Classification schemes and model validation of 3D digital reconstruction process

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Abstract: A scientific hypothetical reconstruction requires a scientific methodology concerning to reconstruction process and its documentation. An appropriate theoretical and analytical study of virtual reconstruction practice of architectural/archaeological heritage artefacts no longer existing and partially documented, as well as a methodological approach to display the data-processing behind the 3D modelling practice are strictly necessary in order to cover the gap between the interpretation and the original data.
In order to validate the 3D modelling reconstruction process and to facilitate the exchange and reuse of information and collaboration between experts in various disciplines we maybe have to look at new standards due to reusability and accessibility of knowledge of 3D digital models: for a better interpretation of digital heritage artefacts we need a comprehensive interpretive method. Because many hypothetical reconstructions are the result of highly complex design decision we decide to focus attention to the cognitive-process.
The process of reconstruction is essentially composed by decisions based on various set of input data that are interpreted and integrated. This subjectivity, if not correctly reported, compromises the validity of a whole virtual reconstruction. According to “The London Charter” we need to prescribe a specific method, and to define a guideline for the use of computer-based visualization in relation to intellectual integrity, reliability, documentation, sustainability and access of heritage artefacts.
The results concern the definition of a new approach to Paradata Documentation - for creating a conceptual scheme able to clarify the relationship between research sources, implicit knowledge, explicit reasoning - a visualisation-based outcomes – able to show the level of uncertainty related to the reconstructive process of every single element of artifact - and the purpose to establish a “model validation” process, able to define a common and agreed upon standards.

Keywords: Virtual reconstruction, Paradata documentation, Uncertainty visualization, Semantic structure, Virtual reconstructive process.

Introduction

The digital revolution produced, in architectural representation and surveying techniques, an important development of new tools and methods for 3D data acquisition, documentation and dissemination of information related to architectural-archaeological heritage, leading to a drastic transformation in the way of collecting, processing, representing and spreading data and information related to any kind of artifact. If we wish to use the artifact as more than a purely geometrical object, and we aim to describe it univocally we need more than the traditional triplet of geometrical co-ordinates (x,y,z).

The availability of new and more effective digital technologies introduce, in fact, the possibility of interchangeable media able to offer multiple nodes of access to a given term or object, and enable a multidimensional approach to knowledge on several levels. The digital technologies propose new meanings of the concept of architectural representation, adding an extra dimension, the temporal one (diachronic and synchronic), which in turn allows to know that artifact not only in its evolution and transformation during its life cycle, but also through the analysis of its composition and geometric-formal matrix.
The advent of Virtual Archaeology (REILY 1990) opened the debate on the multidisciplinary approach to a wide amount of theoretical problems related to documentation, analysis and interpretations of archaeological artifacts (DELL'UNTO, LEANDER, FERDANI, DELLEPIANE, CALLIERI, LINDGREN 2013), and about the theme of transparency in virtual reconstruction (HERMON, SUGIMOTO, MARA 2007).
Within this context, a huge amount of studies have been carried out to define new protocols for processing spatial data (acquisition, manipulation and management) and to offer new opportunities to the reconstruction offered of no longer extant historic objects (MÜNSTER 2013; GRELLERT, PFARR-HARFST 2014).
To validate the entire 3D modeling reconstruction process and to facilitate the ex-change and reuse of information and collaboration between experts in various disciplines, new standards are necessary, due to the reusability and accessibility of knowledge linked to 3D digital models. For a better interpretation of a digital heritage artifact, a comprehensive interpretive method is needed. Because many hypothetical reconstructions are the result of highly complex design decisions (KŐLLER, FRISCHER, HUMPHREYS, 2009), we have to focus attention on the cognitive-reconstructive process.
Through the semantic structuring of digital models, it is possible to develop a process of acquiring knowledge that is able to note and make understandable and reusable the analysis of preliminary data and interpretation criteria used to validate the entire process. As just stated in Apollonio et al. (APOLLONIO, GAIANI & ZHENG, 2013) the semantic structuring gives the possibility to visually assess the related level of knowledge, with its flaws and lacunae, and to carry out comparative operations on the set of data and information held, allowing the compatibility of the digital model with alternative modes of representation.
As documented by many researches and papers (BRUSEKER, GUILLEM & CARBONI, 2015; KUROCZYŃSKI, HAUCK & DWORAK, 2014), the outcomes of virtual reconstructions are based on complex chains of reasoning which gives primary and secondary evidence that enable a historically probable hypothesis to be reconstructed from the partial data sources and/or find records available. Some authors (KUROCZYŃSKI & HAUCK 2014) explored the possibilities for documenting and storing in an information system the phases of the reasoning, decision and procedures that bring and can be linked to a virtual reconstruction output.
They assert that main goal of these kind of researches is to present, through an interdisciplinary methodological approach, a semantic indexing of sources and description of 3D objects, and of visualization based on interactive 3D models, documenting the foundations of evidence for the reconstructed elements, and the reasoning adopted about them (KUROCZYŃSKI & HAUCK 2014). Regardless of technologies proposed (CIDOC-CRM and its extensions CRMinf, CRMBa and CRMgeo, or CHML and E-CRM, or ConML) all the authors agreed to adopt the ontological model, as a starting point for modelling the arguments,

