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A PARADATA DOCUMENTATION METHODOLOGY FOR THE UNCERTAINTY VISUALIZATION IN DIGITAL RECONSTRUCTION OF CH ARTIFACTS

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Abstract

The virtual reconstruction of no longer existing historic structures is obviously a subjective process that simplifies a visualization of the historical original monument. In this paper we define a methodological procedure focused on the validation of the 3D reconstructive model. The case study reported, cause of its complexity and overabundance of informations, allows to focus the attention to the level of subjectivity that concern the 3D modelling process trying to find a methodological solution to visualize the uncertainty level of the reconstruction process: the goal is to create an hypothetical virtual reconstruction based on a 3D model scientifically correct in morphological and dimensional terms derived from the integration of 3D recording, historical documentation and renaissance representations. A methodological workflow from data acquisition to the formulation of reliable hypotheses related to the 3D virtual-model of Porta Aurea ables to allow the verification of the assumptions used during the reconstruction pipeline is proposed.

Keywords

Palladio, Porta Aurea, Ravenna, Range-Based Survey, 3D Modelling, Virtual Reconstruction, Semantic structure, Uncertainty visualization, Roman gate.

1. *Introduction*

The digital revolution, since 1990's when Paul Reilly firstly used the term Virtual Archaeology at the 1990 CAA Conference, open the debate on the multidisciplinary approach to a huge amount of virtual reconstruction projects. The virtual reconstruction practice over the past years shows many theoretical problems related to documentation, analysis and interpretations of archaeological artefacts (Dell'Unto, Leander, Ferdani, Dellepiane, Callieri, & Lindgren, 2013), also because different discipline have their own methodology, the theme of transparency in virtual reconstruction is largely discussed but not commonly shared (Hermon, Sugimoto, & Mara, 2007).

A scientific reconstruction requires a scientific methodology concerning to reconstruction process and its documentation. The paper is focused on theoretical and analytical study of virtual reconstruction practice of architectural heritage artefact no longer existing and partially documented and on exploring a methodological approach to display the data-processing behind the 3D modelling practice (Apollonio, Gaiani & Zheng, 2013a), with the aim 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 a digital heritage artefacts we need a comprehensive interpretive method. Because many hypothetical reconstructions are the result of highly complex design decision (Koller, Frischer, & Humphreys, 2009) 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. In response to this problem in 2006 was draft the "The London Charter for the computer based visualization of Cultural Heritage" in order to set principles for visualisation methods and its outcomes in heritage contexts. The aim was not to prescribe a specific method, but to define a guideline for the use, in research and communication of cultural heritage, of computer-based visualisation in relation to intellectual integrity, reliability, documentation, sustainability and access of heritage artefacts (London Charter, Preamble). Following the Principle 4 of the London Charter our methodology try 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, 4.6).

2. *Porta Aurea in Ravenna as a case study*

Porta Aurea in Ravenna has always aroused the interest of many scholars and archaeologists. Despite today the roman gate is a no longer extant monument, we have the availability of a lot of Renaissance representations that there have handed down its original architectural appearance and which have been the subject of large studies by H. Kähler (1935) and G. Rosi (1939). In 1986 G. Tosi did a deep examination of the metrological informations that were within Renaissance drawings by Andrea Palladio preserved at Royal Institute of British Architecture and unknown to previous scholars.

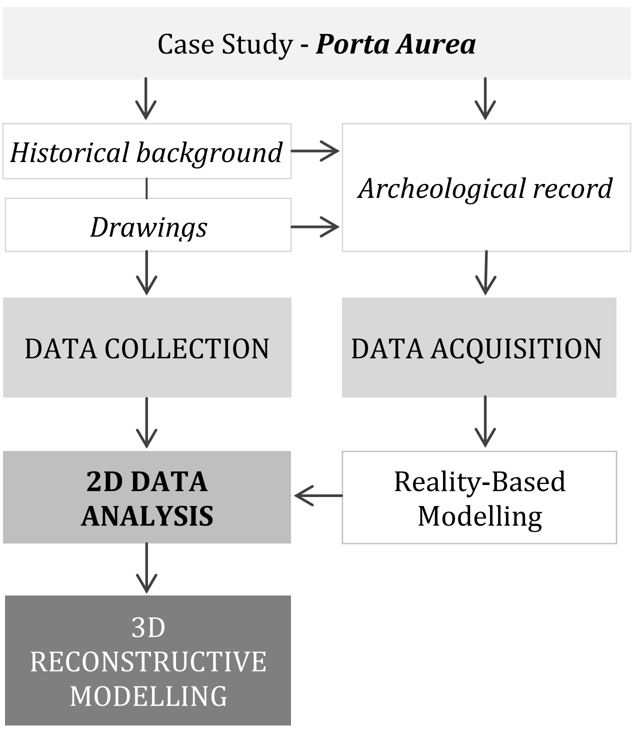

Fig. 1: Diagram of the reconstruction process

The main goal of the study here reported is related to the definition of a 3D reconstruction process based both on historical iconographical sources and 3D range-based survey.

2.1 Historical Background

Porta Aurea is probably the most ancient of Roman gates in the city of Ravenna. Noway, ruins are still evident on Via Porta Aurea where the gate once stood. Like other ancient *oppida municipali* (fortified cities) Ravenna had a quadrangular perimeter. The Decumano stretched from Porta Aurea along the Via Popilia, an ancient Roman road which started at the Roman settlement of Ariminum (Rimini), and led to the city of Aquileia, passing through Ravenna.

The gate has been known by various different names throughout its history, including Asiana, Aziana, Pinciana, Pinziana, Dè Pizzi, Dè Pizi, Dè Pici, Speciosa and Trionfale.

During the early fifth century the capital of the Western Roman Empire was transferred from Milan to Ravenna, by Honorius, who promoted a new urban growth. The gate was given the name of Aurea because of its magnificent ornamentation and use of marble.

As for the date of its original construction, one refers to an inscription bearing the words: "TI CLAUDIUS DRUSI FIL CAESAR AUGUSTUS GERMANICUS PONT MAX TRIB POT II COS II DESIG III P P DEDIT"[1]. The conclusion shared by scholars – including Biondi[2] and Rossi (1996) – is that Porta Aurea had been built by Tiberius Claudius, the fourth Roman emperor, probably in the first century: both believe it to be likely that not only Porta Aurea but also the walls of Ravenna are were built or, indeed, rebuilt by the same emperor. It is also believed that its construction is attributable to the commemoration of the victories in the Roman expedition against the British Isles, in the 796-797 ab urbe condita (43 AD). Even if Domenico Maioli[3], on a report, quotes Regoli that says the

[1] Cfr. C.I.L. , XI, 5

[2] Manuscript of Flavio Biondi of Forlì, *Italia Illustrata (quella parte che riguarda la romagna soltanto)* held at the Biblioteca Classense of Ravenna

[3] Domenico Maioli was charged with the regency of the Superintendent of Ravenna from 1903 to 1911, in place of Corrado Ricci and drafted several documents and reports about excavations at Via di Porta Aurea including *"Scavi di Porta Aurea - Relazione"* on the dated May 15, 1908 (SPAB-Ra, AS , Ra 12/91)

