Systematizing Virtual Reconstruction of Lost or Never Built Architectures

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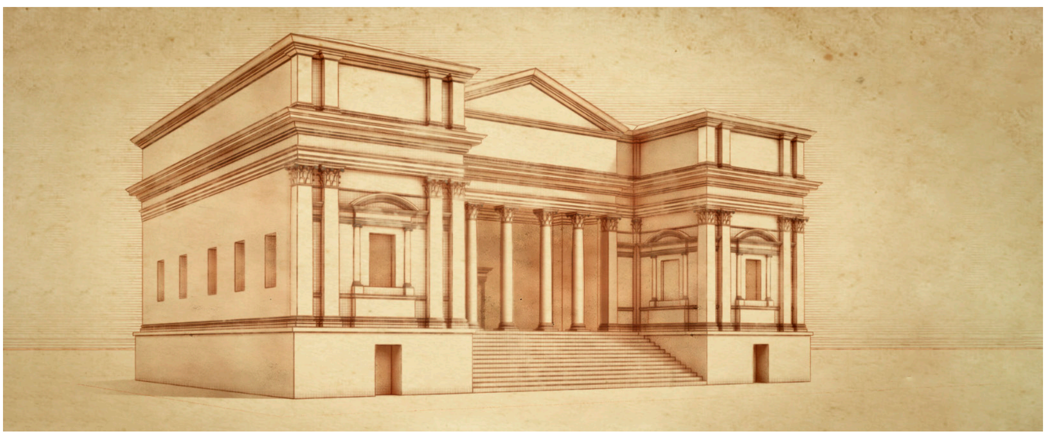
Abstract

European Architectural Cultural Heritage is immense. Yet part of this Heritage is invisible: churches, synagogues, mosques that have either been destroyed or never been built. Now the digital world offers the possibility to bring these artefacts to a new life, through 3D reconstruction. This way of studying and representing the past has become increasingly important in the academic world and the domain of digital entertainment. These applications make use of the so-called 'virtual 3D reconstructions', which are 3D models based on figurative/textual sources or ruins of artefacts that no longer exist or have never been built.
This paper aims to present 'CoVHer' (Computer-based Visualisation of Architectural Cultural Heritage), an Erasmus Plus Project that deals with this vast theme and involves five universities and two private companies from five European countries (Italy, Spain, Portugal, Poland and Germany). The main objective of CoVHer is to define applicable/practice guidelines and operational methodologies aimed at the study, implementation, visualization and critical evaluation of the 3D models. Some of the ongoing theoretical studies developed in the project will be presented. In particular, this paper will focus on the systematization of the reconstruction process. It defines and classifies different aspects of 3D digital modelling; and other aspects concerning visualization in the field of architectural hypothetical reconstruction.

Keywords
3D Reconstruction, Architectural Cultural Heritage, Guidelines, Digital Representation, Modeling methods



3D critical model of [Apollonio et al. 2021b] Andrea Palladio's *Design for a villa: facade and plan* [Palladio 1560], (graphic elaboration by the authors).

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Introduction

The reconstruction of heritage from the past in form of 3D digital models is the main medium of investigation and visualization both in the academic and entertainment fields. The large production of these models has encouraged an international debate about their scientific reliability. Two important theoretical guidelines have been drawn up in this regard: the London Charter [London Charter website] and the Seville Principles [Seville Principles website]. These documents have fixed general theoretical principles on the scientific nature of Computer-based Visualisation of Architectural Cultural Heritage (CVCH) models. However, so far there are still no specific operational standards that can help share and reuse models inside and outside the academic community. The growing interest in promoting the study, preservation, and dissemination of CH through digital technologies [Albisinni et al. 2016] was widely proved by the numerous financed European Horizon projects on these topics (e.g., Inception [Inception website]; Time Machine [Time Machine website]; V4Design [V4design website], Crosscult [Crosscult website]), but no one is still specifically focused on 3D hypothetical reconstructions of unbuilt or lost architectural projects. Thus, at present, there is still no shared reference procedure or list of requirements that could help validate a scientific 3D virtual reconstruction from an amateur one. For this reason, most of the time, scholars are more inclined to rebuild the models entirely rather than reusing models built by others.

