A SHARED TERMINOLOGY FOR HYPOTHETICAL 3D DIGITAL RECONSTRUCTIONS IN THE FIELD OF CULTURAL HERITAGE

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INTRODUCTION

Working in synergy with experts coming not only from different fields (computer scientists, archaeologists, historians...), but also from different countries, thus speaking a variety of languages, is very often essential in the field of digital 3D reconstructions for cultural heritage, for heuristic rather than entertainment purposes.
This inevitably leads to the comparison of different methods and workflows, each of which is based on its own terminology. Therefore, comparing the terms that are used, following their evolution and, to some extent, attempting to standardise them is a prerequisite for making the reconstruction as objective and reproducible as possible, qualities that are of prime importance especially when the goal is the publication of results in online platforms, so that they are accessible and comprehensible to a wide audience of interested users.
Terminology is only one of the open problems in the field of digital 3D reconstructions, which, as is well known, also faces issues related, for instance, to different software and file formats, or even to data storage and to the platforms used to share them.
These problems, however, can hardly be tackled without a shared terminology and methodology, which should be the basis of any 3D digital reconstruction used to disseminate (and potentially enrich with new discoveries) cultural heritage, especially when it comes to hypothetical reconstructions of artefacts that have been destroyed or have never been built.
In this case, the dialogue between experts is a central element and it is therefore clear why, first of all, it is necessary to agree on the terms that are used. This study aims to analyse some of the most frequent ones in this sense, especially those relating to the certainty and reliability of a reconstruction, whose data model becomes a social and cultural object that we cannot ignore.

FREQUENCY AND CLASSIFICATION

In this framework, an analysis was conducted on 27 papers[1] concerning hypothetical digital 3D reconstructions, published over a period of 25 years, from 1994 to 2019. For each of them, a word cloud was created (fig. 1) based on the frequency of the words themselves, resulting in a series of values that were then reported in a spreadsheet and from which some graphs were created. Compared to the initial word clouds, at this stage we did not focus so much on words whose high recurrence was

almost predictable (trivially "model", "line", "design", "reconstruction") and which do not really lead us to new discoveries, but more specifically on those concerning a critique of the model and the reconstruction[2] process. As a result of this selection (fig. 2), the high use of the word "uncertainty" emerged, followed by "knowledge", "science", "interpretation", "hypothesis". Other words such as "plausibility" and "reliability" are less frequent, as we can see in more detail in the graph created later, when only the 13 papers in which the most frequently used terms relating to reliability or certainty in hypothetical reconstructions were analysed (fig. 3).

It is evident that the frequency of these terms is a value to be taken into account for the drafting of a shared terminology that fosters dialogue between the experts involved in the reconstruction. However, this remains an abstract value and tells us nothing about the use that is made of a term within a text. Furthermore, the papers considered are written in different languages: most of those in fig. 3 are in English, but there is also one in French[3] and one in German[4]. The terms analysed in the case of these two languages are as follows: *incertitude*, *crédibilité*, *probabilité* for the former document; *Unsicherheit*, *Glaubwürdigkeit*, *Wahrscheinlichkeit* for the latter. They translate "uncertainty", "credibility", "probability" to the extent that a translation can maintain the original meaning of a word.

For this reason, it is necessary to go a step further and connect the examined documents according to certain dominant macro-themes. Six main areas have been identified: "virtual archaeology", "model/visualisation", "documentation", "authenticity", "uncertainty", "cultural heritage".

The evolution of the definitions of these themes (and related terms) was then followed within the documents in which they mostly appeared (fig. 4). Three of these paths are studied in the following section, keeping their recurrence in English in the title and indicating each time in the text, in italics, the original language in which they appeared.

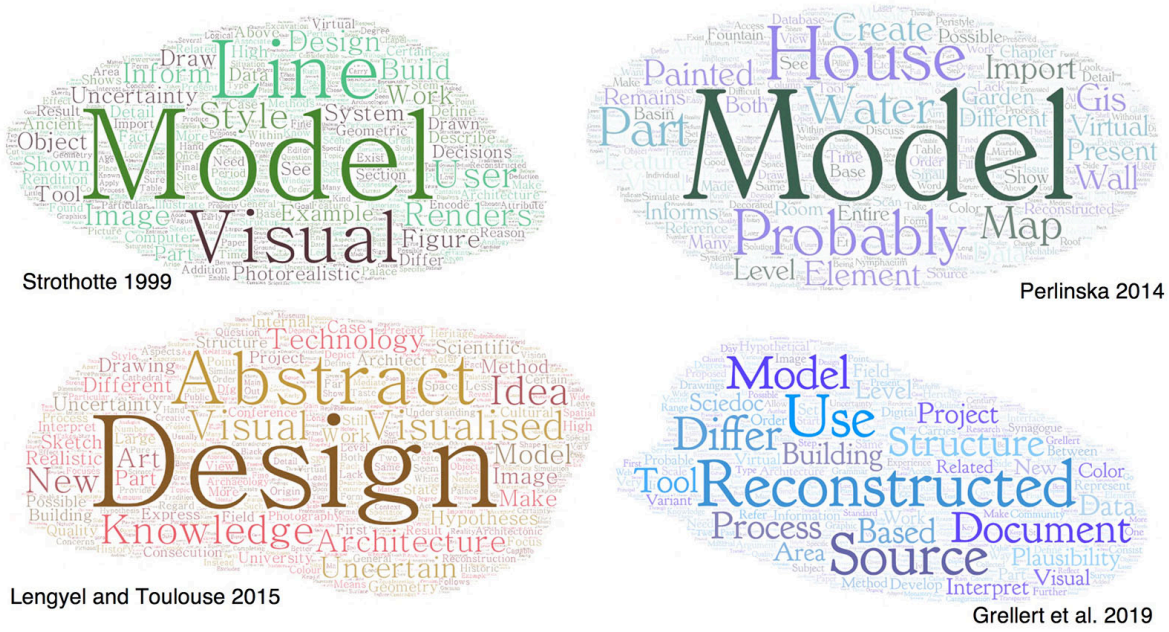

Figure 1. Word clouds concerning four of the 27 papers considered. © Irene Cazzaro.