annotations and relations, combining metadata, provenance and paradata, as well as the shape, appearance and material data (APOLLONIO, GIOVANNINI 2015).
In Virtual Reconstruction, due to the uncertainty in knowing of the past, where the evidences do not allow to recreate the entire structure a valid theoretical and methodological framework is request.
Starting from these assumptions, scholars agreed about the opportunity that transparency and traceability of processes of interpretations are necessary for a better understanding of knowledge embodied by 3D models and their visualizations.
Transparency is necessary, not only, for an interdisciplinary communication, but also for the evaluation of results for the benefit of future generations. A Virtual Reconstruction Information Management Modeling (VRIMM) allow to acquire a "pre-knowledge" before starting a virtual reconstruction process and adding new information in, when new results become available (APOLLONIO, GIOVANNINI 2015].
Starting from sources to the 3D model the main problem is the traceability of subjective decisions and conjectures affecting the process of a certain grade of uncertainty that open the possibility to alternative options of reconstruction usually not declared (MCCURDY, 2010). The VRIMM involve all passages related to the virtual reconstruction process in which it is possible to identify five steps:

1. Data Collection
2. Data Acquisition
3. Data Analysis
4. Data Interpretation
5. Data Representation

The paradata schema shows the semantic contents of the virtual reconstruction process, helping in understanding and interpreting data objects. The geometrical documentation allows different kind of reconstructive hypothesis based on a controlled use of documented information about interpretation that is showed through the use of colors which label the sub-elements of 3D model.
The resulting uncertainty validation of the reconstructed model is based on different levels of interpretation of source data, characterized by a progressively increasing level of uncertainty of the geometrical definition (accuracy) of constitutive elements making up the artifact.

The reconstructive process

A scientific reconstruction requires a scientific methodology concerning to reconstruction process and its documentation. In order to validate the 3D modelling reconstruction process and to facilitate the exchange and reuse of information and collaboration between experts in various disciplines we maybe have to look at new standards due to reusability and accessibility of knowledge of 3D digital models: for a better interpretation of digital heritage artefacts we need a comprehensive interpretive method. The process of reconstruction is essentially composed by decisions based on various sets of assumptions that may be obvious to the scientific curator of the reconstruction process but not to public, the final user or those who later could view the final project.

This process can be developed according to the following operational pipe-line (Fig. 1):

1. collection of documentary sources
2. semantic structuring of the artifact
3. analysis of documentary sources and extrapolation of information on the consistency of the artifact (geometrical shape, surface appearance, physical characteristics) through a process of analysis/interpretation (induction/deduction/analogy)/decision assumed to extract the data based on the evidence, the relationship between information, deduction or conjecture
4. correlation between data used in the process of reconstruction and the level of un-certainty that characterizes each constitutive element
5. reconstructive modeling 3D
6. semantic enrichment of 3D reconstructed model
7. validation of the reconstructive hypothesis obtained through the data enrichment of each constitutive element and its displaying.