The CoVHer Project

CoVHer [1] project tries to give a concrete answer to these needs by defining applicable guidelines and operational methodologies aimed at the study, implementation, visualization, critical evaluation, and transparent documentation of scientific 3D hypothetical reconstructive models, following the Charter on the Preservation of Digital Heritage (UNESCO, 2003). Scientific 3D models should be built and shared in a rigorous and transparent way, to be used as instruments for scientific dissemination and as a three-dimensional reference document for scholars of CH. For this to be true, the definition of a clear methodology shared at the international level becomes crucial. This is why CoVHer starts from the FAIR data principles [FAIR principles website], and some of its partners are chosen among those actors who contributed to previous similar projects (e.g., Time Machine project, DFG 3D Rekonstruction Netzwerk) [DFG website]. The proposed innovation starts from the definition of univocal unambiguous terminology (gathered in a glossary), and the outlining of the qualities that the 3D model must fulfil to reach scientific reference standards:

- Constructive quality: the geometry accuracy and qualification of the 3D models.
- Traceability quality: the clarity of the critical apparatus that documents the reconstruction process, from the sources to their critical use.
- Accessibility quality: the compatibility with the publication on platforms/repositories.
- Interoperability quality: the possibility to exchange data in different exchange formats.
- Visualization quality: the quality of the graphic output to communicate scientific content.

Another outcome of the CoVHer project, aimed at simplifying the transmissibility and reuse of the 3D models, is the development of a digital repository where the models will be enriched with sources, texts, and metadata concerning their qualities. The platform, therefore, will have two different and complementary vocations. The first is being a reference place for scholars (architects, engineers, art historians, archaeologists, and other field experts) where they can share, download, and study 3D reconstructions and the sources used to build them. The second is being an open-access repository accessible also to laypersons (non-experts) and will contribute to the dissemination of cultural identity at the European level.
Another outcome of the CoVHer project, aimed at dissemination, is the development of open-access University-level online courses dedicated to the virtual reconstructions of CH. The courses will help to create an international community that shares a common language.

The Raw Model, the Informative Model, and the Critical Digital Model

One of the first theoretical issues addressed in the CoVHer project is the definition of different types of 3D models of virtual reconstructions. Concerning the digitization process, digital models can be divided into two broad categories: Raw Models (RM) and Informative/Informed Models (IM).

RMs are digital models obtained through quasi-automatic procedures starting from raw data captured from physical sources (digital photogrammetry or scanner laser). IMs, on the other hand, are digital models that contain information processed and interpreted by an author. An architectural survey, according to this classification, generally consists of both types of models overlapped: the RM, which is the point cloud (or triangulated mesh) obtained automatically; and the IM, which is the critical interpretation of the point cloud (planes and lines are derived critically from homologous groups of points). The first one is useful because it is more objective and can be used for validation checks or precise measuring. The latter is useful for extracting 2D technical drawings and operating measures or variants. When a virtual 3D reconstruction aims to represent the past, drawn by a specific author in a specific period, it is possible to refer to it as a Critical Digital Model (CDM) [Apollonio et al. 2021]. The CDM is the architectural equivalent to the critical edition of a text, and it is defined as a publication of a 3D model itself aimed at restoring the original form of the object of study, as complete and as close as possible to the will of the author in a given period, based on a comparative study of all the available sources. The CDM is always provided with a critical textual and graphical apparatus where sources and processes are documented precisely. Eventual variants of the same building are still IMs but they are not considered CDM in fact they are attached as appendices to the critical apparatus of sources and outputs of the CDM. According to this definition, the CDM is a special case of the IM.