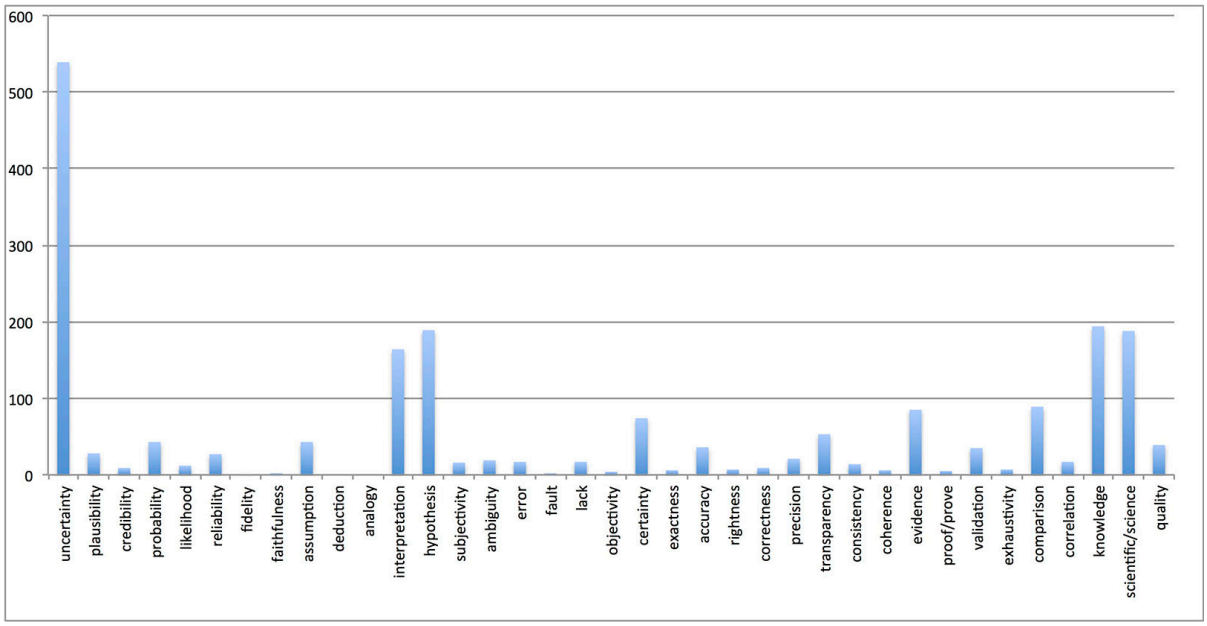

Figure 2. Frequency in the use of words related to the critique of hypothetical reconstructions in 27 representative papers published from 1994 to 2019. © Irene Cazzaro.

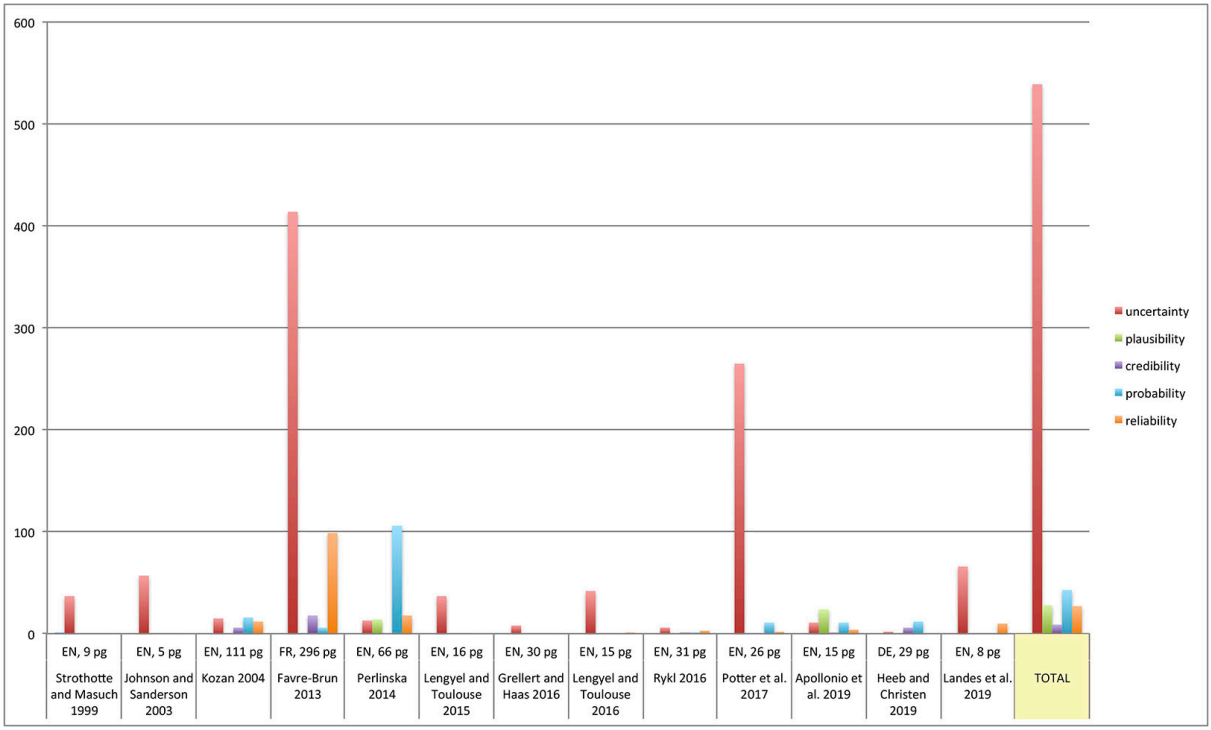

Figure 3. Frequency in the use of words related to certainty in hypothetical reconstructions in 13 representative papers published from 1994 to 2019. © Irene Cazzaro.