This subjectivity, if not correctly reported, compromises the validity of an entire virtual reconstruction. The "THE LONDON CHARTER"(2006) and, lately, the Sevilla Principles (2009) aim to set principles for visualization methods and their outcomes in heritage contexts, high-lighting the need for the formalization of re-constructive processes. Within this framework, the granularity of data relies on the different types, typologies and characteristics of sources used, which is tightly connected to the proper segmentation adopted for the reconstruction process (i.e., finds, ruins, ancient drawings, literary sources, etc.). It defines, according to the assumptions adopted by evidence, inference or conjecture, the different degrees of certainty and the levels of confidence (KENSEK 2007) of the solution adopted or proposed, which can be shown through the visual representation of the related level of certainty.
A proper methodological framework help in defining a process of acquisition knowledge that is able to note and make understandable, as well as reusable, the analysis of preliminary data and interpretation criteria used to validate the entire process.
Following the Principle 4 of the London Charter a proper methodology is able to find a new approach to Paradata Documentation creating a conceptual scheme able to clarify the relationship between research sources, implicit knowledge, explicit reasoning, and visualisation-based outcomes (LONDON CHARTER 2006, 4.6).

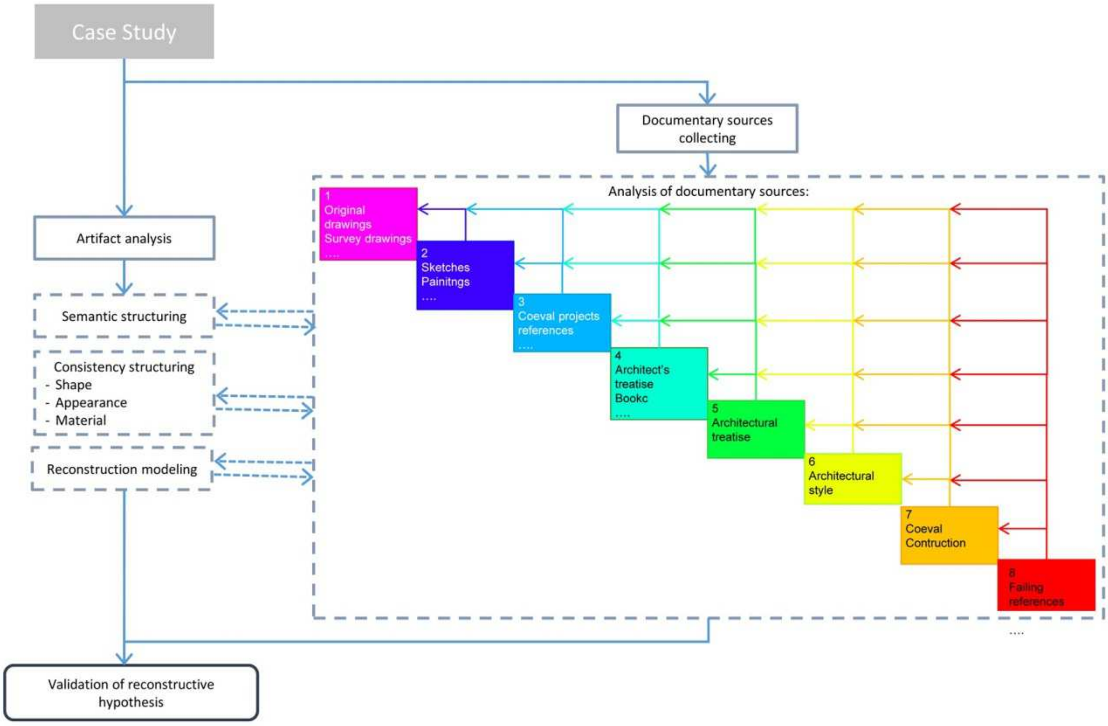

Fig. 1 – Diagram of reconstructive process, with definition of uncertainty degree

Uncertainty visualization

Troughout a process of virtual reconstruction researchers have to make decisions firstly based on data evidence and secondly they need to refer to different kind of sources. Therefore we decide to adopt (APOLLONIO, GAIANI & ZHENG, 2013; APOLLONIO, GIOVANNINI, 2015) a gradient colour scale in order to indicate the grade of uncertainty which characterize the single element, related to different kind of sources involved in its reconstruction process. This methodology – as well as other similar propose by different researchers - suitable for tracking and documenting the cognitive process related to the dimensional and morphological definition of each architectural element but is not enough.

3D models visualization, able to distribute pieces of information in time and space, has led to exploit representation itself for displaying information related to it, as well as the development of visualization techniques able to make manifest the latent uncertainties.

Among all methods adopted and proposed for representing probability, ambiguity, reliability or uncertainty in 3D reconstructions, the use of color is undoubtedly the most efficient method and unambiguous.