Methods And Techniques of Digital Representation

Other than classifying the model according to its Level of Interpretation (Raw model and the Informative Model), it is also possible to consider other aspects that concern its creation process or its mathematical nature. CoVHer project tries to put order to the classification criteria of 3D modelling considering many different aspects (fig. 1): the Configura-

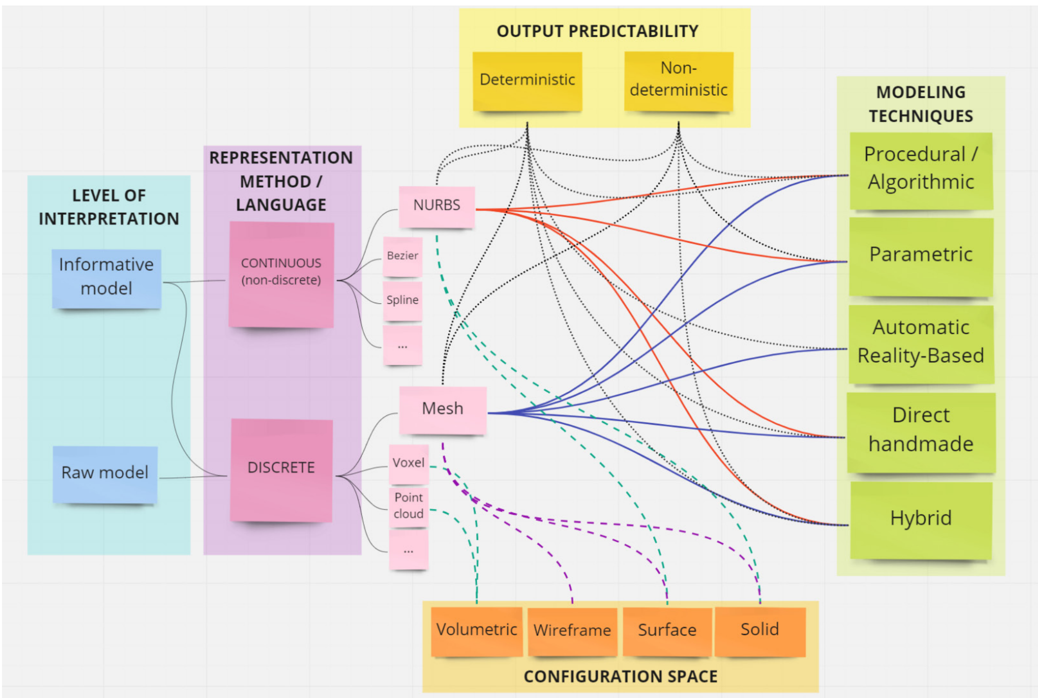


Fig. 1. Conceptual scheme of 3D modelling classification (graphic elaboration by the authors).

tion Space (how the software considers their occupied volume); the Modelling Techniques (how the models are generated in practice); the Digital Representation Methods/Languages (what's the mathematical language used by the software to describe their geometry); and finally the Output Predictability (if the same set of inputs always produces the same results or not). If the configuration space [2] and the output predictability [3] are pretty self-explanatory, the Digital Representation Methods/Languages and the Modelling Techniques need a further explanation. The Digital Representation Methods/Languages deal with the intrinsic mathematical nature of the models. It is important to know the criticalities and potentialities of each method to properly choose when to apply them. The digital representation methods are the following two (fig. 2):

- Continuous Methods: the geometry is described through mathematical equations that define precisely its properties in a non-discrete way at any point, the Mathematical/Surface Modelling is part of this category (for example NURBS modelling, Bezier modelling, Spline modelling, etc.);
- Discrete Methods: the geometry is described in a discrete way, not with equations, but with points identified by their coordinates (vertices), meaning that curved surfaces are only approximated with lines (edges), and planar faces (triangles/polygons); the Numerical/Polygonal Modelling is part of this category (for example mesh modelling, Point Cloud modelling, Voxel modelling, etc.).