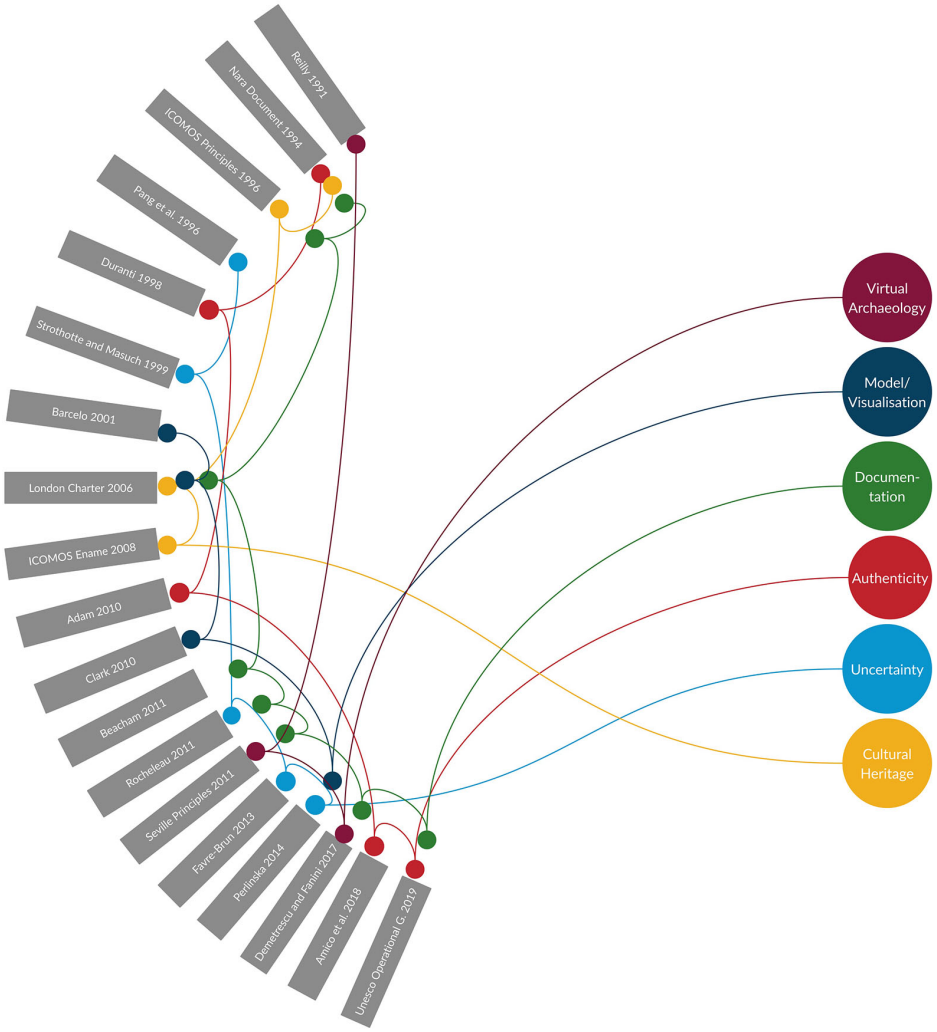

Figure 4. Classification of the papers according to six dominant macro-themes. Compared to those indicated above, the paper by Reilly [1991], important for the definition of virtual archaeology, has been added. © Irene Cazzaro.

PATHS: THREE EXAMPLES

Cultural heritage

Following the path related to the definitions of "cultural heritage" (fig. 5), we can see how they are connected to those of "sources of information (or research)", "conservation", "transparency". In this context, the Icomos and Unesco papers are relevant because, focusing on the conservation of cultural heritage, they also give definitions of specific terms, as we can see for example in the *Nara Document* (1994)[5] – concerning physical heritage rather than digital models – which defines "conservation" as «all efforts designed to understand cultural heritage» and «ensure its material safeguard». It also defines "information sources" as a list of all the different types of sources that bring knowledge to cultural heritage. The *Icomos Principles for Documenting Monuments, Groups of Buildings and Sites* (1996)[6] provide definitions regarding other related concepts, such as "recording" understood as the

«capture of information which describes the physical configuration, condition and use of monuments, groups of buildings and sites», thus quoting the definition of cultural heritage given in the *Nara Document* and, before that, in the *Unesco World Heritage Convention* (1972)[7], but now including «tangible as well as intangible evidence». Consequently, documentation can contribute to «the understanding of the heritage and its related values» and is «an essential part of the conservation process». The scope of this definition is similar to the analogous one contained in the *Unesco Charter for the conservation of digital heritage* (2003)[8], which refers to any type of «information created digitally, or converted into digital form from existing analogue resources» which are «frequently ephemeral» despite having «lasting value and significance», constituting «a heritage that should be protected and preserved for current and future generations».

