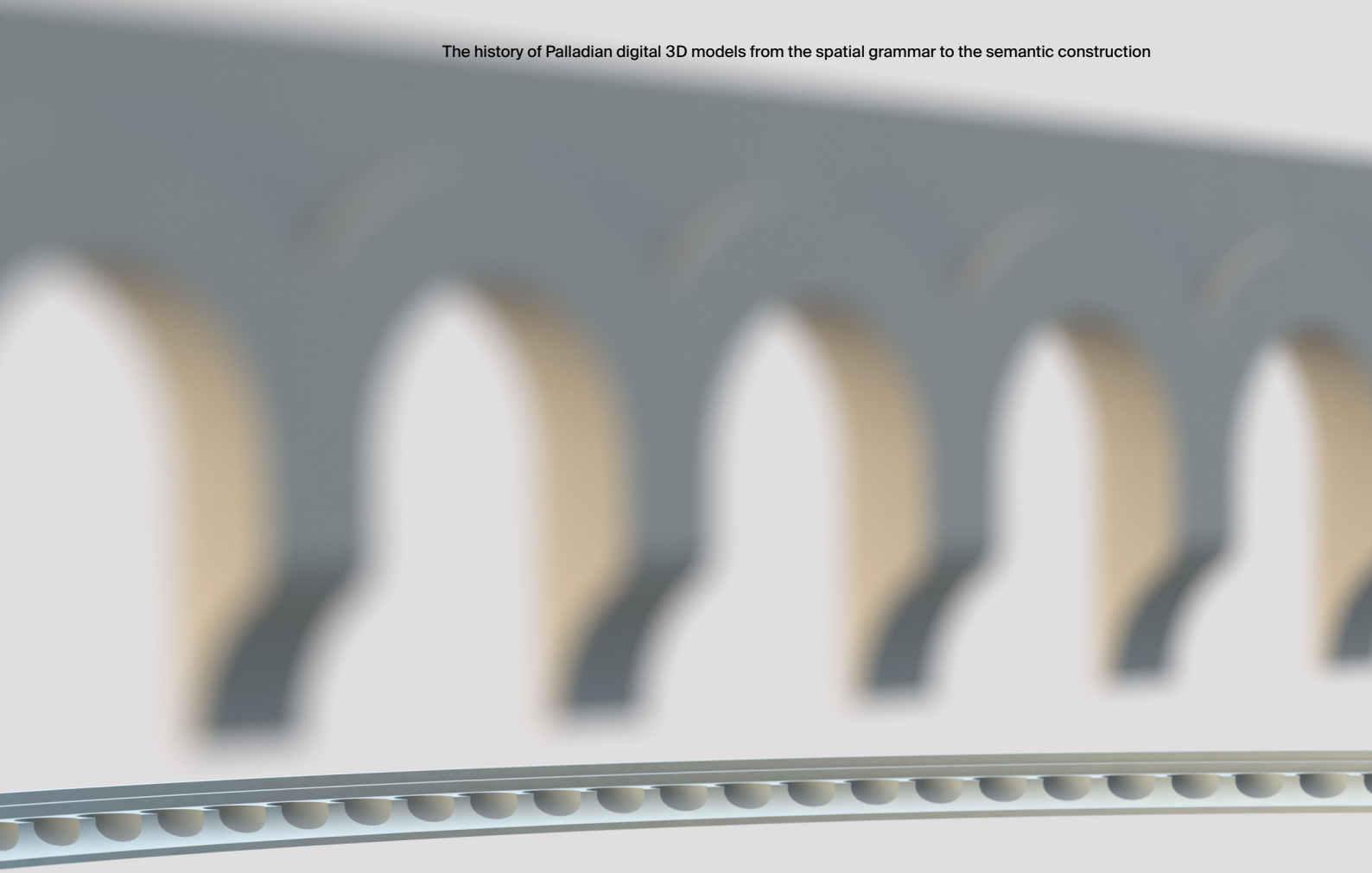
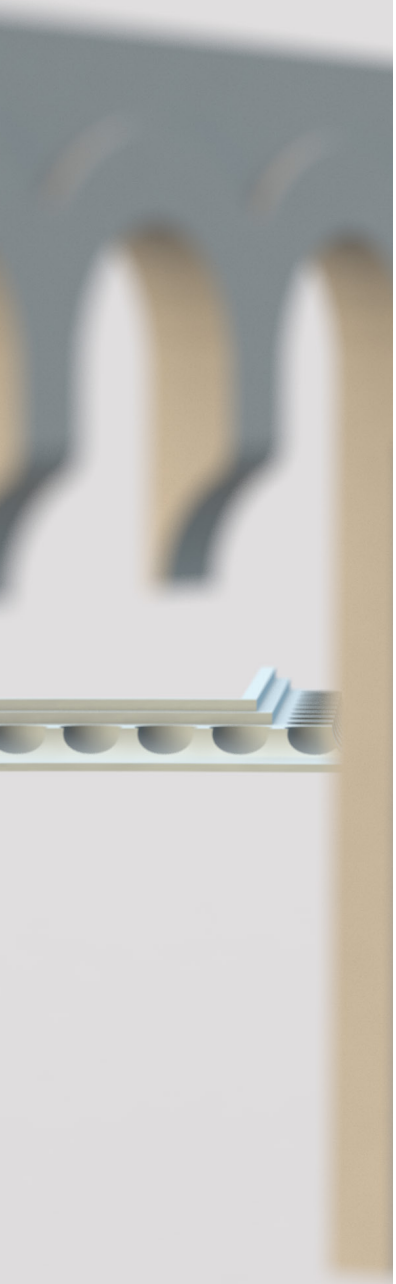