Continuous and Discrete methods are also called Parametric and Non-parametric by some authors [Khatamian, Arabnia 2016], however, to avoid ambiguities with the 'Parametric modelling technique' which has a completely different meaning, we won't use this terminology in this paper. The naming 'Digital Representation Methods' comes from their analogies with the traditional Methods of Representation. Some scholars [Migliari 2009] propose to consider them as a direct addition to the traditional representation methods which are the following:

- Double orthogonal projections;
- Axonometric projection;
- Perspective projection:
- Topographic terrain projection (with contour lines).

The analogy between digital methods and traditional methods concerns the way they are used. Continuous methods are used to describe precisely the shape and dimensions of an object (mechanical pieces, CNC moulds, cars' chassis, etc.), discrete methods are usually used to produce models for visualization (games' models, characters, natural environments…). In the same way, the axonometric, and double orthogonal projections are used to describe shapes and dimensions precisely, and the perspective projection is used to mimic human vision.
Another analogy is that discrete and continuous methods can coexist in the same 3D model, in those cases, we talk about Hybrid Methods. This also happens in traditional representation methods: for example, in the perspective section the sectioned elements are in true form

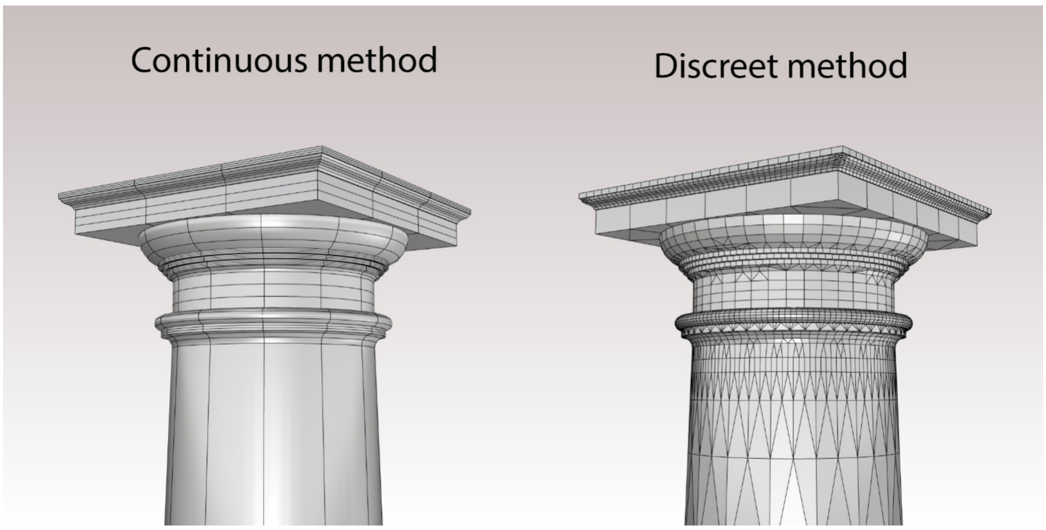
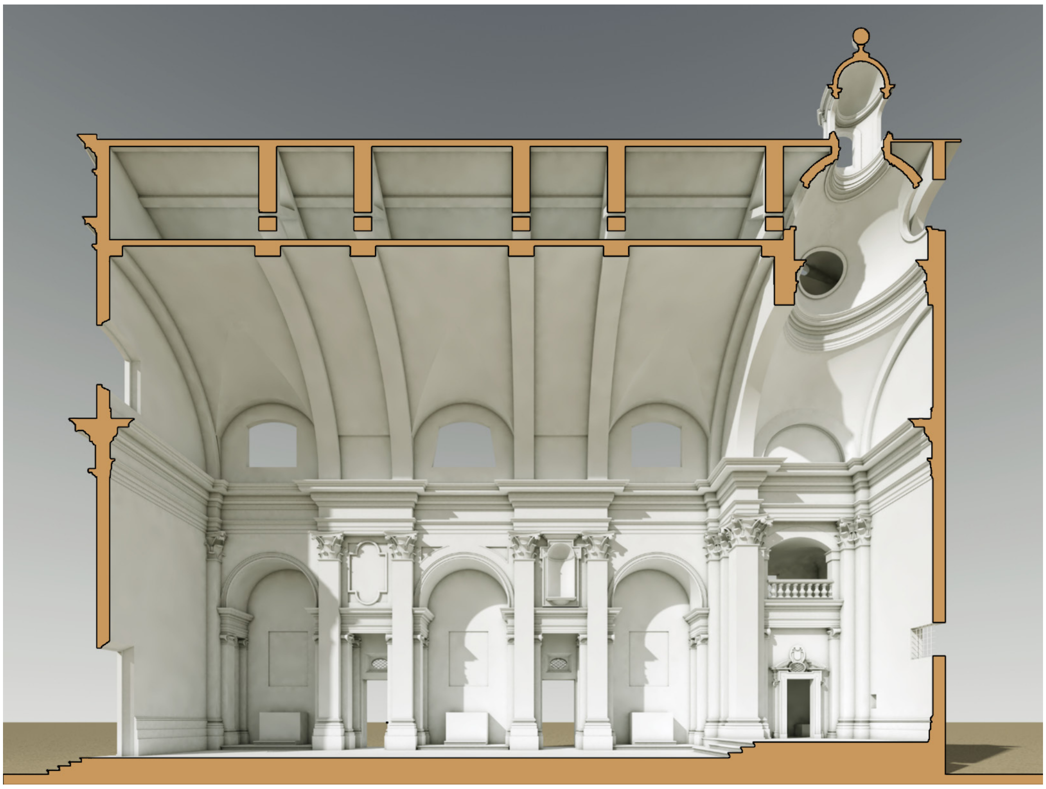