The concept of "research sources" that emerges from the *London Charter* (2006)[9] can be linked to that of "sources of information" in the *Nara Document*, although the purpose of the former is its application not so much to physical heritage, but to computer-based visualisations. The "research sources" are therefore, in this case, «all information, digital and non-digital, considered during, or directly influencing» the creation of a model: therefore a list of sources is not provided, but rather, we focus on the effect that can be generated by them, regardless of their nature. Even "cultural heritage" in the London Charter is generically defined as «all domains of human activity which are concerned with the understanding of communication of material and intellectual culture», but in this case some of the domains are then in any case listed (museums, art galleries, heritage sites…).

Similarly, the concept of "cultural heritage site" contained in the *Icomos Ename* paper (2008)[10], which derives from the previous Icomos documents, involves places, localities, natural landscapes, settlements, architectural complexes, archaeological sites and existing structures.

The *Principles of Seville* (2011)[11] then specifically apply the guidelines established by the London Charter to the field of archaeology, therefore, instead of generally talking about "cultural heritage", they focus in particular on "archaeological heritage" (*patrimonio arqueológico*) defined as «the set of tangible assets, both movable and immovable, irrespective of whether they have been extracted or not […] which together with their context […] serve as a historical source of knowledge on the history of humankind».

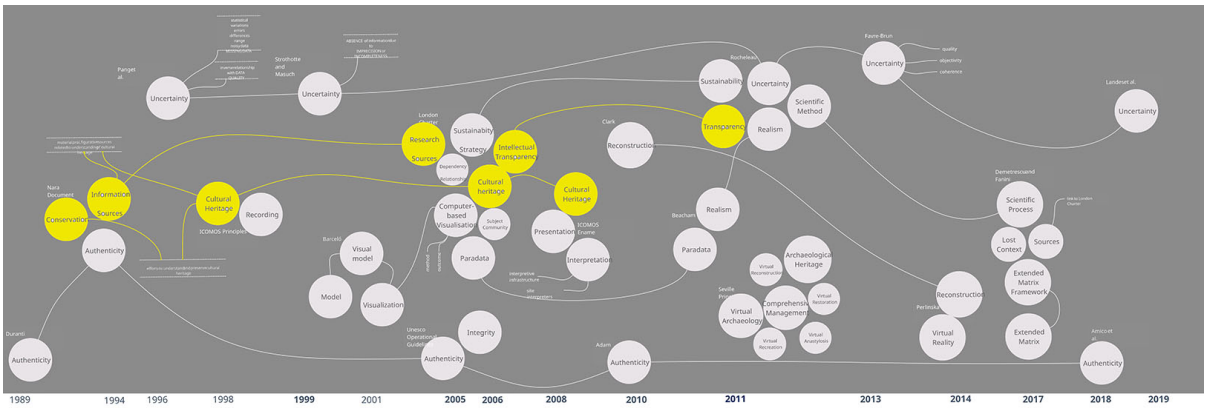

Figure 5. Path of the definition of cultural heritage. © Irene Cazzaro.

Authenticity

The term "authenticity" (fig. 6) also appears mainly in the Icomos and Unesco documents, which evaluate it as the «degree to which information sources may be understood as credible or truthful»[12]; this definition is also part of the *Unesco Operational Guidelines for the Implementation of the World*

Heritage Convention starting from the 2005[13] version. More specific definitions of "authenticity" can be found in the field of archival studies, which distinguish legal, diplomatic and historical authenticity[14].
However, it is recommended to use the word "faithful" instead of "authentic" in relation to digital objects or physical replicas, which are never original and unique, but always copies that can be replicated and modified[15].

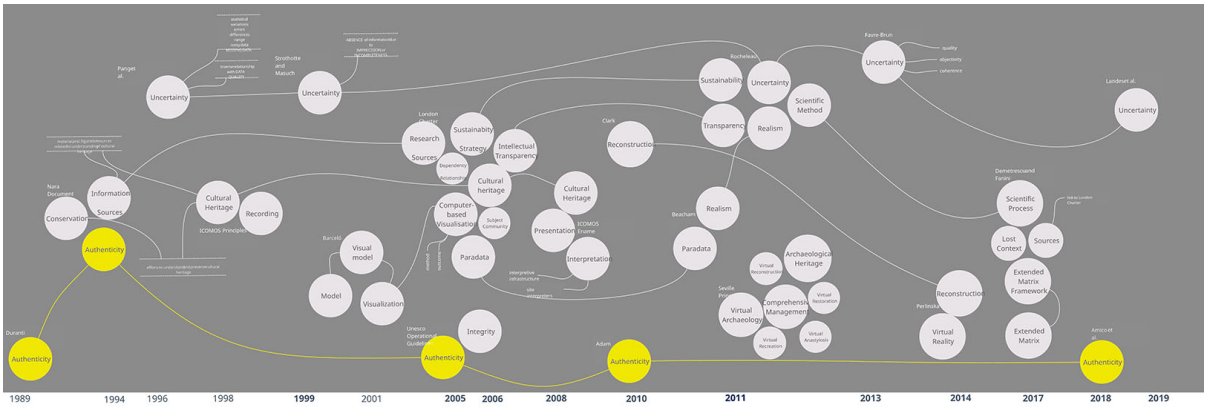

Figure 6. Path of the definition of authenticity. © Irene Cazzaro.