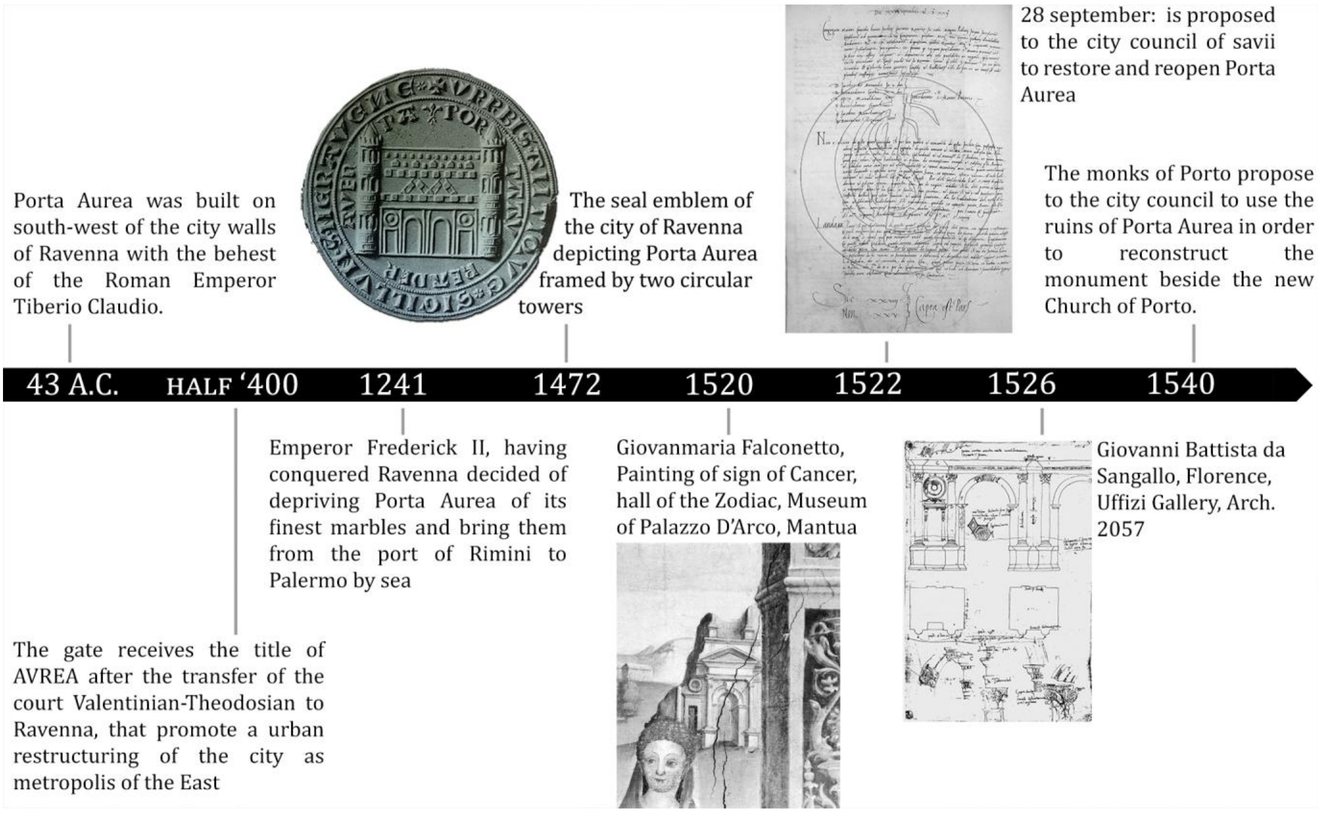

Fig. 2: Timeline of the historical background of the monument until 1540

time when the city gate was erected was in the year 795 ab urbe condita (42 AD), the first date is the most accredited by historians.

Porta Aurea was much afflicted by vicissitudes of misfortune throughout its history (Fig. 2 and Fig. 3). In 1241, it was deprived of stones and marble slabs by Frederick II, Holy Roman Emperor, and thereafter passed into an increasingly ruinous state.

The City Council successively expressed the will to restore it to its former splendor, as witnessed by various archival sources; proposing in 1522 to expose it from the ground which had, by now, rendered it partially hidden[4]; eighteen years after the Prior of Canonica di Porto, Francesco of Vicenza, sought to have it dismantled piece by piece, and rebuilt elsewhere[5]. The demolition of its ruins finally came about in 1582 at the hands of Cardinal Guido Ferreri who used the material to embellish other buildings (Kähler, 1935).

2.2 Architectural Drawings and Sketches

One of the earliest representations of Porta Aurea appears in a seal dating back to the fifteenth century which depicts the door between two circular towers and shows how the structure, crowned by pediments was most likely made up of three more levels above (Fig.2 – 1472).

Proof of its ruinous state in the early sixteenth century can be seen in the pictorial transposition made by Falconetto, within the "sign of Cancer" of the Zodiac Room at Palazzo d'Arco in Mantua (Fig.2 - 1520). The earliest representation of the raised structure and details was drawn by Giovanni Battista da Sangallo[6] (Fig. 2 - 1526).

Porta Aurea is described as a double-fronted structure characterised, on the front façade, by a double archway with pointed arches, each framed by two semi-columns with Corinthian capitals supporting the entablature. On both sides, always within half-columns, there are niches topped with medallions. In particular, Sangallo, shows us the inscription (as quoted above) as it appears in the frieze of the entablature. The drawing shows

[4] State Archives of Ravenna, sez. Ancient State Archives, Parti, vol. 28 c.244v
[5] *Ibid.* vol.29 c.270r
[6] Florence, Uffizi Gallery, Arch. 2057

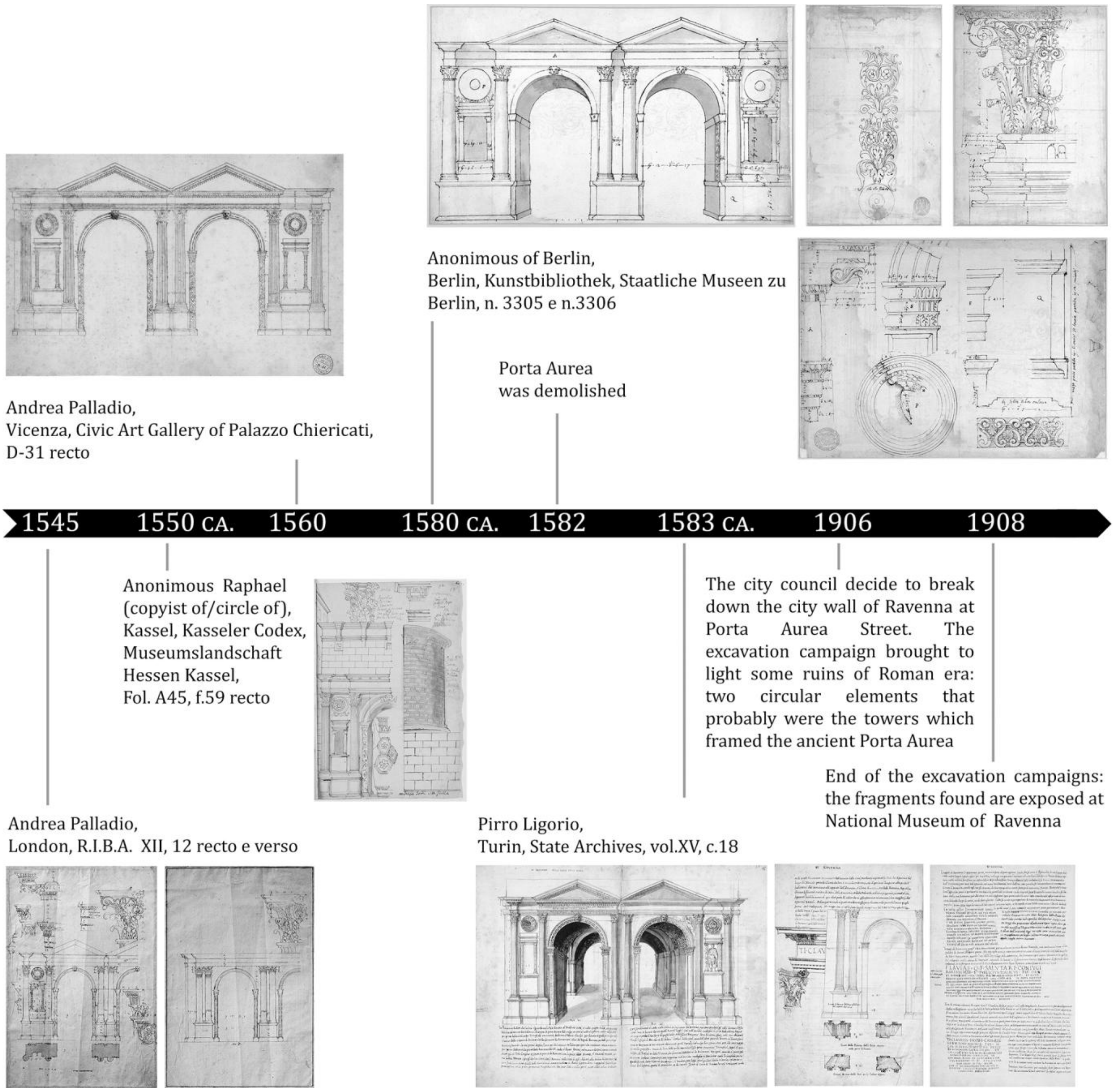

Fig. 3: Timeline of the historical background of the monument from 1540 to 1908

quite a schematic layout, accompanied by some key measures, while the drawings provide details. The prospectus is full of important notes about the various parts as well as the state of preservation of the monument as a reference to the sign that indicates the water-level of the moat built in the Middle Ages around the city walls (Vasori, 1981).

In 1545 Andrea Palladio, on the way to Rome the convoy of Trissino stopped in Ravenna (Zorzi, 1958), sketched and measured the monument.

In the drawings, now preserved in London[7] (Fig. 3 - 1545) the two fronts and the layout with the main measurements are illustrated in detail as well as drawings of individual architectural details.

A second drawing, held at the Civic Museums of Vicenza[8] (Fig. 3 - 1560), considered by Howard Burns (1973) to be the work of Palladio, represents only the side facing the city. This drawing according to Puppi (1995) goes back to a

[7] London, R. I. B. A, XII, 12 recto e verso
[8] Vicenza, Civic Art Gallery of Palazzo Chiericati, D-31 recto

more mature period of the author and was probably designed for translation in print.

Another quite interesting sketch, never mentioned in previous studies on the Porta Aurea is located at Hessen Museumslandschaft Kassel[9], within the codex of Kassel, in turn, part of a book of fragmentary drawings by an unknown author. Arnold Nesselrath (2002) believes that the document can be attributed to a copyist of Raphael or a member of his circle, and it is to be dated no earlier than the fourth decade of the 1500s. The special feature of this representation, albeit without any indicative metric, is the deliberate intention to describe the urban context (Fig. 3 -1550 ca.). On the left-hand side, Porta Aurea is incorporated inside buildings, as for example, Porta dei Borsari in Verona.

Of uncertain date but probably contemporaneous with the previous drawings are 4 eidotypes by an unknown artist, better known as Anonymous of Berlin. These are stored at the Kunstbibliothek - Staatliche Museen zu Berlin[10] and represent architectural details meticulously listed, the capital and the decoration of the pillar (Fig. 3-1580), in addition to the representation of the external front with letters in reference to details.

In "Roman Antiquities" Pirro Ligorio, volume XV2, the author also writes about the city of Ravenna. In this case, an accurate description of Porta Aurea is given with an accompanying graphic of a perspective view of the external front of the Gate, the layout and the entire front facade (Fig. 3-1583 ca.).

