
8		Textual evidence		Strong archaeological and documental evidence in photographs and detailed plans		Based on historical context, nature and culture
9		Based on similar structures		Still existing (or partially existing) with modifications		
10		Imagination		Still existing in its original form		

Table 5
Statistical results obtained from the questionnaire.

Question	Mean	ANOVA ('Gender' variable)	ANOVA ('Age' variable)	ANOVA ('Education' variable)
4	1.37	Pr(>F): 0.271	Pr(>F): 0.74	Pr(>F): 0.0746
5	2.07	Pr(>F): 0.546	Pr(>F): 0.866	Pr(>F): 0.71
6	2.50	Pr(>F): 0.184	Pr(>F): 0.69	Pr(>F): 0.0885
7	1.90	Pr(>F): 0.491	Pr(>F): 0.848	Pr(>F): 0.0757
8	2.27	Pr(>F): 0.64	Pr(>F): 0.118	Pr(>F): 0.854
9	1.73	Pr(>F): 0.101	Pr(>F): 0.236	Pr(>F): 0.298
10	1.90	Pr(>F): 0.00375	Pr(>F): 0.213	Pr(>F): 0.0568
11	1.23	Pr(>F): 0.489	Pr(>F):0.147	Pr(>F): 0.706
12	1.20	Pr(>F): 0.253	Pr(>F): 0.708	Pr(>F): 0.0233
13	1.43	Pr(>F): 0.607	Pr(>F): 0.0361	Pr(>F): 0.705
14	1.20	Pr(>F): 0.346	Pr(>F): 0.119	Pr(>F): 0.959
15	1.83	Pr(>F): 0.345	Pr(>F): 0.466	Pr(>F): 0.00863
16	1.86	Pr(>F): 0.626	Pr(>F): 0.312	Pr(>F): 0.208
17	1.80	Pr(>F): 0.279	Pr(>F): 0.596	Pr(>F): 0.726
18	2.59	Pr(>F):0.412	Pr(>F): 0.0086	Pr(>F): 0.00539

Table 6
Evidence levels and their associated colours of the new proposition of historical-archaeological evidence scale.

Level of evidence for virtual reconstructions	Definition	Colour	RGB	HEX
1	Elements of the historical and natural context		128 0 52	800034
2	Representation through comparative architecture		243 33 47	F3212F
3	Archaeological hypotheses		241 78 37	F14E25
4	Textual references		249 153 33	F99921
5	Graphic references		239 206 4	EFCE04
6	Preserved archaeological remains		255 234 15	FFF30F

Table 7
Scale of greys of the veracity levels of the new proposition of historical-archaeological evidence scale.

Level of evidence for virtual reconstructions	Definition	Colour
1	Elements of the historical and natural context	
2	Representation through comparative architecture	
3	Archaeological hypotheses	
4	Textual references	
5	Graphic references	
6	Preserved archaeological remains	

Table 8
Identification of the RUs, evidence levels, name, description, chronology and bibliography of the new proposition of historical-archaeological evidence scale of the virtual reconstruction of the Baker´s House of Torreparedones.