Uncertainty

The path corresponding to the definitions of "uncertainty" (fig. 7) starts from the article by Taylor and Kuyatt[16], who give a definition related to that of measurement error in physics, having a random and a systematic component: the difference between "error" and "uncertainty" lies in the fact that, in the second case, it is not necessary to know the real value of a quantity. Pang et al.[17] take up this definition and propose some scientific views. Two years later, Gershon[18] inserts "uncertainty" into the broader concept of "imperfection", which also includes "incompleteness": with respect to the latter, which refers to a lack of information, in the case of "uncertainty" the information is known, but the user is not sure. Turning to studies directly related to 3D digital reconstructions, Strothotte et al.[19] take up Gershon's terms, but change their hierarchy: this time "imprecision" and "incompleteness" are both part of the more general category of "uncertainty", defined as the – at least partial – absence of information. Kensek et al.[20] refer to "ambiguity, evidence and alternatives" for the analysis of ancient, historical and no longer existing sites, thus highlighting the lack of terminological uniformity. The authors themselves initially speak of the "uncertainty level" of a reconstruction, while later they cite tools to indicate the "types of reliability". The absence of a declaration on the "level of uncertainty" of a model is listed, according to Blaise and Dudek[21], among the limits of its credibility, together with the lack of connection to documentary sources and of dynamic updates as new information elements are collected. A correspondence with similar terms is also established by Rocheleau[22], who links "transparency" (*transparence*) and "intellectual honesty" (*honnêteté intellectuelle*) to "uncertainty" (*incertitude*), inserting the latter among the five rules proposed for obtaining scientific digital reconstructions. Different types of uncertainty have been traced by Favre-Brun[23], who identifies three main categories related to the quality of information (*qualité de l'information*), its coherence (*cohérence*) and its objectivity (*objectivité*). However, the use of these terms is still under discussion and, according to Perlinska[24], "uncertainty" is «a misleading word», since it refers to our subjective evaluation. "Plausibility" would be the most suitable word, since it «states the possibility of an event to occur» even if it is impossible to mathematically calculate its "probability". However, at the end

she decides to use the word "probability" because, according to her analysis, it turns out to be more frequent. As far as our study is concerned, however, we have seen in the previous tables that "uncertainty" seems to be the most used word in relation to this context: this fact motivates our choice. Even in more recent works, expressions such as "uncertainty" and "uncertain knowledge" are taken into consideration to refer to that state «between knowledge on one hand and lack of knowledge on the other hand»[25], or to the result of missing data[26] that cannot be «defined, quantified and expressed with the help of statistical measures»[27].

In addition to the path of the term "uncertainty", we also followed that of its representation by means of colour scales in the models relating to hypothetical reconstructions. We can see that it is not always possible to directly compare scales segmented in different ways and terms in different languages (Italian, English, Spanish – fig. 8). Furthermore, the classification of the level of uncertainty is sometimes based on the operation that is performed (objectivity, deduction, analogy...), other times on the type of document that is considered (original drawings, drawings by other authors, textual evidence...) or on the level of knowledge we have about it (high, moderate, weak…).

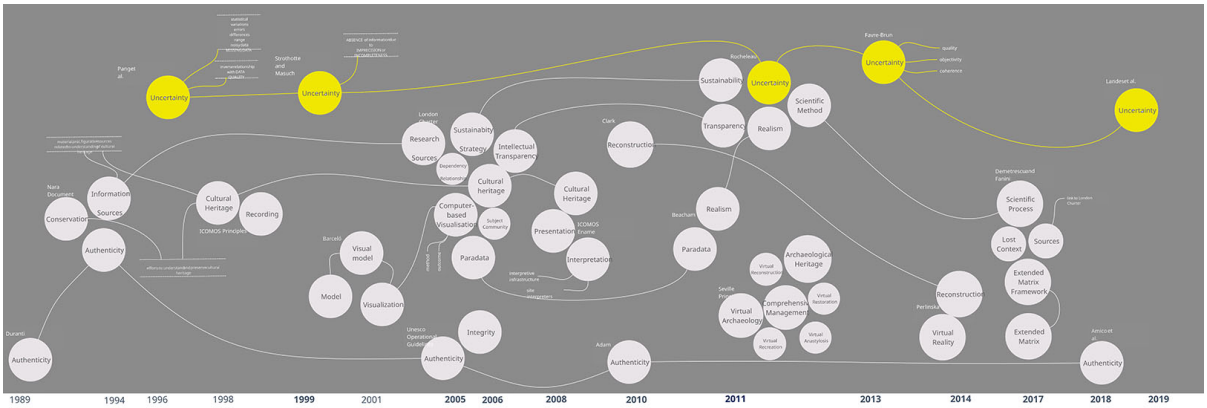

Figure 7. Path of the definition of uncertainty. © Irene Cazzaro.