The use of a colour scale (false-colour image) - even sacrificing natural colour rendition - in some disciplines (KENSEK 2007) have been long last using in order to ease the detection of features that are not readily discernible otherwise.

The use of false color allows for understanding in a clear manner and according to widely shared semantic codes, the degree of uncertainty surrounding the hypothetical reconstruction of each element of an artifact. Therefore, the use of colors in 3D visualization could be considered as a symbology, able to allow the traceability of uncertainty that characterizes each element based on a subjective but controlled understanding and interpretation of data objects (BENTKOWSKA-KAFEL, DENARD, BAKER 2012).

In the field of architecture and archaeological virtual reconstruction use of colour sometimes defines a temporal correspondence (STEFANI, BUSAYARAT, RENAUDIN, DE LUCA, VÈRON, FLORENZANO 2010) and sometimes (BAKKER, MEULEMBERG, DE RODE 2003; BORRA 2004; BORGHINI, CARLANI 2011; DELL'UNTO, LEANDER, FERDANI, DELLEPIANE, CALLIERI, LINDGREN 2013; POLLINI, DODD, KENSEK, & CIPOLLA, 2007) is used to depict uncertain.
A solution proposed by APOLLONIO ET. AL. (2013) shows how it is possible to display, or let understandable and evaluable, the methodology used in analyzing the architectural evolutions of that artifact, based on interpretation and comparison of various types of documentation through the use of a gradient colour scale.
The information related to reconstruction process may be conveyed using different technologies of visualization, defining a modeling structured procedure based on different levels of interpretation, characterized by a progressively increasing ordinal scale of uncertainty. This scale ranges in the interval from 0 to 1, where 0 (zero) uncertainty means a modeled element is totally certain and 1 (one) means it is absolutely uncertain (Fig. 2):

1. reconstruction based on archaeological/architectural evidence (reality-based data; stratigraphic record);
2. reconstruction based on original drawings (survey/projects/scratches and therefore affected by a low level of dimensional accuracy, etc.)
3. reconstruction based on design data related to stylistic/coeval similarities (e.g., coverage, type of roof, gutter frame, frames, roof, basement, or the openings and decorative system);
4. reference to treaties, books, journals, articles or architectural guidelines written by the author (architect/artist) of the artifact studied;
5. reference to treaties, books, journals, articles or the manual that the author (if known) has or could have used as his own reference (e.g., measurements of the rooms, stair design, detail design and equipment, the architectural orders, if any, as well as for the definition of the height of the internal doors or types and sets the height of the time);
6. interpretative hypotheses related to a specific architectural style and/or historical period;
7. interpretative hypotheses more thrusts, referring to coeval construction systems at that time to achieve solutions constructively plausible and compatible with the project, by which, however, is not always possible to reach conjecture or univocal solutions;
8. reconstructive conjectures failing references.

Each of these categories is defined by the degree of accuracy of data geometric, dimensional, formal, material and construction that can be derived, infer or assume from the documentary source available for that particular element of case study.

Level of knowledge

Color code (R,G,B)	Uncertainty value
255,0,255	r.c. based on archaeological/architectural evidence (reality-based data, statigraphic record, etc.)
60,0,255	r.c. based on original drawings
0,180,255	r.c. based on design data related to stylistic similarities
0,255,210	r.c. based on treaties, books, etc written by the author
0,255,60	r.c. based on reference to treaties books, etc
235,255,0	r.c. based on reference to a specific arhcitectural style and/or historical period
255,195,0	r.c. based on reference to coeval bulding systems
255,0,0	Reconstructive conjectures failing refrences

Degree of Iconicity

Fig. 2 – Uncertainty gradient color code

The usability of a density slicing - as well as of other color progressions - is granted by the principles of human visual perception. Based on the theory defined by Kim VELTMAN (1993), who introduced a scheme of ten levels of knowledge, talking about the computers, able to offer multiple nodes of access to a given term or object, and to the Abraham MOLES's (1981) degree of iconicity, the inverse of the degree of abstraction, meant as the quality identity of the representation relative to the object represented, a full spectral progression, containing a hue from blue through red, sliced in eight categories, seems to be the most suitable method to represent uncertainty of a hypothetical reconstructive process (REICHERT & BORSUK, 2005).