Fig. 2. A 3D model of a column represented as a continuous NURBS surface and approximated through a polygonal discrete Mesh (graphic elaboration by the authors).

Fig. 3. Perspective section of the church of S. Margherita, Bologna, informative reconstructive model (CDM) of the never realized church designed by Agostino Barelli in 1685 [Costarelli 2015], (graphic elaboration by the authors).



(as in double orthogonal projections) and the inside spaces are in perspective view (fig. 3). Knowing that, it is easy to understand why operators in the field of 3D hypothetical reconstructions should be able to use all methods because each method of representation has a specific vocation and is more effective than the others only in some contexts (fig. 4) (e.g., NURBS can be effective to model arches, walls, floors, doors, etc.; and meshes can be effective for ornaments, fabrics, characters, etc.).

The modelling techniques differ from digital representation methods because they are focused on the creation process of the models and not on their intrinsic mathematical nature. They deal with all those practices, processes and norms that describe the act of constructing 3D shapes.

To make an exemplificative analogy with traditional drawing: the watercolour technique, for

Fig. 4. Reconstruction of Spirito Santo church (Bologna), as it was in 1816 during Canova's exposition [Apollonio et al. 2021a]. Mesh models in red and NURBS models in grey (graphic elaboration by the authors).

	Real object	Direct\primary sources		Other sources		Reliability
		Clear/ consistent	Damaged/ unclear	Same author/s	Other author/s	
1	available	\	\	\	\	Reality
2	unavailable	available	\	\	\	Reliable conjecture
3	unavailable	unavailable	available	available	\	Conjecture
4	unavailable	unavailable	available	unavailable	available	Conjecture
5	unavailable	unavailable	unavailable	available	\	Conjecture
6	unavailable	unavailable	unavailable	unavailable	available	Conjecture
7	unavailable	unavailable	unavailable	unavailable	unavailable	Conjecture
\	\	\	\	\	\	Abstention

Fig. 5. Level of uncertainty scale, with 7+1 levels (graphic elaboration by the authors). For a more in-depth discussion refer to [Apollonio et al. 2021b].

example, can be used to add shadings to perspective views, axonometric views, or double projections. Analogously, the procedural modelling technique can be used to generate both mesh and NURBS models.