Marco Gaiani

II. The history of Palladian digital 3D models from the spatial grammar to the semantic construction

→ 3D modelling, Andrea Palladio, high-quality rendering, historical reconstruction, real-time rendering, semantic modeling, shape grammar

This paper presents a critical history of the Palladian digital 3D models starting from the Stiny & Mitchell spatial grammar to the reconstruction as **instauratio** suggested by Howard Burns during the years 1990, finally to the semantic modeling developed from the end of the last century. This narration faces up central topics of the whole history of the digital 3D reconstruction applied to the architecture field, mainly concerning the strategy followed. Palladian 3D model construction techniques and the final outcomes, marginally follow the well-recognized path of photorealistic interpretation of a lost past. In the Palladian case the use of digital technology as interpretation tool involved a philological analysis of unbuilt projects, unfinished works and disappeared architectures, developing — as shows the rich and systematic contributions of William Mitchell — techniques and methods to construct the 3D models as cognitive and interpretative system. The feature of Palladio's drawings to be flattened patterns of spatial solutions and the existence of a grammar described by the architect (his The Four Books of the Architecture), allowed many attempts to reconstruct the complete project from partial representations, with the aim of discover design intents, the logic of architecture and possible interpretations of the original drawings.

The paper aims to describe not only the many attempt and results from different group, but also to provide an in-depth analysis of methods and techniques, both investigating its origins in architectural design and methods of historical architecture analysis, and illustrating digital implementations and developments allowed contributions to capture the qualities of the built projects, the deficiencies of those abandoned, the complexities that have endangered some achievements.

II.1 Introduction

This paper presents a critical perspective of the digital 3D models demonstrating the works of the architect Andrea Palladio, an exceptional and impressive figure in the panorama of 16th Century architecture, whose opera had a tremendous impact and influence in the following centuries all over the world. 01 In our opinion, the subjects described here play a key role in the whole history of the digital 3D reconstruction applied to the historical architecture field and architecture theories, for reasons related to the methods and the techniques developed to tackle the issues that lie in representing and interpreting his work.

■ 01
Guido Beltramini, Howard Burns (Eds.), Palladio, Venezia 2008.

Motivations regarding the subject are well explained by Wolgang Lotz:

»Since the eighteenth, the name of Andrea Palladio (1508–1580) has stood for architectural perfection. [...] The reasons for the present interest in Palladio lie in particular qualities of his work. [...] many of his buildings have remained practically unaltered, so that it requires no historical imagination to see them in their original form. Finally, Palladio founded his own enduring fame by a book of illustrations and comments on his own work.« 02

■ 02
Wolfgang Lotz, Architecture in Italy, 1500–1600, London 1995, p. 147.

Motivations regarding the digitalization of the Palladio work are well explained by the title of the Howard Burns essay **La creazione di un'architettura sistematica e comunicabile** that well clarifies the great interest in Andrea Palladio's architecture since the first stages of Information Technology. 03

■ 03
Howard Burns, Andrea Palladio (1508–1580): la creazione di un'architettura sistematica e comunicabile, in: Guido Beltramini and Pino Guidolotti (Eds.), Andrea Palladio: atlante delle architetture, Venezia 2000, pp. 3–12.

The direction given to the Palladian studies by the analysis of Rudolf Wittkower's book **Architectural Principles in the Age of Humanism** (1949) 04 and Colin Rowe's essay **The Mathematics of the Ideal Villa** (1947) 05 connoted the Palladian architecture as an outstanding subject to give a seductive look to an instrument that, rather than offer introspective ability, imposed constraints.