RU	Evidence level	Name	Description	Chronology	Bibliography
1	6	Pavement made of large stone slates	This building technique consisted in extending a bed of *opus incertum* and irregular flagstone paving, being a parallel technique to the one used in the paving of the streets of the city of Torreparedones.	Early Roman Empire	[31]
2	6	Pavement of *opus signinum*	Pavement of *opus* signinum in the room identified as *cubiculum*.	Early Roman Empire	[16, 17]
3	3	Non-preserved pavement	Pavements of the *domus* that are not preserved.		
4	6	"*A bagnarola*" water tank	Supplied with rainwater gathered in the roofs, given its location in one of the corners of the *atrium*.	Late Roman Republic	[16, 17]
5	3	Stairs	Stairs proposed for bridging the different levels of the rooms.		
6	2	Latrine	The presence of a limestone slate that stands out in size in all the pavement could be an indication of the location of the latrine hole.		[17]
7	4	Structure designed for the sale of bakery products	Garret made of large 20cm-high slates, located in the southern half of the space.		[17]
8	6	*Impluvium*	Square pond that gathers rainwater and discharges to the street through a canalisation system connected to a larger canalisation system.	Early Roman Empire	[16, 17]
9	3	*Impluvium columns*	First building phase of the *atrium*.		[16, 17]
10	6	Base of the *lararium*	Square structure that could correspond to the base of the recess that held the figurines for domestic worship.	Early Roman Empire	[17]
11	2	*Lararium*	Due to its chronology and location, it seems to correspond to a variant of the aediculae type, pseudoaedicular, characterised for being made of walls or a solid block, with an inner recess-like cavity, where domestic worship figurines would be placed, crowned by a gable.		[32, 33]
12	4	Kitchen structure	Masonry structure		[17]
13	6	Circular base associated with the rotatory mill	Circular base of slightly over 1 m in diameter that seems to correspond to the base of a rotatory mill.	Early Roman Empire	[16, 17]
14	2	Roman rotatory mill	Formed by two hollow cones placed upside down, one over the other, with the grain remaining between the two cones and being milled by the friction between the two cones.		[34, 35]
15	2	Oven vault	In Augusta Emerita, an oven was recovered, which presented an access similar to the one in the *domus* of Torreparedones, consisting of a small passable entrance up to the very mouth of the oven, embedded in a square structure. Similarly, the floor of the oven preserved in Torreparedones is typologically identical to that of the bread oven of the 'Birds' House' and that of the *domus* of the Planetarium (Itálica, Seville, Spain).	Early Roman Empire	[36, 37]
16	2	Oven mouth	It has a diameter of 4 m and it would have been covered by a vault, being embedded, at least in the upper part by a wall, with side openings for putting in and taking out the products to be baked and the fire wood.	Early Roman Empire	[17]
17	1	Roman furniture	Roman furniture associated with each space.		
18	1	Vegetation	Contemporary vegetation in time and space.		
19	6	Skewback of the walls of the *domus*	The walls were built with rammed earth and *opus incertum* for the plinths, resorting to irregular bonds of limestone, which is the natural local rock, applying plaster as the final layer.	Early Roman Empire	[17]
20	4	Elevation of the walls of the *domus*	Since the total height of the walls of the *domus* is not preserved, the work of Vitrubius was selected. It is important to take into account that the ratio relationships established by Vitrubius are approximate.		[38]
21	3	Access to the western area	Without archaeological evidence, it was decided to create an open door to the *hortus*, since there must have been an access in the production area to introduce the elements for their use.		[15, 19]
22	6	Preserved parietal decoration	Ornamental technique in which a mortar coating is repeatedly hit with a mold containing the embossed decoration. Then, the coating is covered with pure lime or mortar.	Early Roman Empire	[16, 17]
23	5	Parietal decoration	This type of decoration has also been found in other Roman sites. The archaeological work conducted in Beatas Street (Cartagena, Spain) recovered panels decorated with embossed motifs.		[39]
24	3	Windows	In the Villa de las Musas (Arellano, Navarra, Spain), a window grill was discovered. The preservation of this type of elements helps in their 3D reconstruction, as well as in the calculation of the size of the hollows.		[40]
25	2	*Atrium* cover	*Compluvium / impluvium* system		[38, 41]
26	2	Cover of the southern rooms	Large gabled cover that discharges the rainwater into the *atrium* and into the street located south of the *domus*.		[38, 41]
27	2	Cover of the storage and milling area	Spaces E-37 and E-38 consist of a hip roof that discharges rainwater into three areas: the northern area (*hortus*), the street located south of the *domus* and the street located west of the *domus*.		[38, 41]
28	2	Cover of the *tablinum* and *cubiculum*	The *tablinum* (E-11) and the *cubiculum* located in the northern area (E-12) consist of a shed roof that also discharges into the *atrium*, since, otherwise, the rainwater		[38, 41]

			would go to the open corridor of the western area of the *domus*, where there are no canalisations or storage structures.	
29	2	Cover of the service area	The other cover is the one that covers spaces E-22, E-23, E-24, E-26, E-28, E-31 and E-46, with a gable roof, which discharges the rainwater into the *hortus* and into the northern area of the *domus*.	[38, 41]
30	2	Cover of the woodshed	Shed roof proposed for the closing of space E-32, identified as woodshed.	[38, 41]
31	2	Cover of the commercial area, redistribution area and latrine	Spaces E-15 and E-16 are composed of a gable roof, discharging, on the one hand, into the western area of the *domus*, and, on the other hand, into the eastern area. The closing of spaces E-36 and E-13 consists of a shed roof that would be the continuation of the previous cover, discharging the rainwater into the 'porch'.	[38, 41]