The following approaches are examples of modelling techniques:

- Procedural/Algorithmic Modeling (Rhinoceros+Grasshopper, Revit+Dynamo, Blender+Geometry Nodes, etc.).
- Parametric Modelling (Inventor, Catia, Creo Parametric, etc.).
- Automatic Reality-Based Modeling (Agisoft Metashape, Reality Capture, etc.).
- Direct Handmade Modeling (Rhinoceros, Autocad, Zbrush, Blender, 3Dmax, C4D, etc.).
- Hybrid Modeling (Almost all commercial software packages nowadays support hybrid modelling).
- Etc.

This list is provisional because 3D modelling applications are constantly evolving. These techniques are not linked to a particular software, the computer applications in parenthesis are added only to help the reader orient, nevertheless, those applications are not exclusive to only one technique.

Visualizing sources and reliability

The traceability of the sources/process of reconstruction is a crucial aspect of scientific hypothetical reconstructions. Transparent documentation can be achieved through texts referred to or appended to the 3D model [Bentkowska-Kafel et al. 2012], or it can be achieved more visually through shading and texturing. False colour scales are widely used shading techniques to embed additional information directly into the model surfaces [Kensek 2007]. This kind of abstract shading is used, for example, to distinguish between physical remains and hypothetical reconstructions, to indicate different periods and ages [Zuk et al. 2005], to make the type of sources used explicit, or to indicate the level of uncertainty [Apollonio 2016] / subjectivity/ reliability [Sorin et al. 2006] of specific parts. In particular, in the context of CoVHer project, a novel scale of uncertainty is being shared and put to test to verify its robustness in the field of hypothetical reconstructions of never built or lost architectural heritage (figs. 5, 6).

Conclusions

In this paper, some of the issues addressed by the CoVHer project are briefly presented, concerning the theme of virtual reconstructions of architectures that no longer exist or were never built. Firstly a possible classification of 3D digital models was proposed. The concepts of the Raw