Scholars agree that Ligorio has reworked rather arbitrarily the instructions contained in the drawings of the London Palladium. The only discrepancy is the representation of the plan in which the author suggests a typical of cisalpine Roman city gates – monumental architectural construction that marked the entrance to the city, consisting of an inner and outer gate separated by a courtyard and flanked by symmetrical towers. Ligorio can be considered the last direct witness of the monument before the gate was denolished.

2.3 Archaeological record on XX century

In May 1906 the city council decided to demolish the city walls of Ravenna at Via Porta Aurea, as the trafic to entry the city had by then been abolished.

The archaeological excavation campaign (1906-1908) brought to light some ruins from the Roman era: two circular elements that were probably the towers which framed the ancient Porta Aurea and other marble architectural fragments.

Finally, there is an extensive collection of survey drawings of the walls, never before published, in the archives of the Superintendence for Architectural Heritage and Landscape for the Province of Ravenna edited by Maioli in 1908[11] including the first hypothetical planimetric reconstruction of the gate within the walls based on the drawing of Sangallo.

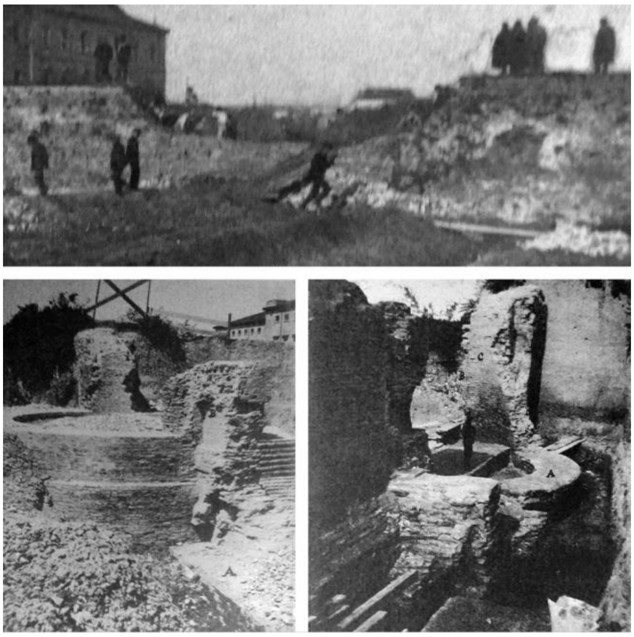

Fig. 4: Ruins of round tower

2.4 3D Data Acquisition

The 3D data survey was concerned with two different places related to the monument. The first one is the “Porta Aurea Hall” at the National Museum of Ravenna, and the second one is the part of the city wall where ruins of the two round

[9] Kassel, Kasseler Codex, Museumslandschaft Hessen Kassel, Fol. A45, f.59 recto

[10] Berlin, Kunstbibliothek, Staatliche Museen zu Berlin, n. 3305 and 3306

[11] *"Scavi di Porta Aurea - Giornale"* (SPAB-Ra, AS , Ra 12/91) and *"Scavi di Porta Aurea - Relazione"* on the dated May 15, 1908 (SPAB-Ra, AS , Ra 12/91) that was published in a full version by Novara (2002)

towers are found that most likely framed Porta Aurea. At both sites we used a ToF laser (Leyca C-10 all-in-one scan station) to acquire data.

Only a portion of the data acquired at the National Museum was processed. The reality-based modelling process was concerned only with architectural fragments most probably related to the monument (Fig. 5):

a) and g) two medallions
b) part of the entablature
c) an element of the archivolt
d) Corinthian capital of the half-column
e) detail of half-column with grooves
f) fragmentary portion of the Corinthian capital
h) part of the column base of the recess
i) and j) fragments of letters of inscription
k) a decorative element of a pillar
l) an element of the column of the reces

Fig. 6: Image of the Laser-Scan campaign

The identification of the fragments was made possible thanks to the interrelated study between the photographic archive and the inventory, both kept stored at the Superintendence for Architectural Heritage and Landscape for the Province of Ravenna. This study has allowed us to return to those fragments – dating back mainly to

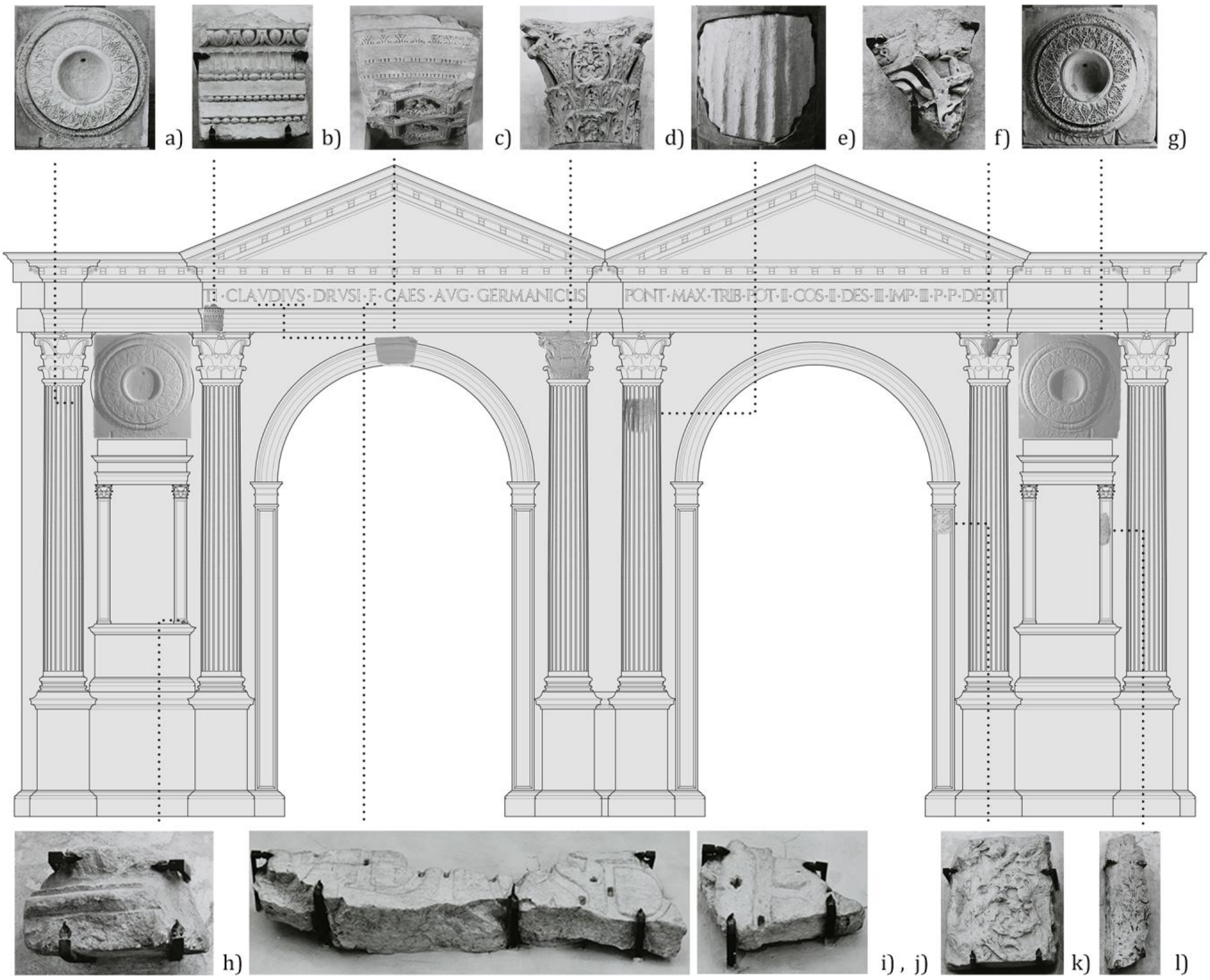

Fig. 5: Architectural fragments stored at National Museum of Ravenna, Hall of Porta Aurea

the 1906-1908 excavations at the walls – which are congruent with the historical/documentary sources.

The second survey campaign was carried out near to the walls in Via Porta Aurea. The data from this survey were compared with those of previous surveys and have been used to re-contextualize the monument and check the validity of the dimensions of the hypothetical reconstruction.

3. *A paradata documentation methodology*

The study takes up the challenge of creating a workflow to document transparency of informations on computer-based 3D modeling. One of the main needs is obviously the transparency of the processes that involves a virtual reconstruction and that includes several problems about management of informations of the whole cognitive-process. Starting from sources to the 3D model the main issues are related to the traceability of subjective decisions and conjectures affecting the process of a certain degree of uncertainty that open the possibility to alternative options of reconstruction usually not declared (McCurdy, 2010).