Furthermore, the spectral progression can be combined with a partial spectral hue progression to map mixtures of two distinct sets of data or to show the sub-range of values of some sub-categories, i.e., using a blend of two adjacent opponent hues and showing the magnitude of the mixed data classes. A spectral hue progression based on an ordinal color-graded sequence is able to allow the visual perception of the ordering of values, in which the darkest hue represents the greatest number (highest value of certainty) in the data set and the lightest shade represents the least number (lowest value of certainty, which means the highest value of uncertainty).

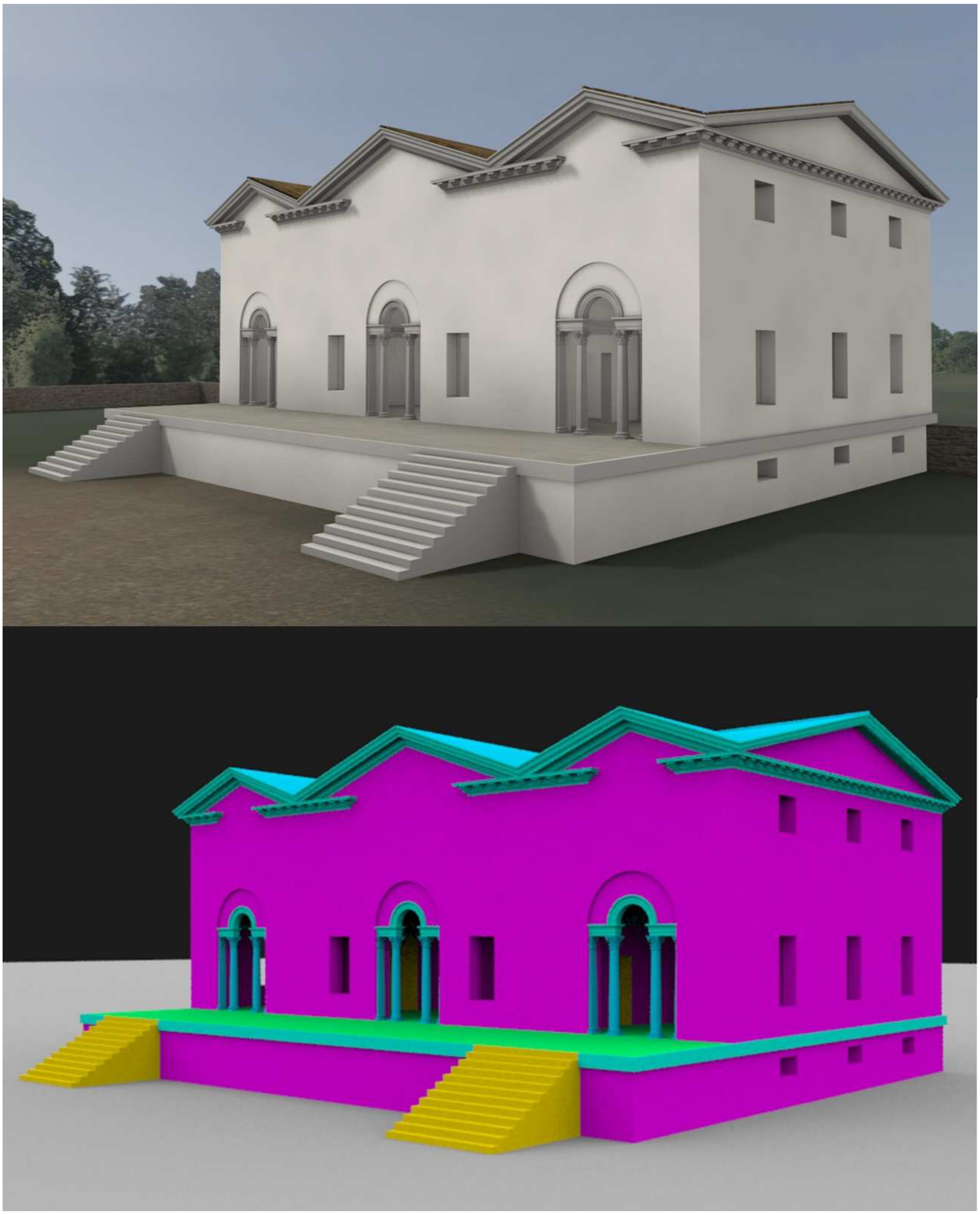

Fig. 3 – A. Palladio, 'Villa for a twin'. 3D Virtual Reconstruction after RIBA XVII 15R: realistic rendering (Up); displaying uncertainty of reconstructive hypothesys (Down).