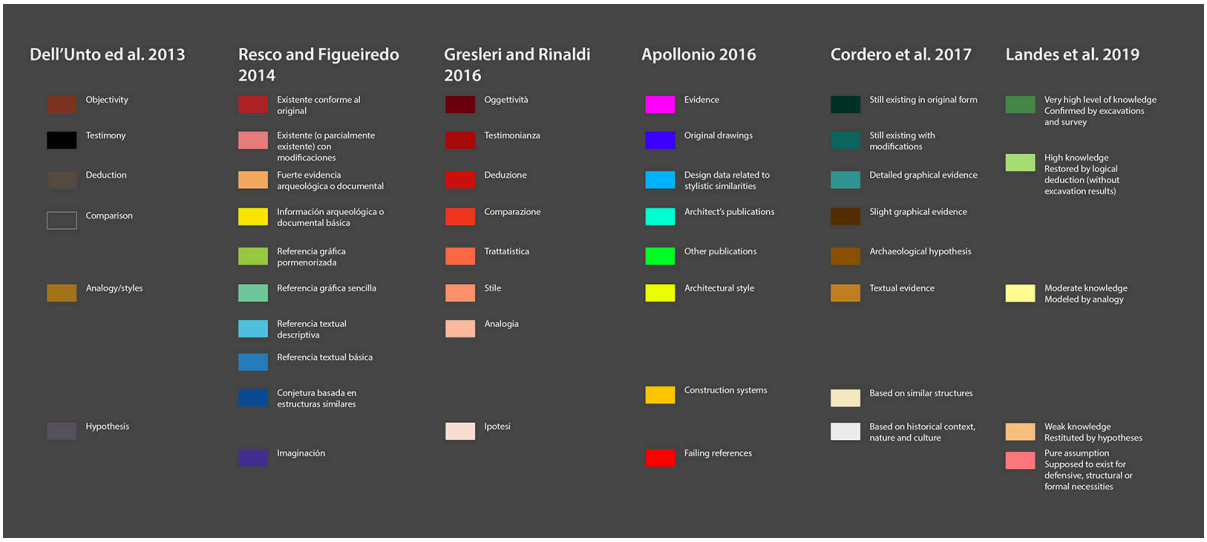

Figure 8. Comparison between different scales used to represent the level of uncertainty of a reconstruction, often segmented according to different criteria, which also correspond to different colour scales. Four of them are in English, one in Italian and one in Spanish; there is rarely a direct correspondence between them. © Irene Cazzaro.

TERMINOLOGY AND STANDARDISATION OF THE WORKFLOW

The analysis on terminology becomes important in the light of publication of models in online 3D platforms: especially when dealing with different disciplines and kinds of audience, standardisation is required not only in terminology, but also (and consequently) in the adopted workflow.

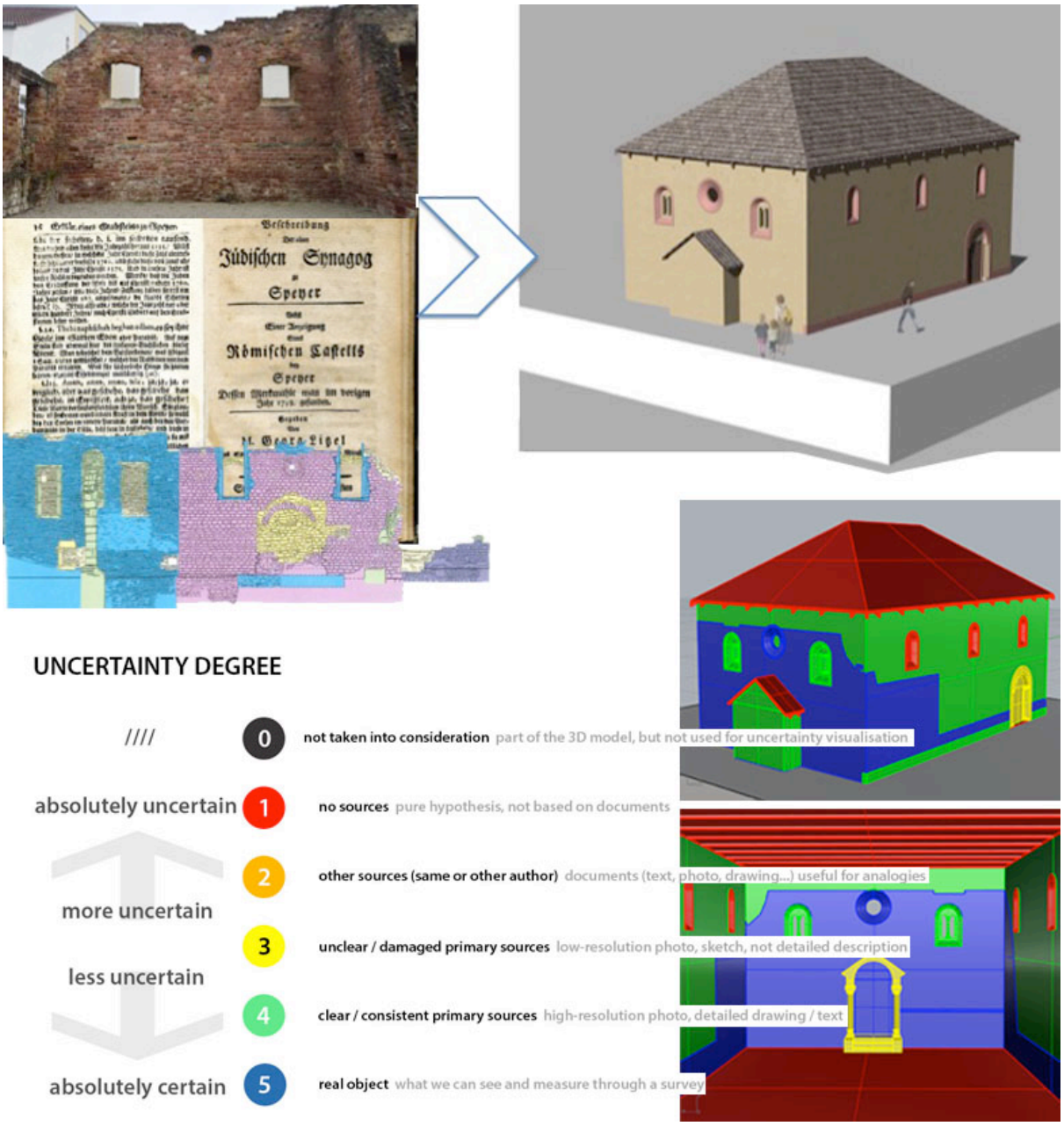

Figure 9. Some of the steps that led to the creation of the source-based 3D model of the medieval synagogue in Speyer. The reconstruction is mainly based on pictures, written descriptions and archaeological reports. Different people were involved in this work, thus a standardisation in both terminology and workflow was necessary. An uncertainty scale, based on the operations made to reconstruct each element of the building, was proposed and tested on models created with different software. The one in this picture was created with Rhinoceros and the information about uncertainty was added in different layers, one for each degree from 0 to 5. © Irene Cazzaro.