■ 04
Rudolf Wittkover, Architectural Principles in the Age of Humanism, London 1949.

■ 05
Colin Rowe, The Mathematics of the Ideal Villa, in: Architectural Review, 101 (3) 1947, pp. 101–104.

Specifically, Palladio is an excellent subject to demonstrate typical features of digital 3D modelers. The drawings are just flattened patterns of three-dimensional solutions. Visualizing them in 3D allows us to notice quickly and clearly the advantages of built projects; the defects of abandoned projects; the complexities that have endangered some of his realizations. Finally, Palladian 3D model construction techniques and the final outcomes, marginally followed the well-recognized path of photorealistic interpretation of a lost past, a re-interpretation of the photorealistic appearance of the **envois** of French architects **pensionnaires** in Rome during the 19th Century.

In the Palladian case, the use of digital technology as interpretation tool involved a philological analysis of unbuilt projects, unfinished works and disappeared architectures — as shows the rich and systematic contributions by William Mitchell — developing techniques and methods to author the 3D models as cognitive and interpretive system. The existence of a grammar

described by the architect (its treatise **I Quattro Libri dell'architettura** published in 1570) 06, allowed many attempts to reconstruct the complete project from partial representations, with the aim of discovering design intents, the logic of architecture and possible interpretations of the original drawings.

At the ground of this work is the concept of **instauratio** detailed by Howard Burns 07, as method allowing to find a convincing solution to the problem of missing parts.

Instauratio recall one of the fundamental points of the Renaissance culture: the aim to restitute the articulated, rich ancient world from the today ruins. The method to approach this restitution lies in the use of rules from the same system. E. g. the grammar, the syntax, a Latin vocabulary are the tools that allow to extract the meaning from the context and to understand and complete the missing. Applying this method to the study of the architecture by Palladio, the rules for integrating missing or unclear parts can be found in its treatise. **I Quattro libri** provides grammar, vocabulary and syntax to be used to proceed in finding a missing part. The text illustrates shapes, general proportions and rooms and bedrooms; Palladio's types for buildings, villas and stairs.

Above all digital technology was used to provide important contributions to highlight the significant of the objects partially lost in the translating the 2D of the paper sheet to 3D space. Our paper aims to describe not only the many attempts and results from different group, but also to provide an in-depth analysis of methods and techniques developed and used.

■ **06**
Andrea Palladio, I Quattro libri dell'architettura, Venezia 1570.

■ **07**
Howard Burns, Conference at seminar Da Palladio a Desgodetz – Progetti non realizzati e monumenti antichi: una collezione di modelli virtuali, Ferrara 28–30 October 1996.

II.2 First trials starting from the shape grammar

In 1986 both Howard Burns and William J. Mitchell were named at the Harvard Graduate School of Design (GSD). Few month later they began a close collaboration working on Palladio architecture, continued until the Mitchell dead in 2010.