The debate on scientifically and methodological approach to transparency of processes is still ongoing but there are accredited international documents in this direction that set up some guidelines:

> *The incorporation of metadata and paradata is crucial to ensure scientific transparency of any virtual archaeology project. Paradata and metadata should be clear, concise and easily available. In addition, it should provide as much information as possible. The scientific community should contribute with international standardization of metadata and paradata.*
>
> (The Seville Principles, Principle 7, 7.3)

The notion of paradata is defined as:

> *information about human processes of understanding and interpretation of data objects. Examples of paradata include descriptions stored within a structured dataset of how evidence was used to interpret an artefact, or a comment on methodological premises within a research publication. It is closely related, but somewhat different in emphasis, to "contextual metadata", which tend to communicate interpretations of an artefact or collection, rather than the process through which one or more artefacts were processed or interpreted.*
>
> (The London Charter, version 2.1)

The theme of heritage paradata has involved several scholars as Forte (Forte, 2010; Forte & Kurillo, 2010; Forte & Pescarin, 2007), Hermon (Hermon & Kalisperis, 2011) and Niccolucci (Niccolucci & Cantone, 2003) who proposed various approaches to represent the process of interpretation. On February 2012 was also published a book "Paradata and Transparency in Virtual Heritage" (Bentkowska-Kafel, Denard, & Baker, 2012) with the aim to focus the attention on cognitive process and its conclusion about heritage objects. Even the intent is to contribute to set up standards and condivisibile methodologies lots of publications available are more technical than theoretical (Huvila, 2013) and closely linked to the case study that their refers to.

Another relevant issue is the largely use of textual metadata, that's show the need to look at a new approach that maybe avoid the use of scripting, preferring the tool of media communication that is closer to the visualisation (Vatanen, 2003) and probably more intuitive and accesible for a multidisciplinary approach and reliable sharing of data.

In a process of virtual reconstruction we make decisions firstly based on archaeological or architectural evidence and secondly we need to refer to different kind of sources so we decide to define a gradient colour scale to indicate the grade of Uncertainty related to different kind of sources involved in the reconstruction. This methodology is suitable for tracking and documenting the cognitive process related to the dimensional and morphological definition of each architectural element but is not enough.

Another issue was the need to make the management of information more user-friendly so in addition to the information related to the sources we define a metadata encoding of classical architectural elements. Metadata, considered as data about data, can help to organize information and provide digital identification (Kao, Yuanyuan & Zhanhong, 2011). The encoding is necessary because the redundancy of architectural terms in the whole reconstruction.

Finally, if Paradata could be considered process of data, our methodology try to create a system to document and visualize through a conceptual model the management of informations related to the reconstruction and cognitive process in Virtual Heritage.

3.1 UncertaintyVisualization

The use of a colour scale within the disciplines that utilize the virtual reconstruction as an investigative tool is not so frequent (Kensek, Swartz Dodd & Cipolla, 2004). Contrary to what happens in other disciplines, in which, false-colour image even sacrificing natural colour rendition (in contrast to a true-colour image) have been long last using in order to ease the detection of features that are not readily discernible otherwise (e.g. the use of near infrared for the detection of vegetation in satellite images, remote sensing satellites, space telescopes or space probes, or even weather satellites that produce grayscale images from the visible or infrared spectrum). 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 et. al., 2013; Pollini, Dodd, Kensek, & Cipolla, 2007) is used to depict uncertain. Therefore the use of colours in 3D visualization could be considered as a symbology able to allow the traceability of uncertainty that characterize each element based on a subjective but controlled understanding and interpretation of data objects (Bentkowska-Kafel, Denard & Baker, 2012).

Referring to our case-study, the information derived from drawings has been classified according to the level of detail (Fig.7) that they concerns. The gradient colour scale start from the green colour to red and its refers to the Apollonio et. al. ones (2013a, Tab.1). We introduced on the scale cited some differences related to our case study.

The data from the laser scanner occupy the first level of the colour-scale and are more reliable as they are obtained from the architectural fragments acquisition.

At the second level of the scale there are drawings by Andrea Palladio. The architect is the only one that gives us information related to the layout and both sides of the Roman gate.

At the third level we have eidotypes by different authors such as Anonymous Berlin, Sangallo, copyist Raphael and Ligorio. These authors are grouped together due to a lack of information on each source. Anonymous Berlin, despite the accuracy in describing ornamentals details, doesn't show the layout of the facade oriented toward the city. Sangallo has drawn the plan and the façade oriented out of the city without pediments, as copyist Raphael did and both representations are of poor measurement. Pirro Ligorio, while having all the characteristics of Palladio's drawings shows us a gate with a completely different layout which leads us to believe his representation to be the least realistic.

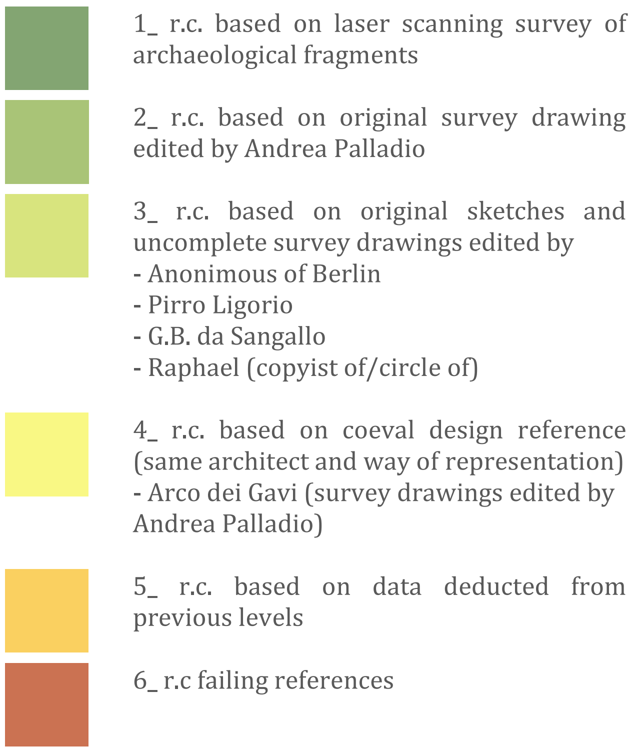

Fig. 7: Uncertainty gradient colour scale

Cause survey-drawing are usually lack of informations, the faithfully reconstruction of the monument from its representations is not quite easy, therefore it is necessary to give a critical interpretation of the data, the fourth level refers to references with significant stylistic similarities. In this case we used the Gavi Arch in Verona as an antecedent of Porta Aurea of about twenty years and attribuited to the same architect Vitruvius Cedrone. As such, we used two eidotypes published by Andrea Palladio depicting the Gavi Arch. The use of informations from eidotypes published by the same author for both monuments, allowed us to assume a formal-typological comparison between them able to

Subject

Subject	codF
Architecture	A
Sculpture	B
Paintings	C

Type of *Architecture*

Type	codT
City walls and gates	01
Roads	02
Public Squares	03
Aqueducts	04
Reservoirs and Dams	05
Fountains and Nymphaea	06
Sewers	07
River Banks and Bridges	08
Political and Administrative buildings	09
Religious buildings	10
Basilicas	11
Porticoes	12
Buildings for public Spectacles	13
Baths	14
Libraries, Schools, Museums	15
Shops, Markets, Warehouse	16
Triumphal columns and Honorary Arches	17
Residences	18
Tombs	19

List of Locations

Name	codL
VERONA	VR
RAVENNA	RA

List of Architecture in Ravenna

NameOfArchitecture	codRA
Porta Aurea	01
(…)	

List of Architecture in Verona

NameOfArchitecture	codVR
Arco dei Gavi	01
(…)	

Fig. 8: Classification for the notation of a 3D model of an Architecture

close the gaps in Porta Aurea drawings and to define some elements characterized by a low level of uncertainty.

The fifth level is a new entry and is occupied by that series of data that results from the 3D modelling-process based on data deducted from previous levels of the gradient colour scale.

At the end, the last colour (red) is related to reconstructive conjectures in the absence of reliable references.

3.2 Metadata Encoding of architectural elements

The use of 3D models in virtual reconstructions opens a debate on how electronic sources related to the reconstruction are classified and how to visualize their hierarchical relationships to provide a standardized vocabulary for information storage and retrieval system so we create a simple notation for classifying classical architecture and its elements. Because we use both numbers letters and symbols the result will be a mixed notation that follow the general principle of expressiveness: notation show hierarchy (Batley, 2005). The final notation is a unique identifier for the 3D model. In this case-study we only have one 3D model but we tried to imagine an hypothetical wider scenario. In our classification we determine a series of classes (Fig. 8) and we encode them in order to forming a final notation.The first part of the notation follows the code of classes of *Subject* and *Architecture* that can be specialised through the relationship *"type of"* into multiple specialised classes as City walls and gates, Roads, Public Square, etc. following the classification of Marta (1996). The second part of the notation is related to the architectural entity and its *Location* class that can be specialised into specialized classes for each location involved in the case-study and for each specialized class we have the list of Architectures in that area.

According to our classification we define an unique code for identify Porta Aurea and its 3D model:

A1:2.1	*3D model of virtual reconstruction of Porta Aurea in Ravenna*

Architectural Elements			
I LoD	***II LoD***	***III LoD***	***IV LoD***
10 Order	1 Entablature	1 Cornice	1 Console
11 Giant Order			2 Dentil
12 Superimposed Order			3 Modillion
13 Intercolumniation		2 Frieze	1 Metope
14 Balustrade			2 Triglyph
15 Door		3 Architrave	1 Guttae
16 Window			2 Regula
			3 Taenia
	2 Column	1 Capital	1 Abacus
			2 Acanthus
			3 Caulicolum
			4 Eye
			5 Necking
			6 Volute
		2 Shaft	1 Apophyge
			2 Annulet
		3 Base	
	3 Pedestal	1 Cap	
		2 Die	
		3 Plinth	
	4 Pediment	1 Racking Cornice	
		2 Tympanum	
		3 Acroteiron	
	5 Brackets		
	6 Panel		
	7 Sill		
	8 Stylobate		
20 Arch	1 Archivolt		
21 Vault	2 Impost		
	3 Keystone		
	4 Intrados	1 Coffer	
			10 Astragal
			11 Cavetto
			12 Corona
			13 Cyma
			14 Cyma Reversa
			15 Fascia
			16 Fillet
			17 Ovolo
			18 Plinth
			19 Scozia
			20 Torus

Fig. 9: Classification and coding of elements of Classical Architecture

With the aim to put order between the 3D model and its documentation we enrich our classification to a specific classification of classical architectural elements and their notations. This step make cognitive reconstruction data semantics more transparent and it is necessary to manage unstructured information related to measurements contained in the drawings and their use in the 3D modelling process because often the goal of represent the architecture as a whole make difficult the possibility to understand difference between the elements based on evidence and others based on interpretation due to an overabundance of conflicting or lacking data.