An example is the source-based hypothetical reconstruction of the medieval synagogue in Speyer (Germany)[28], a building now in ruin. This reconstruction was mainly based on pictures, written descriptions and archaeological reports. After defining a common terminology and sharing all the available sources among the participants in the project, a methodology was set up with a focus on the definition of a hierarchy of elements, as well as on the documentation of each one of them and of the process that led to its creation. An uncertainty scale was proposed and tested on the model (Fig. 9). It is based on the operations made to reconstruct each element of the building, according to this classification:

- Still existing parts that are digitally reconstructed by survey and physical analysis;
- Missing elements reconstructed by deduction, because they should be similar to the existing ones or they are mentioned in documents directly referring to the building (for instance texts, drawings, photos);
- Missing elements reconstructed by analogy starting from other structures of the same historical period;
- Missing elements reconstructed by hypothesis, because there are no available sources for them.

An extra level was then added to identify the elements that were not taken into consideration for the uncertainty estimation: this is the case, for example, of the terrain where the model is situated.
A colour and a number in a scale from 0 to 5 were associated to each uncertainty level.
The synagogue was modelled using different kinds of software, thus the information about uncertainty was added according to the possibilities offered by each one of them: in some cases, the colour was implemented in the visualisation and the number in the attributes of the various elements; in other cases, different layers were used to refer to these uncertainty levels.
The reconstruction of each element was also documented through screenshots and written descriptions: this information was collected in tables that were uploaded to the online platform together with the model itself.

CONCLUSION

The studies on terminology aim to foster dialogue between creators (but also users) of digital 3D models for cultural heritage, especially in view of their publication on online platforms. It is indeed of vital importance to indicate all the choices that are made and the sources that are taken into account, as well as the level of "uncertainty" (using the most frequent term) of each of them, in order to obtain a reconstruction that can be used in a "scientific" way: this documentation and the data model that the reconstruction must bring with it should be based on a shared terminology or, at any rate, on conscious choices.
As far as uncertainty – one of the most discussed terms – is concerned, an accurate definition of it and an analysis of its different segmentations into levels over time ideally aims to arrive at a standard or at least a clear classification with as little ambiguity as possible, so that it can be applied on a large scale in online platforms with 3D viewers (as in the examples in Fig. 10). This would help to keep track of a hypothetical reconstruction process, thus based not only on physical remains (sometimes unavailable), but also and above all on documents that have a different degree of detail and may require more or less interpretation. The use of a shared terminology and methodology is fundamental in this process of declaring which decisions we make and how sure we are of them: ultimately, this would lead us to distance ourselves from reconstructions that are used purely for entertainment purposes and that often represent a perfect, closed and indubitable reality.

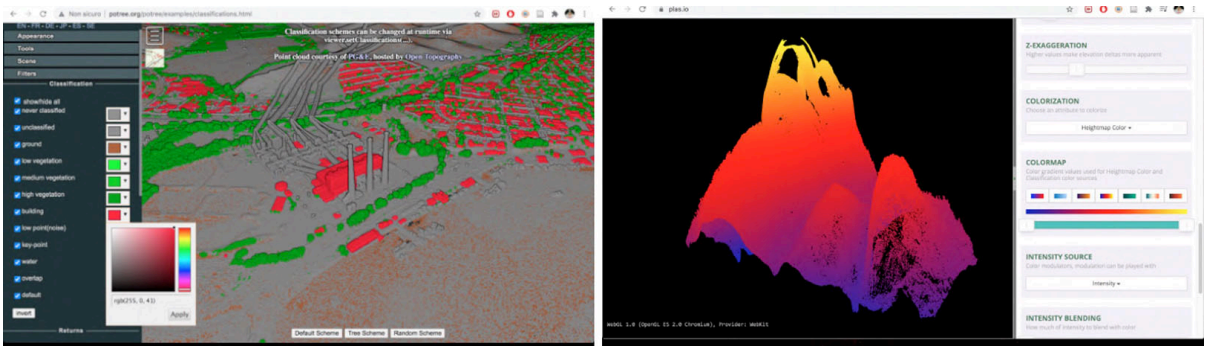

Figure 10. Examples of applying colour scales to models displayed online: in the example on the left (http://potree.org/potree/examples/classifications.html consulted on 04.03.2022) different colours (which can be changed by the user) are assigned to the different elements that make up the model (roads, buildings, vegetation...); in the example on the right (https://plas.io/ consulted on 04.03.2022) a gradient (therefore not exactly a scale composed of defined levels) indicates the height of the different points of a surface. Similarly, also for the representation of uncertainty one could think of a colour scale corresponding to a number of values of a parameter assigned to each element that is considered.