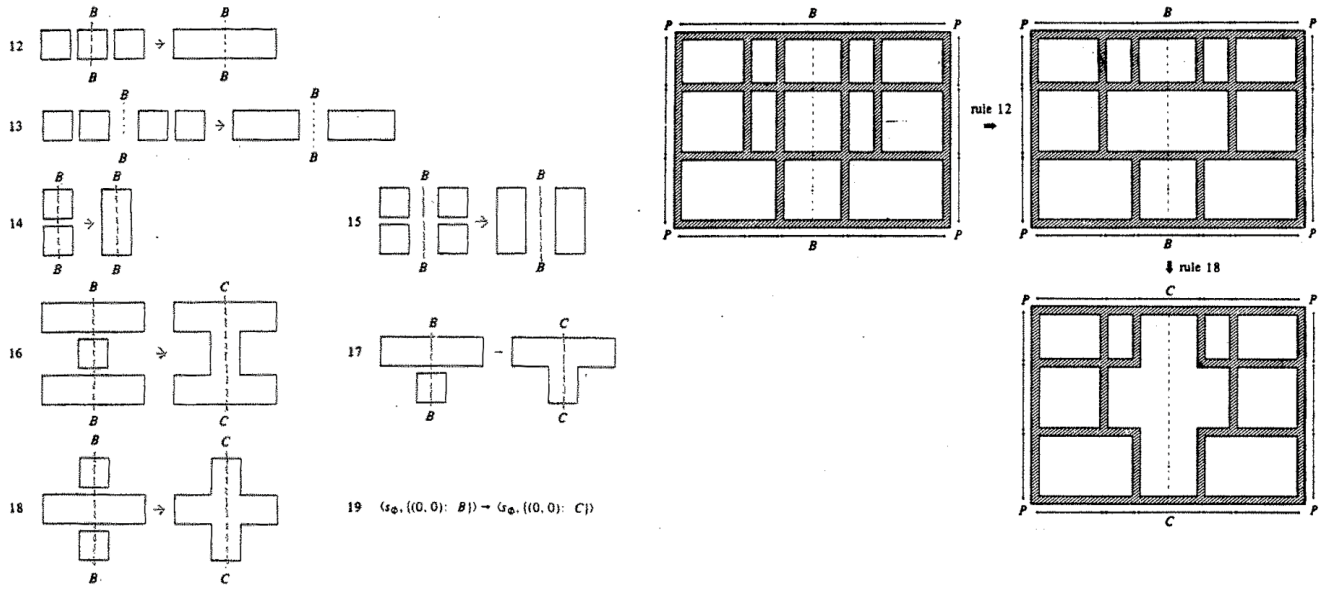
Mitchell's interest in Palladio started more than a decade before of its nomination at GSD, when he published a trilogy of papers with George Stiny, and demonstrated a Palladian grammar that applied 72 rules to generate the plan of Villa Foscari at Malcontenta 08 01. Stiny and Mitchell's grammar was the first explicit, formally rigorous characterization of Palladian villas that was simultaneously analytic and generative. The rules of the grammar explicate the conventions underlying villa plans and can be applied to generate the villa plans in Palladio's **I Quattro Libri**, as well as innumerable other new, hypothetical, or possible plans in the Palladian style. Authors take **top-down** approach which gradually refines a starting generic condition to approximate a Palladian villa. The essay **The Palladian grammar,** fully explains method and aim:

■ **08**
George Stiny, William J. Mitchell, The Palladian Grammar, in: Environment and Planning B, 5 (1) 1978, pp. 5–18; Ibid, pp. 189–198; Ibid, pp. 199–206.

»In this paper a first attempt is made to recast parts of Palladio's architectural grammar in a modern, generative form. The rules of a parametric shape grammar … that generates villa ground plans are specified. In many cases these rules are direct translations of Palladio's explicit canons of design; in others, they are based on examples of villa plans in the **Quattro Libri**.« 09

■ **09**
Ibid, p. 5.

□ 01
The Palladian grammar, rules for room layout and generation of the room layout for the Villa Malcontenta (G. Stiny, W. J. Mitchell)



The so defined grammar generates the main features of most of Palladio's villa plans as drawn in the book. The same Palladian method fueled this new processing. Sketching quickly and on a small-scale Palladio tends to draw further alternatives rather than to rework sketches with which he is not satisfied [10]. Thus, on a sheet like RIBA X/22 verso Palladio was able in ten or fifteen minutes to generate most of the solutions that were compatible with the site and with his architectural system [11].

The process is basically semi-automatic and could be performed by a computer: one can easily experience it for his own by arbitrarily drawing a site, and then trying to insert into it all characteristic features of a Palladian palace. The resulting drawings are not essentially new designs: they rely heavily on memory and the real moment of **invention** is well upstream from the apparent moment of the composition.

A key point of the Mitchell & Stiny work is that they shaped the algorithm through a linguistic standpoint [12]. The villa is thought of as an architectural **sentence** that is constructed through the treatment of **grammatical** rules to basic **words**. The words themselves are generated through a process called parametric shape grammar, whereby labels applied to lines, points, and other basic shapes become the place of transformations and substitutions. In their discussion of the Palladian grammar, however, Stiny and Mitchell point to work needed to complete their grammar. For example, the details of plans proportions, the designs of facades, and historical questions relating Palladio to his neoPalladian successors need to be investigated further [13]. At this point the collaboration between Mitchell and Burns begins, introducing new major elements:

- → a more consistent cultural environment to develop researches based on a systematic collaboration with the Centro Internazionale di Studi di Architettura Andrea Palladio (CISAAP), the most important institution focused on Palladio studies. [14] The main result of this collaboration was a later project for a Palladio Virtual Museum, a heterogeneous database of history and architecture [15];
- → a more convincing reconstructive approach based on the notion of **instauratio**;
- → more consistent 3D reconstruction techniques based on the general notion of **design knowledge** following the — at that time — emerging CAD paradigm of knowledge-based design [16]. In the Mitchell's **design knowledge** vision shape grammar systems are putted in a rather Aristotelian view of design knowledge: things have their uses, these uses can be defined by specifying rules of usage, and application of the rules yields designs in which elements are employed appropriately to contribute to the functioning of the whole [17]. So Stiny and Mitchell's Palladian grammar is generalized into a design technique in which elements of classical architecture are used to put together country dwellings in the Veneto;
- → the use of 3D digital models instead of 2D patterns as a representation tool brings new contributes to the ability of a grammar to accurately capture the whole knowledge. 3D modeling technique allow a systematic analysis of problems and solutions and facilitate the assembling of both

■ **10**
Howard Burns, The Lion's Claw: Palladio's Initial Project Sketches, in: Daidalos, 5 1982, pp. 73–80.