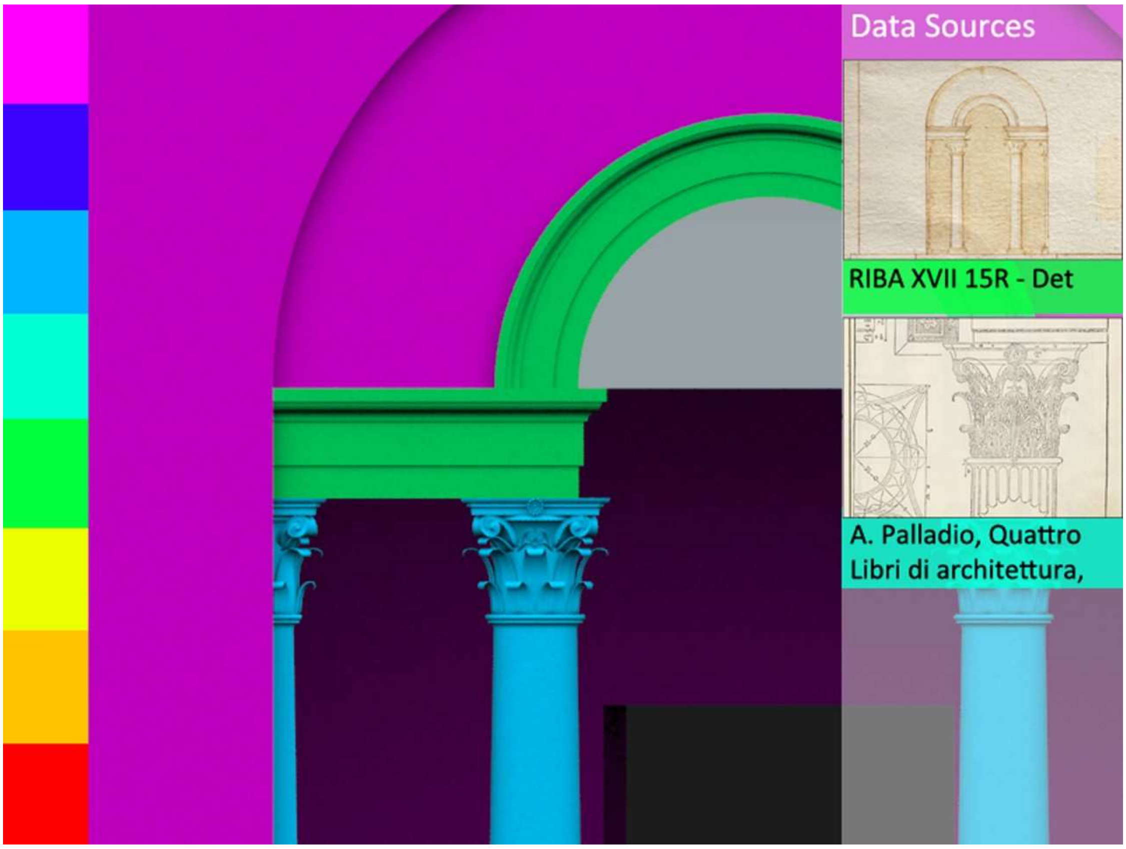

Fig. 4 – A. Palladio, 'Villa for a twin'. 3D Virtual Reconstruction after RIBA XVII 15R. Detail of loggia with Serliana and Corinthian order: displaying uncertainty of reconstructive hypothesys based on different data sources.