NOTES

[1] The 27 papers considered in the initial analysis (reported in full in the bibliography) and the 13 of them relating to uncertainty (indicated here with an asterisk) are the following: Strothotte et al. 1999*; Johnson and Sanderson 2003*; Kozan 2004*; Kensek 2007; Gooding 2010; López-Menchero Bendicho and Grande 2011; Potter et al. 2012*; Dell'Unto et al. 2013; Dufaÿ and Mora 2013; Favre-Brun 2013*; Perlinska 2014*; Resco 2014; Quattrini and Baleani 2015; Apollonio 2015; Lengyel and Toulouse 2015*; Apollonio 2016; Chandler and Polkinghorne 2016; Grellert and Haas 2016*; Jahn et al. 2016; Lengyel and Toulouse 2016*; Messemer 2016; Rykl 2016*; Ortiz-Cordero et al. 2018; Lercari 2017; Grellert et al. 2019*; Heeb and Christen 2019*; Landes et al. 2019*.
[2] It should be noted that we decided to use the term "reconstruction" based on the high frequency in the occurrence of the word rather than on its appropriateness. It is clear that we are "always constructing models, whether visual, verbal, or some other type, which are tools for understanding, not statements of reality" (Clark 2010), thus "construction" would be a more suitable word with respect to "reconstruction". However, "reconstruction" is far more used and it has become a standard in the field of digital 3D models.
[3] Aurélie Favre-Brun, "Architecture virtuelle et représentation de l'incertitude: analyse des solutions de visualisation de la représentation 3D. Application à l'église de La Chartreuse de Villeneuve-Lez-Avignon (Gard) et à l'abbaye Saint-Michel de Cuxa (Pyrénées-Orientales)" (PhD thesis, Université d'Aix-Marseille, 2013).
[4] Niklaus Heeb and Jonas Christen, 'Strategien Zur Vermittlung von Fakt, Hypothese Und Fiktion in Der Digitalen Architektur-Rekonstruktion', in *Der Modelle Tugend 2.0*, 2019, 226–54.
[5] See https://www.icomos.org/charters/nara-e.pdf (accessed 30.07.2022).
[6] See https://www.icomos.org/charters/archives-e.pdf (accessed 30.07.2022).
[7] See https://whc.unesco.org/archive/convention-en.pdf and the operational guidelines for its implementation that have been developed in the following years: https://whc.unesco.org/en/guidelines/ (accessed 30.07.2022).
[8] See https://unesdoc.unesco.org/ark:/48223/pf0000179529 (accessed 30.07.2022).
[9] See https://www.londoncharter.org/ (accessed 30.07.2022).
[10] See http://icip.icomos.org/downloads/ICOMOS_Interpretation_Charter_ENG_04_10_08.pdf (accessed 30.07.2022).
[11] See http://sevilleprinciples.com/ (accessed 30.07.2022).
[12] *The Nara Document*, https://www.icomos.org/charters/nara-e.pdf (accessed 30.07.2022).
[13] We refer to the following version: https://whc.unesco.org/archive/opguide05-en.pdf (accessed 30.07.2022).
[14] Luciana Duranti, 'Diplomatics: New Uses for an Old Science', *Archiviaria*, no. 28 (1989): 7–27; Sharon Adam, 'Preserving Authenticity in the Digital Age', *Library Hi Tech* 28, no. 4 (November 2010): 595–604.
[15] Nicola Amico et al., 'Theorizing Authenticity - Practising Reality: The 3D Replica of the Kazaphani Boat', in *Authenticity and Cultural Heritage in the Age of 3d Digital Reproductions*, ed. Paola Di Giuseppantonio Di Franco, Fabrizio Galeazzi, and Valentina Vassallo (Cambridge: McDonald Institute for Archaeological Research, 2018), 111–22.
[16] Barry N. Taylor and Chris E. Kuyatt, 'Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results', *NIST Technical Note 1294*, 1994, 1–20.
[17] Alex T. Pang, Craig M. Wittenbrink, and Suresh K. Lodha, 'Approaches to Uncertainty Visualization', *Visual Computer* 13, no. 8 (1996): 370–90.
[18] Nahum Gershon, 'Visualization of an Imperfect World', *IEEE Computer Graphics and Applications*, 1998, 43–45.
[19] Thomas Strothotte, Maic Masuch, and Tobias Isenberg, 'Visualizing Knowledge about Virtual Reconstructions of Ancient Architecture', *Proceedings - Computer Graphics International, CGI 1999*, no. February (1999): 36–43.
[20] Karen M. Kensek, Lynn Swartz Dodd, and Nicholas Cipolla, 'Fantastic Reconstructions or Reconstructions of the Fantastic? Tracking and Presenting Ambiguity, Alternatives, and Documentation in Virtual Worlds', *Automation in Construction* 13, no. 2 (2004): 175–86.
[21] Jean-Yves Blaise and Iwona Dudek, 'Modélisation Informationnelle: Un Cadre Méthodologique Pour Représenter Des Connaissances Évolutives Spatialisables', *EGC '06 - Extraction et Gestion Des Connaissances*, August (2006): 347–58.
[22] Mathieu Rocheleau, 'La Modélisation 3D Comme Méthode de Recherche En Sciences Historiques', *Actes Du 10ème Colloque International Étudiant Du Département d'Histoire*, 2011, 245–65.
[23] Favre-Brun, 'Architecture Virtuelle et Représentation de l'incertitude: Analyse Des Solutions de Visualisation de La Représentation 3D. Application à l'église de La Chartreuse de Villeneuve-Lez-Avignon (Gard) et à l'abbaye Saint-Michel de Cuxa (Pyrénées-Orientales)' (Université d'Aix-Marseille, 2013).
[24] Marta Perlinska, 'Palette of Possibilities' (Lund University, 2014).
[25] Dominik Lengyel and Catherine Toulouse, 'The Consecution of Uncertain Knowledge, Hypotheses and the Design of Abstraction', in *CHNT 20 - Proceedings of the 20th International Conference on Cultural Heritage and New Technologies*, 2015.

[26] Tom Chandler and Martin Polkinghorne, 'A Review of Sources for Visualising the Royal Palace of Angkor, Cambodia, in the 13th Century', *Virtual Palaces, Part II: Lost Palaces and Their Afterlife: Virtual Reconstruction between Science and Media*, 2016, 149–70.
[27] Tania Landes et al., 'Uncertainty Visualization Approaches for 3D Models of Castles Restituted from Archeological Knowledge', *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 42, no. 2/W9 (2019): 409–16.
[28] The research has been conducted at the Institute of Architecture of the University of Applied Science in Mainz (Germany), where a 3D repository has been developed: see https://3d-repository.hs-mainz.de/ (accessed 30.07.2022).

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