■ **11**
Andrea Palladio, twenty alternative plans for modernizing the house of Camillo Volpe, Vicenza Late 1560s; pen and dark brown ink; 315x392 mm., London, RIBA Library, Drawings and Archives Collection, sc. 219/XI/22r.

■ **12**
George Stiny, and William J. Mitchell, The Palladian Grammar, in: Environment and Planning B, 5 (1) 1978, p. 5.

■ **13**
Terry Knight, Possible Palladian Villas by George Hersey and Richard Freedman, Review, in: Journal of Architectural Education, 44, 1994, pp. 258–260.

■ **14**
Palladiomuseum, www.palladiomuseum.org.

■ **15**
Daniel Tsai, The Palladio Web Museum — a Heterogeneous Database of Architecture and History, in: CAADFutures 1997, 1997, pp. 655–662.

■ **16**
Richard D. Coyne, Michael A. Rosenman, Anthony D. Radford, Bala M. Balachandran, John S. Gero, Knowledge-Based Design Systems, Reading 1990.

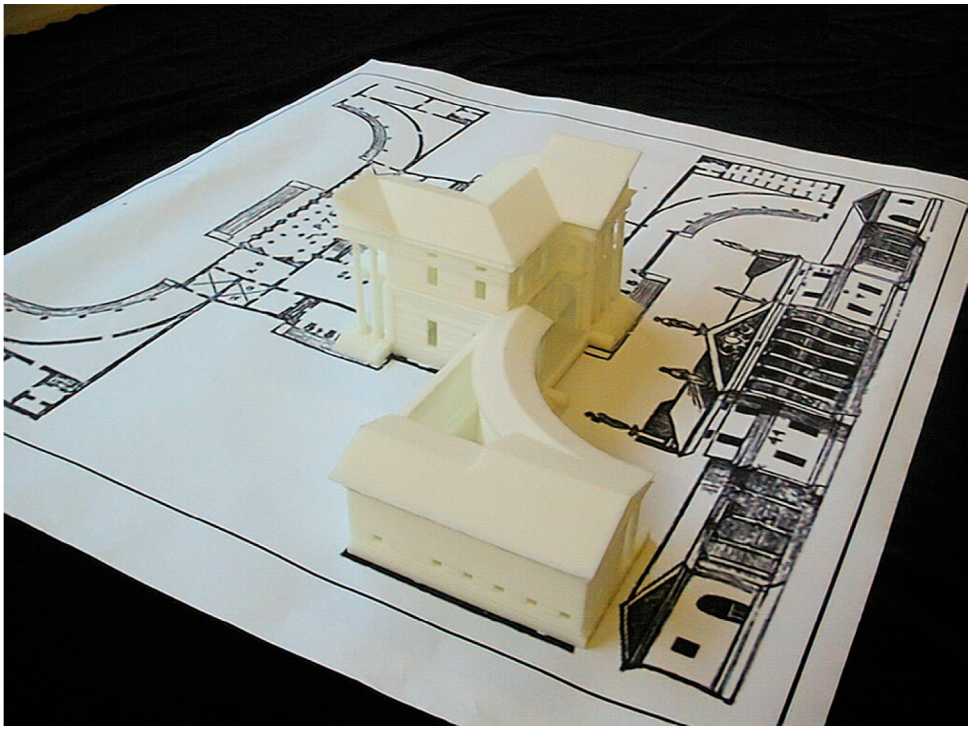
■ **17**
William J. Mitchell, Three paradigms for computer-aided design, in: Automation in Construction, 3, 1994, pp. 239–245.

artifacts and information to form a coherent view. Analytical reconstructions of unbuilt, destroyed or incomplete works allow the development of a robust grammar;

→ the involvement of the students in the development of computer models of all the villas published in Palladio's book. As the students started to develop their own interests in the work, the results were far more divergent than Mitchell had originally expected. The original idea of simple renderings evolved into the building of physical models using 3D printing technology.