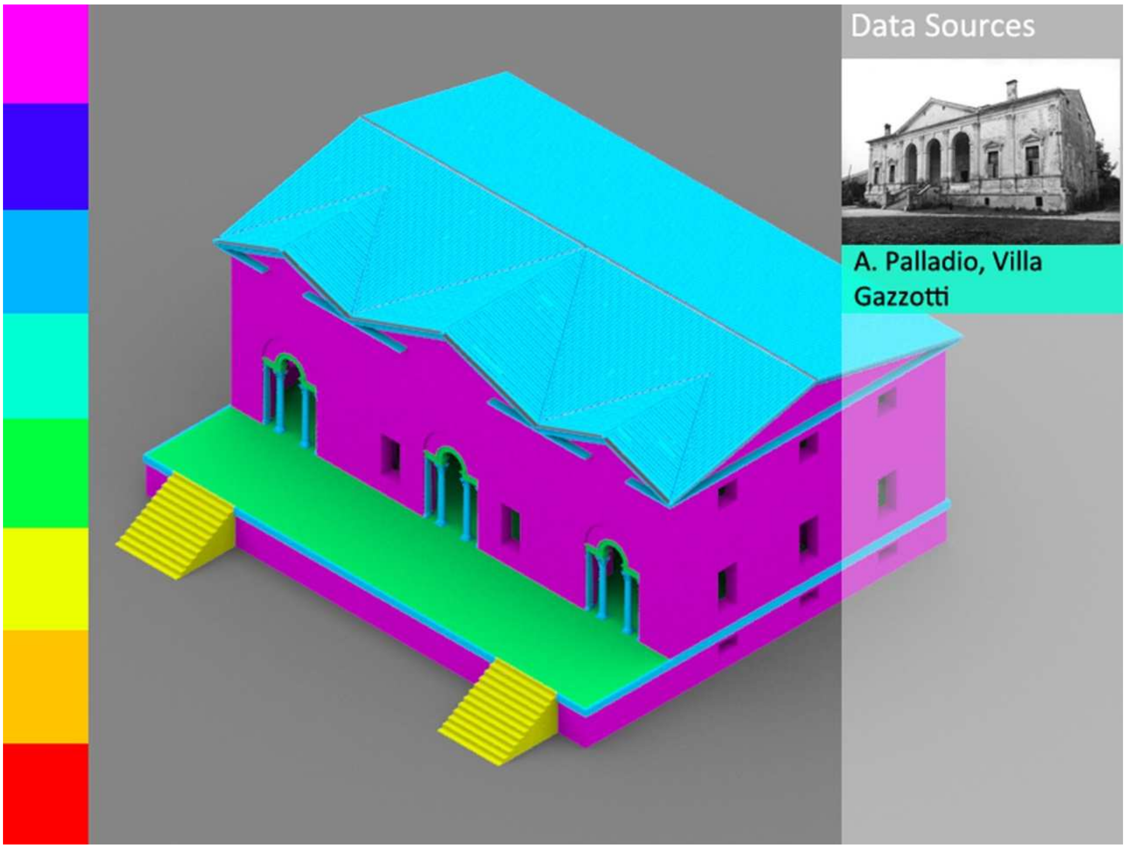

Fig. 5 – A. Palladio, 'Villa for a twin'. 3D Virtual Reconstruction after RIBA XVII 15R. General axonometric view: displaying uncertainty of reconstructive hypothesys based on different data sources.

Conclusion

The use of VRIMM, applied to a reconstruction process, enable the possibility to let transparent, understandable and retrievable the relationship between data sources, implicit knowledge, explicit reasoning adopted through the reconstruction process. It is based on the critical analysis and interpretation of data source, able to express the intrinsic value of each modeling process. Each different type of source is characterized by its own specific grade of information granularity that can be transformed into a hypothetical 3D model with its own level of detail. Each unit element of the reconstructed virtual model is, therefore, identified by its corresponding degree of uncertainty, which will be used to visually assess the proper level of knowledge related to the reconstruction process. A real work of interpretation, obtained according to the process of simplification inherent in the schematic of the 'model', allows us to create views that refer more to a vision of interpretation than an accurate reconstruction of the object created today. The use of analytical mechanisms for reading and interpretation within a reconstructive process expresses the desire to enrich the cognitive model and demonstrate their level of knowledge with the aim of using the representation as a tool for scientific evaluation.

The scientific community should contribute in setting up an international standardization of metadata and paradata (The SEVILLE PRINCIPLES, Principle 7, 7.3) and in defining reasonable methodologies able to allow procedural-relational methods, variant methods (with their own constraints or degrees of freedom), associative methods and generative techniques of modeling.

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Imprint:

Proceedings of the 20th International Conference on Cultural Heritage and New Technologies 2015 (CHNT 20, 2015)

Vienna 2016

http://www.chnt.at/proceedings-chnt-20/

ISBN 978-3-200-04698-6

Editor/Publisher**:** Museen der Stadt Wien – Stadtarchäologie

Editorial Team: Wolfgang Börner, Susanne Uhlirz

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