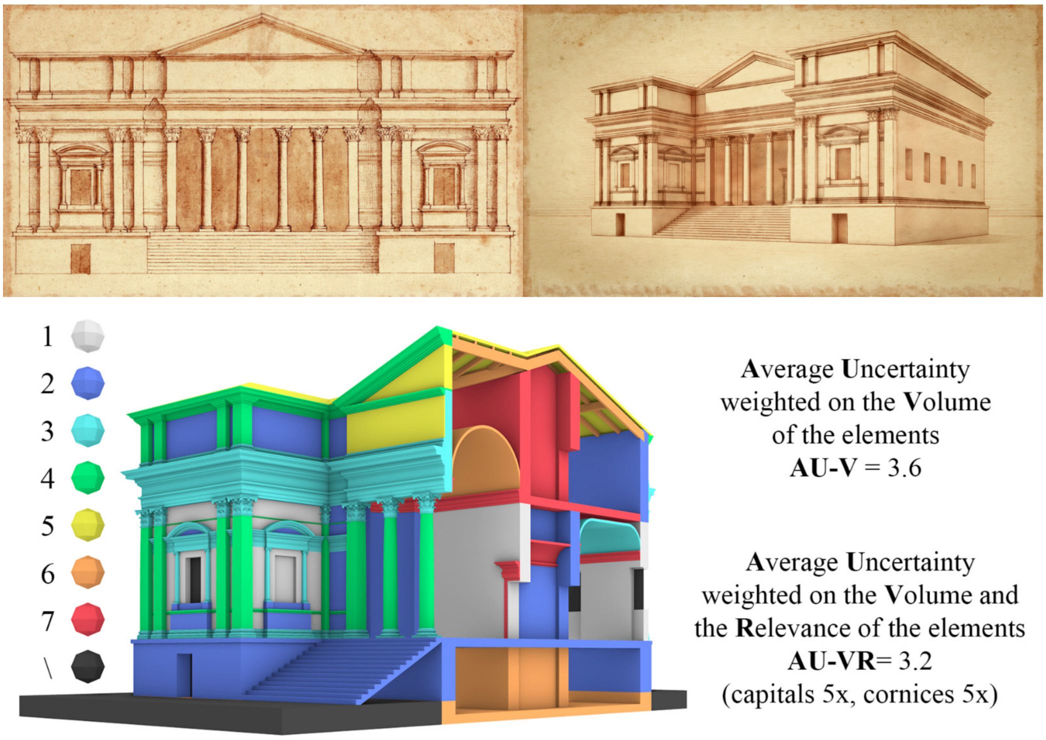


Fig. 6. *Design for a villa: facade and plan* [Palladio 1560]: (left) scale of the level of uncertainty (7 + 1 levels); (right) two alternative ways to calculate the average uncertainty numerically [Apollonio et al. 2021b] (graphic elaboration by the authors).

model and Informative model were defined. The concept of the Critical Digital Model was introduced as a subset of the family of informative models. The differences between digital modelling methods and techniques were illustrated. Finally, the concept of the scale of uncertainty was mentioned. There are still several theoretical and practical issues to be addressed and discussed, which are not addressed here due to the synthetic nature of this presentation. It is evident, therefore, that this article aimed to introduce the project and disseminate its preliminary results which are the basis of a more complex work still in progress, which involves several researchers from five European countries and which has the ambition of finding a common ground shared between architects, engineers, historians of art and archaeologists who deal with the problem of virtual reconstructions.

Notes

[1] CoVHer (Computer-based Visualisation of Architectural Cultural Heritage) is an Erasmus Plus Project (ID KA220-HED-88555713). It is a 36 months project and it started in February 2022. There are seven principal partners from five different European countries. The partners are: University of Bologna (Bologna, Italy), Hochschule Mainz University of Applied Sciences (Mainz, Germany), Politechnika Warszawska (Waraw, Poland), Universidade Do Porto (Porto, Portugal), Universitat Autonoma de Barcelona (Barcelona, Spain), Tempesta Media SL (Barcelona, Spain), Interessengemeinschaft für semantische Datenverarbeitung e.V (München, Germany). The scientific coordinators of the partners involved are: Federico Fallavollita, Piotr Kuroczyński, Krzysztof Koszewski, Joao Pedro Sampaio Xavier, Juan Antonio Barceló Álvarez, Marc Hernández Güell and Mark Fichtner. For more detailed information, compare the two websites: www.CoVHer.eu and https://erasmus-plus.ec.europa.eu/projects/search/details/2021-1-IT02-KA220-HED-000031190.

[2] Different 3D applications consider the configuration space of a 3D model in different ways, volumetric models are usually made with point clouds or voxels, which are the 3D counterpart of pixels; wireframe models are usually meshes without faces; surface models are models made with collections of zero-thickness surfaces connected by their borders; solid models usually have the same math of surface models however they are checked for water-tightness in order to guarantee compatibility with Boolean operations. What it is important to understand is that solid models even if they might look filled inside, they are actually not, they are empty shells of surfaces that enclose an empty volume, the illusion of a solid volume is given by the automatic addition of the necessary surfaces when they are processed through cuts, splits or Boolean operations.

[3] The output predictability of a 3D modelling process determines how much control the operator has over the final result. Non-deterministic modelling is usually based on complex algorithms which might output different results even with the same set of inputs (e.g., genetic evolutionary algorithms are non-deterministic).

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