Lawrence Sass, one of best Mitchell's students, systematized some years later this research path 18. Sass demonstrated how Palladio's text could be applied to the reconstruction of an entire villa exclusively by rules, from the foundation to the roof. The rules used to reconstruct each villa have been rewritten in a format that allows a direct application to a computer program or shape grammar. The nature of 3D rules (versus 2D rules) associated with 3D printing techniques defines a new grammar type based on assembly, physical modelling, and manufacture, the so-called construction grammar 02.

■ **18**
Lawrence Sass, Reconstructing Palladio s Villas: a computational analysis of Palladio's villa design and construction process, in: ACADIA Proceedings, SUNY Buffalo, 2001, pp. 212–226; Lawrence Sass, A Palladian construction grammar — design reasoning with shape grammars and rapid prototyping, in: Environment and Planning B, 34 (1) 2007, pp. 87–106.



□ 02
3D print of Palladio's un-built Villa Mocenigo at Meledo by Larry Sass (Larry Sass)

We just remark that the Sass goal was to reconstruct Palladio's ideal intentions by the rules expressed in Books One and Two of **I Quattro Libri** and not rules coming from the built [19].

The process developed involves qualitative and quantitative methods for evaluating and testing the process and resulting model. The new construction grammar is made of 3D parametric descriptions and rules based on full-scale materials and material assembly. These construction rules do not determine appearance; instead, they define assemblage of physical objects in 3D space. Alternatively, a design rule for a shape grammar builds shapes and shape relationships for visual evaluation; design rules tend not to provide functional or structural information for the manufacture of objects. The method used to build the construction grammar was inferred collecting information from three sources. The first one was the onsite analysis of existing villas. Secondly, rules were derived from drawings in **I Quattro Libri**. Then, as a third source, information on building elements was taken as described in **The Portico and the Farmyard** [20]. These will be also the starting points of the following studies by the same group and other scholars around the world.

■ **19**
Lawrence Sass, Reconstructing Palladio's Villas: An Analysis of Palladio's Villa Design and Construction Process, PhD diss., MIT, 2001.

■ **20**
Howard Burns, Andrea Palladio 1508–1580: the Portico and the Farmyard, London 1975.

□ 03
Reconstruction of project for Palazzo Porto in Vicenza. Elevation on Contrà Porti and longitudinal section from drawings RIBA, XVII, 9r, 12r. (Pier Carlo Ricci)

II.3 Semantic as 3D modelling technique

In the Academic Year 1993–94 Howard Burns moved from Harvard to the University of Ferrara. There he led, always helped by students, 3D model construction works starting from Palladian unbuilt designs. These are usually a plan, an elevation or a half-section half-elevation 03. The rest of the project is missing or never developed by Palladio.

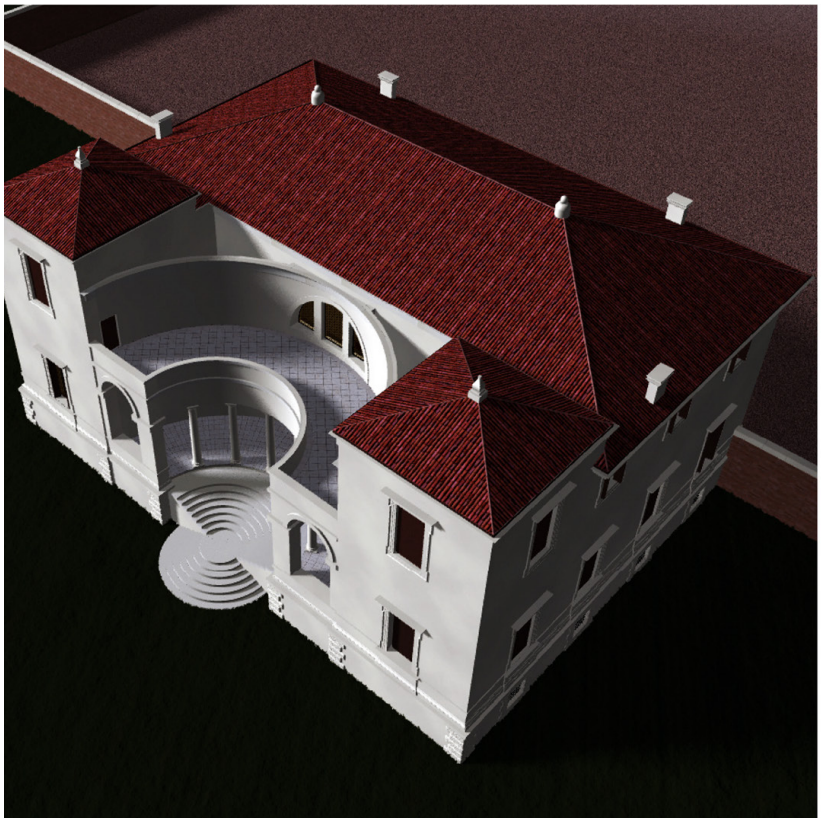
At the end of 1997, after 4 years of extensive experimentation, three 3D digital models of Villa Pisani at Bagnolo, an emblematic case study of the typical Palladian issues found in the analysis of Palladio's corpus, were done 21. These 3D models are an excellent demonstration of the techniques developed in those years with the students and with a new research group that systematized all the new ideas and methods shaped 22.