The classical architecture elements classification that we propose is hierarchically structured into four levels of detail (LoD) (Fig. 9).

Each level is based on different level of information with an increase scale of detail for each level and to each elements we assigned a code that is subsequently referred to the level above. In some cases we can have groups of elements through each level.

An example of its use it could be the notation for the pedestal elements related to the order:

10 Order
10.3 Pedestal
10.31 Cap
10.32 Die
10.33 Plinth

As showed above the expressiveness of the notation clearly show the hierarchy of elements with a not very long notation.

In the end it was given special attention to the IV LoD because at this level we include all elements that can't be divided, but can only be combined to form the element in the level above.

Even if some of that elements are directly connected to others because of their specificity, there are others the use of which is not specific but generic: this elements correspond to moulding elements and for this reason we assign them a specific notation from 10 to 20.

A set of previous knowledge related to classical architecture and a generic formalism for the semantic modelling and representation of architectural elements (De Luca, Véron, & Florenzano, 2007) explain how we can read an architectural artefact as an entity composed by number of sub-elements with a whole-part relationships that can be displayed in a hierarchy-tree: Rattner (1998) defines mouldings as the smallest physical unit of classical architecture. For this reason an important consideration is about their physical position. As explained before all elements from I to IV LoD have a notation that hierarchically corresponds to its order in space, for the final notation of the moulding this is not possible because of the redundancy of the use of each moulding in different situations, for this reason we add other 2 elements in the notation: a number before and one after. The firs number in the notation identify its postion according to an upper-down approach and the final number of the notation is usefull to avoid the repetition of the same moulding notation if it is necessary.

An example of the final notation for the pedestal elements of Porta Aurea is:

10.31 Cap
1:10.3113 Cyma
2:10.3111 Cavetto
10.32 Die
10.33 Plinth
1:10.3313 Cyma
2:10.3320 Torus
3:10.3319_1 Scozia
4:10.3319_2 Scozia
5:10.3318 Plinth

3.3 Towards a conceptual scheme to document Paradata managment

For each architectural element we decide to use a conceptual model to create a simplified representation of relationship between references and virtual reconstruction of architectural elements at different Level of Detail. The conceptual model was developed using ConML 1.4 (Gonzales-Perez, 2012) trying to describe the 3D data-management involved in the process in a systematic way that defines how the dimensional and morphological data informations are related to the 3D model. Following the specifications of ConML we organise the metamodel elements into its two components of Type and Instances.

The Type Components are Class, Attribute and Association so first we define all elements that we put in the model with the definition of their concepts (Tab. 1). The second passage will involve the Instances components where classes will become real elements referring to classes that we previously commented (Fig. 9) and we will have list of values instead list of attributes.

The class "Architecture" is an aggregation of the class "Architectural Element" that according to the Fig.9 it could be repeated several times for each LoD, so in the graphical notation we use a self-aggregation to indicate that each elements can have several aggregation of sub-elements that refers to previous levels. For this reason we add an attribute "Level" to the class "Architectural Element" to capture the level that we're working on: it allows us to work at different levels avoiding the use of the whole conceptual model, creating single mini-model for each architectural element uniquely identified by its notation (Fig. 9) indicated in the attribute "Code".

Because we are working on virtual reconstruction we start with the assumption that we are working on visualization and representation of each architectural element. For this reason an important role is played by the class of "Representation". The conceptual model explain how we can have many representations according to the use of different informations from each sources. Each representation is so characterized by its attribute "Uncertainty Level" that refers to the gradient colour scale (Fig. 7).

If there are some evidence and we have the possibility to capture data, our representation will correspond to the 3D Reality-Based Model whose class is "3D_Object". In this case the class of "Representation" in related to the "3D_Object" class by the association "Has Evidence On".

In absence of archaeological/architectural evidence we have to desume "Morphological Information" and "Dimensional Information" from a set of sources as survey drawings of information related to historical background of the case-study that are identified with class "Reference Element". If the "morphological information" class can be related to the class "Reference Element" by associations "Has Evidence/Reference On", "Dimensional Informations" class can be subdivided on other three classes "Measure of Height/Width/Depth". In order to better define which kind of measure we use, we add some attribute to these class as "Type", "Unit" and "Measure". It is clear that measures of I LoD architectural elements consequently affect measures of levels below.

Also in the development of a conceptual scheme we use a different approach for moulding elements. In this case the definition of "Dimensional Information" class is more detailed. Because mouldings are the smallest elements their "Geometrical Representation" is a central class. To define it we refers to De Luca et. al. (2007) refering to their terminoly for "Geometrical Atom"class. The Geometrical Atom is necessary for the construction of the profile of mouldings of classical architecture and it is constituted as set of 10 geometrical primitives (Fig.8 in De Luca et. al., 2007) that, by combining them, allow the reproduction of any kind of moulding of the classical architecture language.

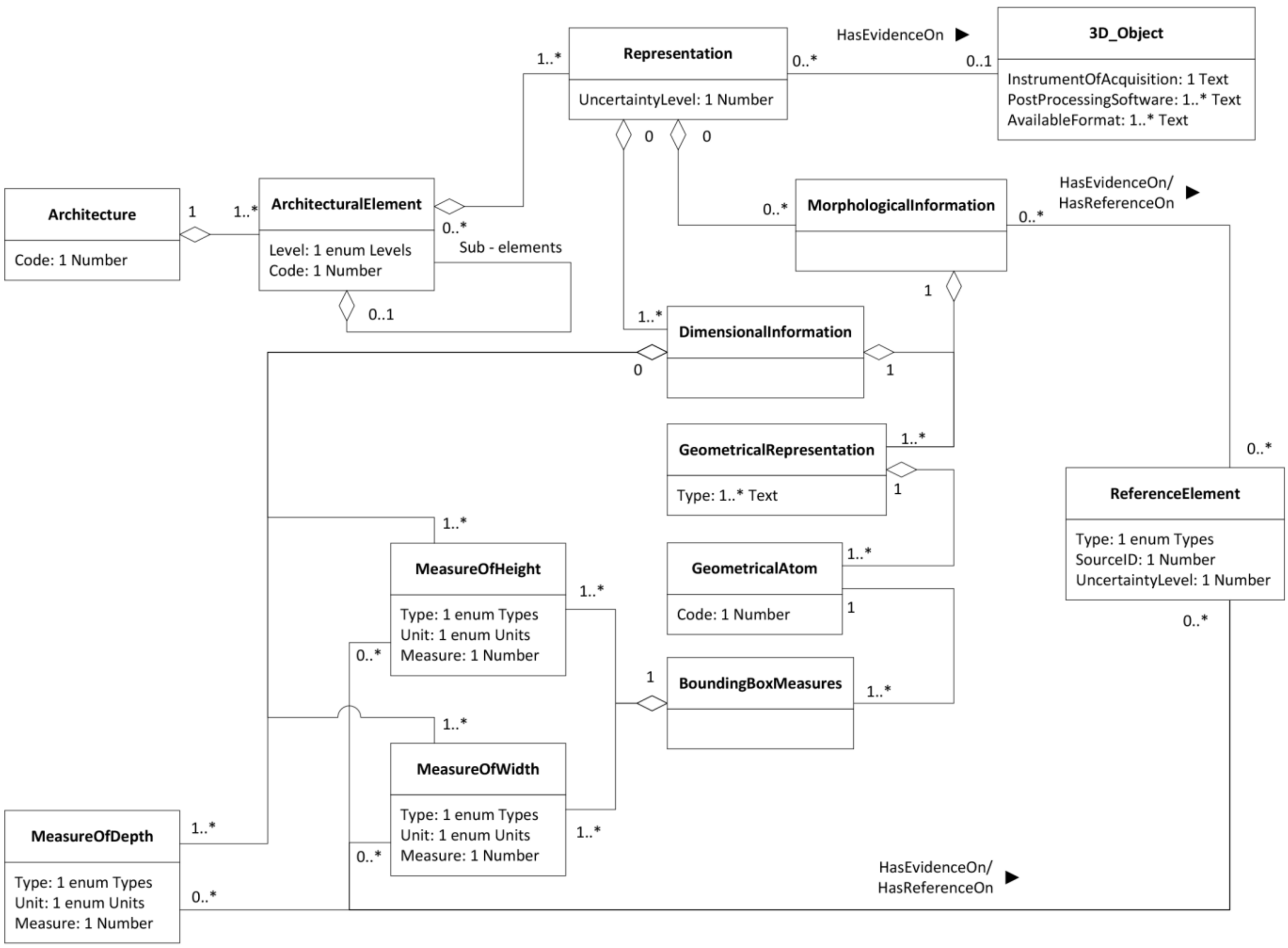

Fig. 10: Conceptual model about the information managed in a virtual reconstruction

Each geometrical atom is built on a bounding box constitutes by a deformable 9-point grid. To allow the deformation we need to add class of "Bounding Box Measure" that will identify the Height and Width of the Box.