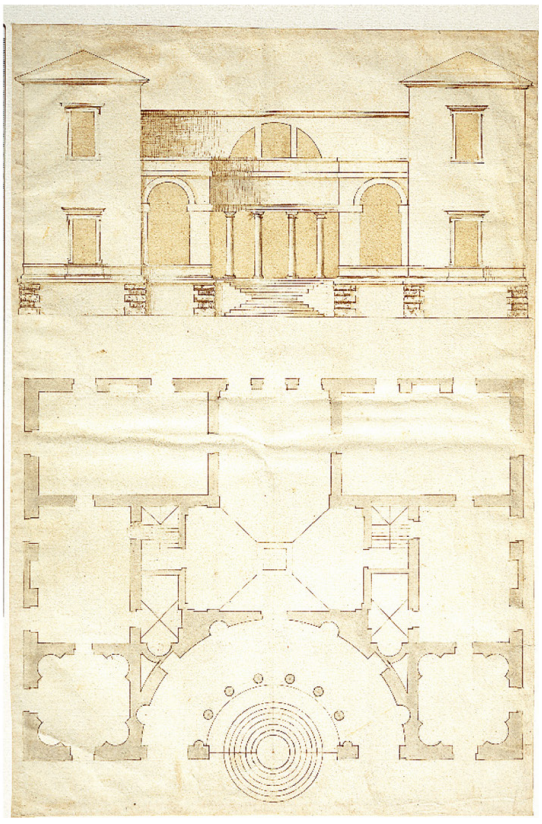
The first model represents one of the projects that Palladio developed for the villa: the solution depicted in the drawing RIBA XVII, 17 04. This plan is more complex than the built villa, echoing the architecture of the Roman baths as well as Bramante's buildings he had previously seen in Rome.
Being more expensive, however, it was probably not approved by the client.

The second 3D model represents the villa and the surrounding countryside around the villa in 1569, thanks to the availability of extremely detailed maps 05. Palladio had great ability not only in designing the villa but also in landscaping the surrounding terrain.

■ **21**
Howard Burns, Villa Pisani a Bagnolo, in: Palladio, Venezia 2008, pp. 64–71.

■ **22**
Guido Beltramini, I modelli per villa Pisani a Bagnolo (Vicenza), in: Paesaggio urbano, pp. 31–32.





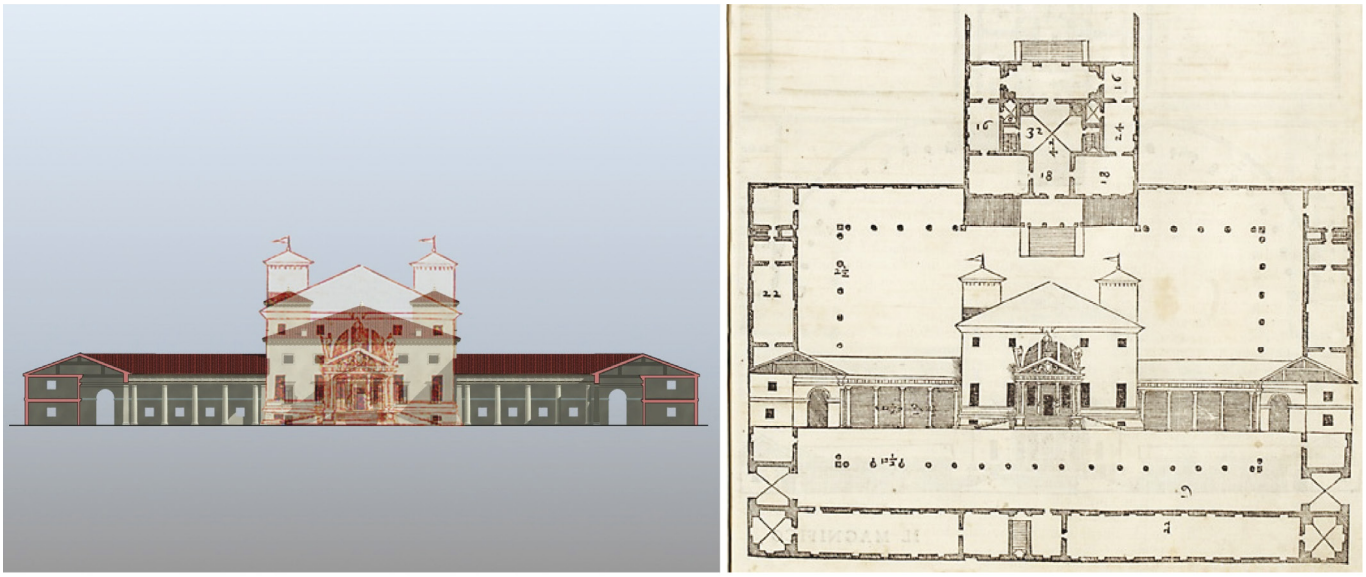
☐ 04
Villa Pisani at Bagnolo: hypothesis of reconstruction from RIBA XVII/17 drawing with the covering of the loggia at esedra settled arbitrarily (Marco Gaiani)