Tab. 1: ConML specification table

Class
Name **Architecture**
Definition
According to Classification for the notation of a 3D model of an Architecture (Fig. 8) Architecture class correspond to the 3D model of which we want to manage information

Attribute
Name **Code**
Cardinality 1
Type Notation
Definition
The code is a identifier used to uniquely identify the 3D model and it refers to specific notation explained on Fig. 8.

Class
Name **Architectural Element**
Definition
According to classification of elements of Classical Architecture (Fig. 9)

Attribute
Name **Code**
Cardinality 1
Type Notation
Definition
According to coding of elements of Classical Architecture (Fig. 9)

Class
Name **Representation**
Definition
This class is the most relevant because it is the 3D model representation of the architectural element. In the conceptual model each Representation is labelled by the colour of the gradient colour scale (Fig. 7) to which it refers. The class of Representation could be referred to each architectural element of each LoD (Fig. 9).

Attribute
Name **UncertaintyLevel**
Cardinality 1..10 enumerated Levels
Type Number
Definition
The uncertainty level correspond to the gradient color scale (Fig.7)

Class
Name **3D_Object**
Definition
The 3D object is the result of data process of a survey related to archaeological/architectural evidence.

The list of architectural fragments of Porta Aurea and archeological evidence are specified on Par. 2.4

Attribute
Name **InstrumentOfAcquisition**
Cardinality 1..* enumerated Instruments
Type Text
Definition
It refers to the instrument used to survey the archeological/architectural evidence.

Enumerated Instruments Of Acquisition:
are referred to the set of Instruments used in the 3D data capture of the 3D object.
According with our case study the Intrument of acquisition is the *Leica ScanStation C10*

Attribute
Name **PostProcessingSoftware**
Cardinality 1..* enumerated Softwares
Type Tex
Definition
It refers to the software used during the post-processing of data.

Enumerated Softwares:
are referred to the set of software used in the 3D data process of the 3D object.
In our case study we firstly use the Leica Cyclone Software to manage the poin cloud and later we create 3D models using MeshLab.

Attribute
Name **AvailableFormat**
Cardinality 1..* enumerated Softwares
Type Tex
Definition
It refers to the available format of the 3D model or point cloud.

Class
Name **Morphological Informations**
Definition
Set of knoledge related to the shape of the profile of the architectural element

Class
Name **Dimensional Informations**
Definition
Set of knoledge related to the measures of the profile of the architectural element

Class
Name **Geometrical Representation**
Definition
Set of knoledge related to the geometrical representation of the profile of the architectural

element

Attribute

Name **Type**

Cardinality 1..2 enumerated Type of Geometrical Representation

Type Text

Definition

The type of the geometrical representation concern the number of simple Atomic Elements of which is composed.

Enumerated type of Geometrical Representation are two:

Simple: composed by a single Geometrical Atom

Combined: composed by a sequence of two or more Geometrical Atoms

Class

Name **Geometrical Atom**

Definition

According to the list of Geometrical Atoms proposed by De Luca et al. (2007)

Attribute

Name **Code**

Cardinality 1..9

Type Number

Definition

Its reffered to the list of Geometrical Atoms proposed by De Luca et al. (2007)

Class

Name **BoundingBoxMeasures**

Definition

According to De Luca et al. (2007) Bounding Box definition

Class

Name **MeasureOfWidth/ MeasureOfHeight/**

Definition

Set of informations related to measures of the Bounding Box

Attribute

Name **TypeOfMeasure**

Cardinality 1..3 enumerated Types

Type Text

Definition

Type of measure its referred to the kind of information that we have to manage

Enumerated Types of measure are three:

Indicated:measurement that has evidence on a Reference

Deducted:measurement deducted from an indicate measure

Interpreted:measure interpreted from a set of previous knoledge

Attribute

Name **Measure**

Cardinality 1

Type Number

Definition

Transcription of a measure

Class

Name **MeasureOfDepth**

Definition

Set of informations related to measures of architectural element

Class

Name **Reference Element**

Definition

Set of different kind of sources used in the virtual reconstruction process

Attribute

Name **TypeOfSource**

Cardinality 1...* enumerated Type Of Sources

Type Text

Definition

ID that define the type of source to which we refer.

Enumerated Type of Sorces:

Set of sources involved in the virtual reconstruction that can be Bibliographic Reference and other possibilities

In our case we only manage Survey Drawings

Attribute

Name **SourceID**

Cardinality 1...* enumerated Sources

Type Notation

Definition

ID that define the source to which we refer

Enumerated Sorces:

Set of sources involved in the virtual reconstruction

In our case we use the Notation of all Survey Drawings that refers to different Archives

Attribute

Name **UncertaintyLevel**

Cardinality 1..10 enumerated Levels

Type Number

Definition

The uncertainty level correspond to the gradient color scale (Fig.7)

4. Modelling architectural elements: Annotations

In this last part of the study we analyse the survey drawings of Porta Aurea in detail and we describe how we use information measurements in the 3D modelling process.

The first passage was to transcript all informations in a table that clearly describe the content of all drawings with their specific unit..

Tab. 2: Units conversion table

Author	Unit	To cm
G. B. da Sangallo	Piede Romano	29,7
Andrea Palladio	Piede Vicentino	35,7
Anonimous of Berlin	Graphic Scale	31,4

Tab. 3: Units specifications table

Unit	Sub-Unit	Sub-Sub-Unit
Piede Romano	4 palmi	16 dita
Piede Vicentino	12 once	48 minuti
Graphic Scale	12 once	144 minuti

In the table of "Transcript of measurements" (Tab. 4) we report measures that we use and that have evidence on drawings. Accoriding with our gradient colour scale (Fig. 7) we analyse information related to the 2nd and 3rd level: original survey drawing edited by Andrea Palladio and original sketches and uncomplete survey drawings edited by Anonimous of Berlin, Pirro Ligorio, G.B. da Sangallo and Raphael (copyist of/circle of). We transcript alla measures except the mouldings ones because for them we annotate single considerations.

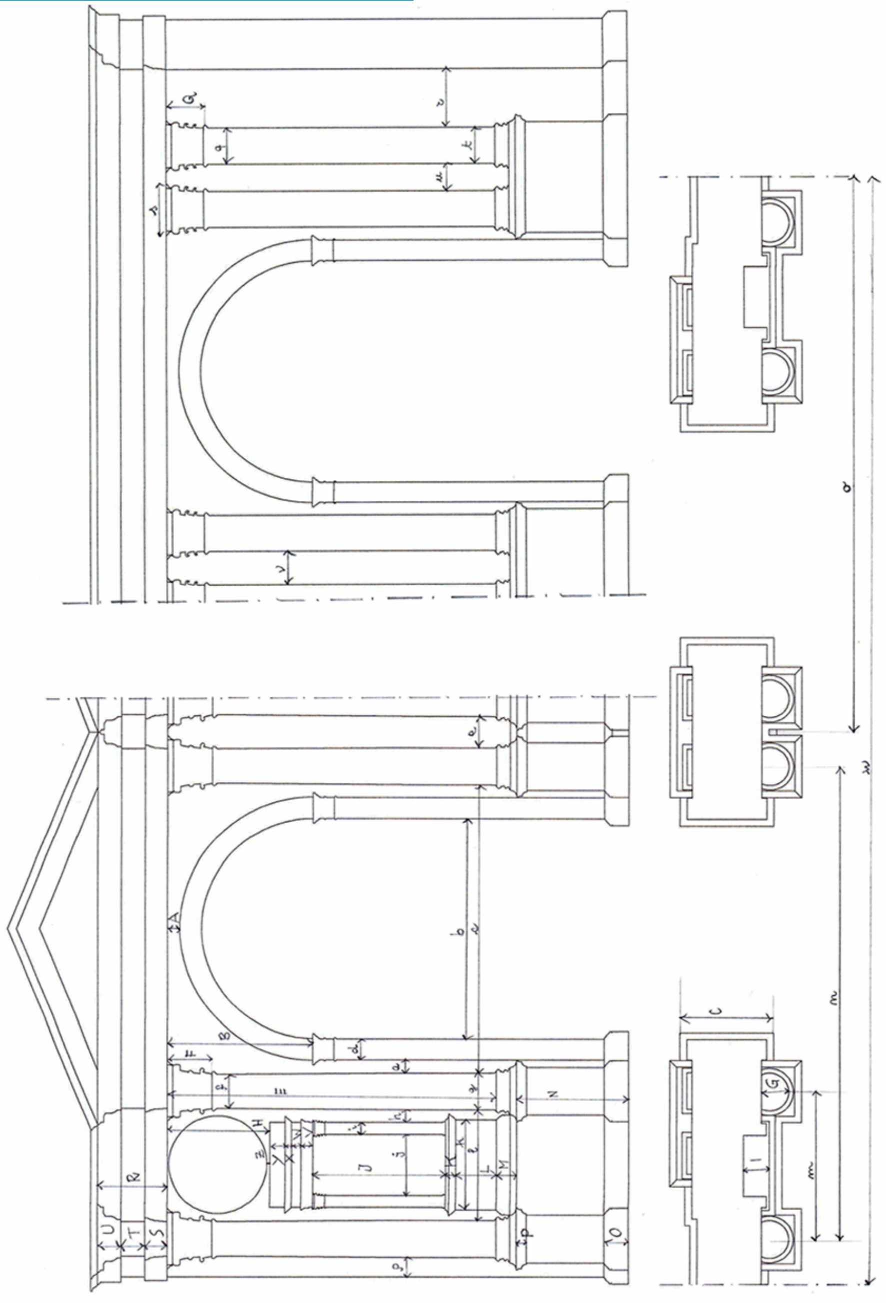

Fig. 11: Figure of measurements

Tab. 4: Transcript of measurements related to Fig. 11

Dimension elements Fig. 11	Andrea Palladio			Andrea Palladio			Andrea Palladio			Anonimous of Berlin			Pirro Ligorio			Giovanbattista da Sangallo		
	London, R.I.B.A. XII, 12 recto			London, R.I.B.A. XII, 12 verso			Vicenza, Civic Art Gallery of Palazzo Chiericati, D-31 recto			Berlin, Kunstbibliothek, Staatliche Museen zu Berlin, n. 3305, n. 3306			Turin, State Archives, vol.XV, c.18			Florence, Uffizi Gallery, Arch. 2057		
	piedi	once	minuti	piedi	once	minuti	piedi	once	minuti	piedi	once	minuti	piedi	once	minuti	piedi	palmi	diti
A					6													
a		8						8			8	7		8				
B	7	1½		7	1½		7	1½		8			7	1½				
b	11			11			11			12	6	7	11					
C																11		8
c				14	9													
D	1			1			1						1					
d	1			1			1			1	2		1					
E	16	1½					16	1½					16	1½				
e	1	3					1	3		1	9	10	1	?				
F	2	2¼																
f										1	11	11						
G	1	4																
g	1	10½					1	10½		2	2	9	1	10½				
H										6	3	5						
h											7							
I	1	1½																
i		7						7			8	10						
J	6½						6½			7	3	8						
j	3						3			3	9	10						
K		6						6			3	6						
k	5						5			5	6		5					
L	2																	
l	5½						5½			6	3	7						
M										1	3	3						
m																8		12
N	5½			5½						6	6							
n																29		
O											9							
o																31		8
P											8							
p							1						1					
Q				1	10½									22				
q														22				
R				3	5													
r	2½			2½									2½					
S	1	2		1	2½		1	2		1	1		1	2				
s	2	5																
T	1	1¼		1	1½		1		5	1	3	1	1		5			
t	1	8		1	9½									22½				
U	1	1½		1	2		1	1¼		1	3		1	1½				
u				1									1½					
V			28					7			8							
v	1			1														
W			24					6			6	4						
w																63		
X			20					5			4	2						
Y			36					9						6				
Z												11						

4.1 The arch

The arch was reconstructed starting from the analysis of the plan. The span of the opening located both in plan and elevation in Palladio (Tab.4 - b) has been retained, as well as the height of the impost of the arch referred to the entablature (Tab.4 - B)

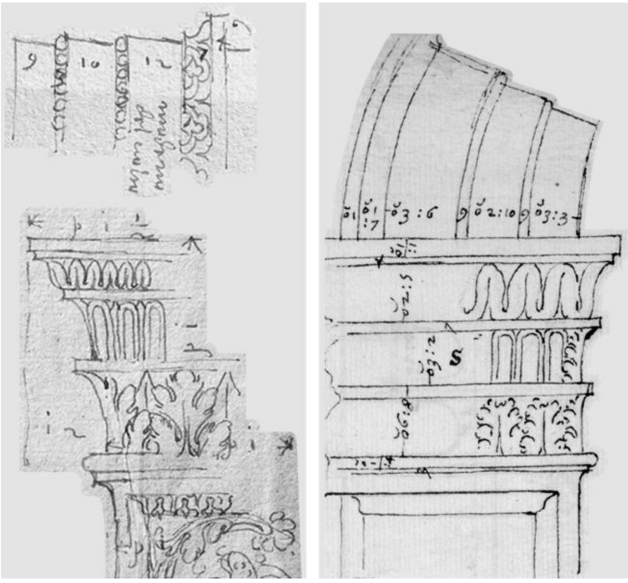

Fig. 12: Detail of Arch
a) R.I.B.A. XII, 12 recto b) K.S.M.B. , N.3305 recto

As regards the pillar, we used the data on both the general measurements of Anonymous (Tab.4 - d) and the elements of the detail (Fig. 12).

As regards the first fascia, Anonymous describes all of it without subdividing the elements and, so the fillet was inferred from the proportion of the upper fascias, and set equal to 11 minutes (graphic scale).

The analysis of the arch and its reconstruction was involved also the question of the size of the plan and of the thickness the monument may have had. Until now it had always been assumed that the thickness of the gate would have been quite significant. The surviving excavation data, albeit in fragments, have always led historians (Kähler, 1935; Rosi, 1939; Tosi, 1986) to believe the planimetric drawing of Sangallo to be considered most appropriate.

In our opinion, the thickness of the gate could have been proportionally similar to the plan as reported by Palladio (Fig 13). The reconstructive study of the vault was based on the analysis of the finds in the superintendence and reality-based measures of the hexagons.

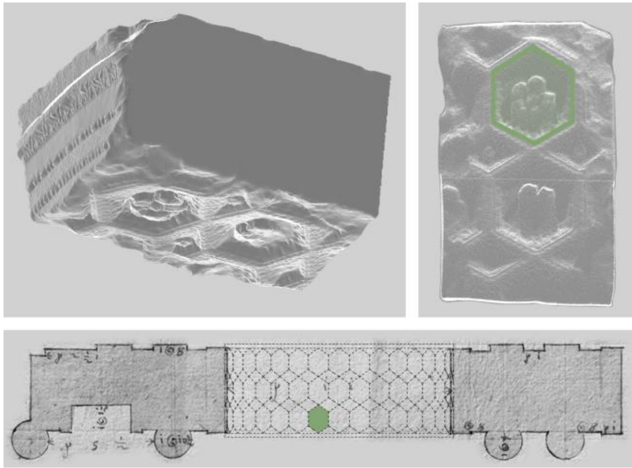

Fig. 13: Detail of Archivolt
a) 3D reality-based model b) laser-scan detail of intrados
c) Plan of Porta Aurea, representing the projection of archivolt intrados

Assuming that the fragment of the archivolt belongs to the ancient monument, it has been joined by a series of three hexagons to reconstruct the thickness. We have identified a definite discrepancy between the 3.4 metres of Sangallo's drawing and the approximate1.6 metres of Palladio. In the drawing of Ligorio, in the face to the right one shows that the number of hexagons in succession is always three. As for the number of hexagons on the longitudinal side, it has remained the number as described by Sangallo *"ne' di sotto de larcho sono seangoli e mandorle e sono ì archolo 17 seangoli"* (under the arch there are coffered shaped hexagonal and quadrilateral , and on the whole vault there are 17 hexagons).

4.2 The Corinthian Order

4.2.1 The entablature

Andrea Palladio provides different data in the three different manuscripts. In the first drawing the entablature shows its three main elements, but in the same paper the measures of the detail appear to be different. In the second drawing, depicting the front facing towards the city, the entablature is shown in its entirety. Finally, in the third drawing it resumes the subdivision adopted in the former but the information changes again. Considering the third drawing to likely be the least reliable and to all the versions differ in their partial representation of the entablature, it was decided to use the total height (Tab.4 - R) while cornice (Tab.4 - U) and architrave (Tab.4 - S) have used data from Anonymous (Fig. 14).

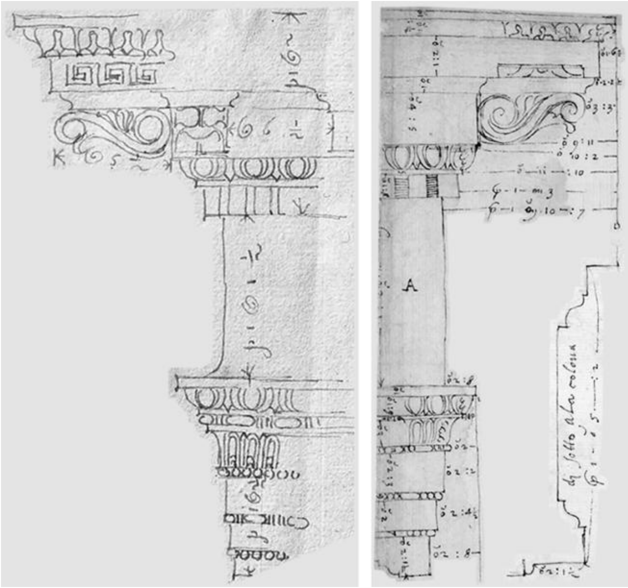

Fig. 14: Detail of Entablature
a) R.I.B.A. XII, 12 recto b) K.S.M.B. , N.3305 recto

Starting from the top of the frame the source did not provide the height dell'ovolo which then is considered equal to the height of the architrave level dell'ovolo and dentil considered in addition to the space provided.

The architrave was considered as depicted by Anonymous that shows us also the section in rosettes.

Considering the alignment of the pediments and entablature compared to the column, it was clear that the entablature as shown by Anonymous would have significantly altered the distance between the half-column in the central pillar. It was therefore decided to use as a share of the overhang of the bracket, not the data from Anonymous but those of Palladio, which rendered the overhang less important and determined a distance between the half-columns of 1 feet 7 ounces (Vicenzan feet), that is, 4 ounces greater compared to the London drawing (Tab. 3 - e).

4.2.2 The semi-colums and lesenas

Data relating to a half-column examined for height (Tab.4 - E), width (Tab.4 - g) and depth (Tab.4 - G) were taken from drawings by Palladio, while the tapering there was supplied by Anonymous (Tab.4 - f) as well as the detail of the base and the Corinthian capital (Fig. 15), for whose overall height (Tab.4 - F) is referred to by Palladio (Fig. 16).

Fig. 16: Detail of two capitals
a) R.I.B.A. XII, 12 verso b) R.I.B.A. XII, 12 recto

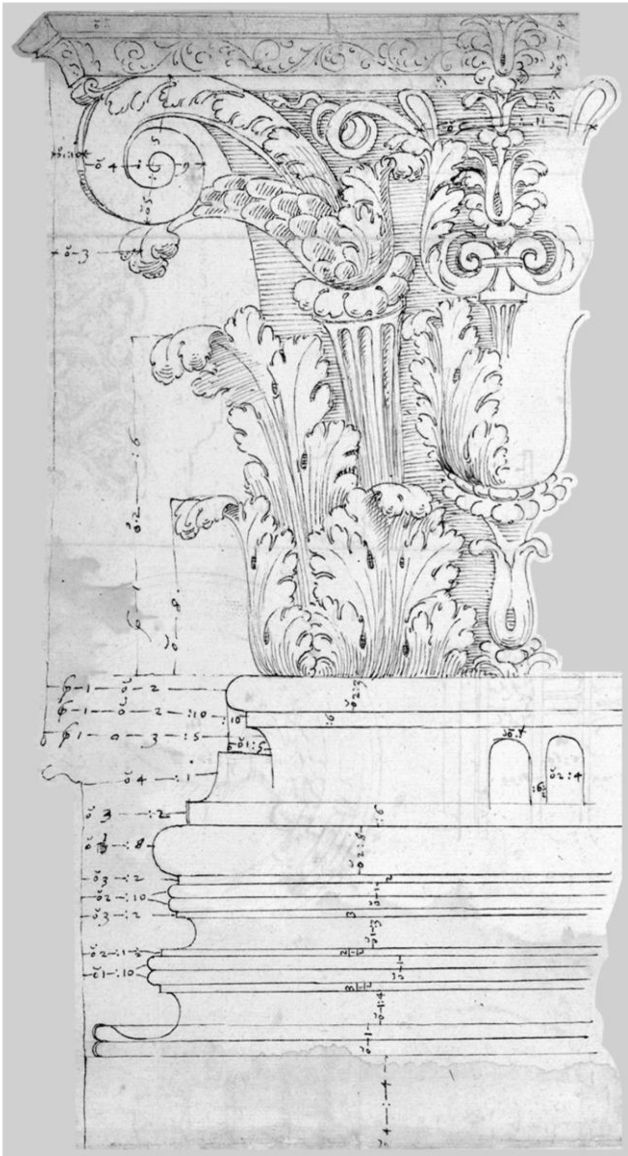

Fig. 15: Detail of capital and base of semicolumn
K.S.M.B. , N.3305 verso

As for the front facing towards the city, it presents the place of the half-columns, Corinthian lesenas also being tapered.

In the drawings of Palladio, different measures are provided in both plan and elevation with regard to their width.

So, in this case, the design of Pirro Ligorio is used to provide us with all of the information regarding its width (Tab.4 - t) tapering (Tab.4 - q) and height of capital (Tab.4 - Q).

The height of the capital of the lesena is the only coincident measure to that is also reported by Palladio.

4.2.3 The Pedestal

As for the analysis of the base section, reference was made to the information in the sheets representing the Gavi Arch in Verona: an eidotype carefully detailed not only at the base section but also the niche above.

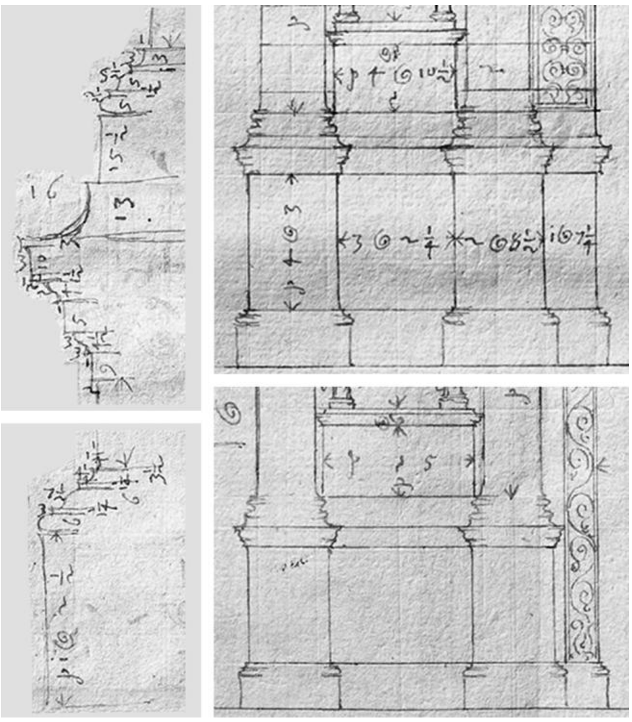

Fig. 17: Detail of Pedestal
a) R.I.B.A. 31820 b) R.I.B.A. 31819
c) R.I.B.A. XII, 12 recto

For aspects of form, the drawings of the Gavi Arch were brought into consideration, those maintaining consistency with the metric data available on the Porta Aurea: the overall height of the pedestal was provided by Palladio (Tab.4 - N), while the cap was considered as represented by Anonymous of Berlin (Tab.4 - P). Regarding the plinth, reference is made only to RIBA 31820 (Fig.17) even if the dado has not used the height to which it refers, but a height of 10 ounces (Vicenzan feet) which was more proportionate than redrawing Palladian gate.

4.2.4 The Aedicula

In the side pillars, framed by two half-columns, are niches (on the front facing out of the city).

The joint on the base was not described in Palladio for which in this case it has also been referred to the design of The Gavi Arch (Fig. 12). From the geometric-formal point of view, again the same base is seen while, from the dimensional point of view, reference was made to the order of the base of the column that was proposed by Anonymous (Fig.18). The upper part remained the size proposed by Palladio to die (Tab.4 -N) and cap (Tab.4 - M).

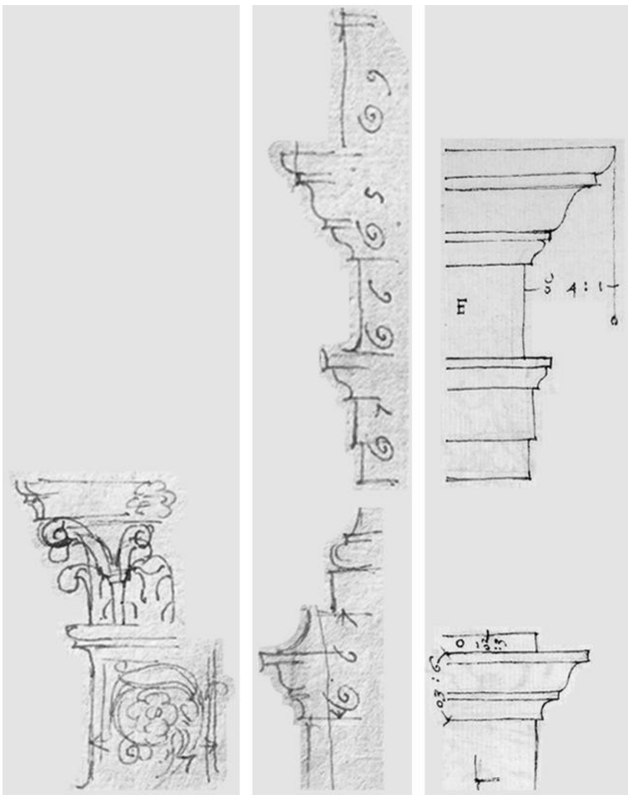

Fig. 18: Detail of Recess
a , b) R.I.B.A. XII, 12 recto c) K.S.M.B. , N.3305 recto

Among the drawings of Anonymous and Palladio, one notices the difference between the base of the pillars (fig.13), compared to the dado at the base of the pillar which is considered the measure by Anonymous 2 ounces 3 minutes (graphic scale).

Regarding the recess, the information has been from Palladiofor both height (Tab.4 - J) and width (Tab.4 - j) has been maintained.

The width of the pillar was considered as shown by Palladio (Tab.4 - i), since the hypothesis of Palladio for the entire entablature would be too high and would not permit the insertion of the fragment of the clipeo at the top. Anonymous Berlin is the source for the entablature above and for the architrave (Tab.4 - V) frieze (Tab.4 - W) and cornice (Tab.4 - X) with the addition of part of the frieze at the top, not recorded by Palladio (Tab.4 - Y).

5. Conclusions

The paper presents a technical pipeline of the 3D Model creation with the addition of metadata describing information about digitation processes and paradata to keep tracks of the complete modelling process. The paradata schema is able of reconstruction process and in understanding and interpretating data objects. The geometrical capturing all the semantic present in the virtual documentation gave research possibilities to conceptualize different kind of reconstructive hypotheses based on a controlled use of documented informations about interpretation workflow Moreover, the main purpose of the study was to make the process of 3D modeling as clear as possible, adding clarity in respect of the sources used.

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