☐ 05
Villa Pisani at Bagnolo: 3D model of the actual state, facade towards the courtyard and view of the loggia towards the courtyard (Marco Gaiani)

The last 3D model represents a version of the villa as it appears in **»I Quattro Libri«**, with embellishments like the pronaos to the back wall overlooking a large closed colonnaded courtyard 06. The reconstruction shows up all the natural and functional faults of Palladio's addition. The output of 3D model construction of the Villa Pisani was a 20-minute long photorealistic computer animation (15000 frames) computed on a Silicon Graphics Origin server, visualizing the three solutions of the villa 07.

The 3D models were not made simply for visualization purposes only, rather as **architectural cognitive systems**, able to create multiple representations: interactive objects to be included in a 3D data-base or a hypertext or in web-based systems; analytical images; visualizations able to support the preservation of the building.

☐ 06
Villa Pisani at Bagnolo: solution from Palladio's drawing on the Quattro Libri dell'Architettura, showing the difference between the Palladio's drawing and the built villa (left: visualization by Marco Gaiani, 1997; right: drawing from Palladio's I quattro libri dell'architettura, Venice 1570)



☐ 07
Villa Pisani at Bagnolo 1997 computer animation: images from the movie (Marco Gaiani)

This solution allowed the development of a consistent method allowing to describe: the relationship between the existing building and Palladio's drawing; features and limits of the graphic framework provided by Palladio's drawings; the solutions that cannot be univocally solved and their possible variants; and how the building could interact with the surroundings at the design time.

An **architectural knowledge representation** could be depicted as a series of structured objects using a specific architectural lexicon. **I Quattro libri** are an outstanding example of hierarchical **architectural knowledge representation**, where structure and level of detail are systematically organized. Following this logic, the existing building and the interpretative hypotheses of the unbuilt solutions of Villa Pisani were considered as an assembly of generic objects; these objects retain a structural logic inherent and relative to the whole, embedding at the same time their constructive history. This method is certainly in line with the Mitchell's design knowledge and shape grammar, however starting point and purpose are different.

Unlike ideal models of Palladio's treatise, the starting point of Villa Pisani's models is surveyed data and geometries able to illustrate the **real life** of the building. The developed method used cubic polynomial curves and non-uniform rational beta-spline surfaces (NURBS).

Secondly, a cognitive strategy based on the idea of similarity to the real, taking advantage of Tomás Maldonado [23], theoretical thought, was set up. The aim of this cognitive strategy was not to create a generative semi-automatic system but to constantly define the level of certainty of that reconstruction, and to emphasize invariants and variables related to design, construction and a-posteriori interpretation. Due to the similarity and homology between architectural buildings and their 3D digital representations, an architectural knowledge system can describe a series of structured objects using a specific architectural lexicon, like that of structure and organization in the Andrea Palladio treatise **I quattro libri**. The use of a cognitive strategy for model construction is not only a technique to see a building as a cognitive system, the usual working hypotheses with a hierarchical structure, but also to have self-representative results.

■ **23**
Tomàs Maldonado, Reale e virtuale, Milano 1992.

The 3D modeling system developed was based on the accepted and general convention whereby structures are described as a series of structured objects using a specific architectural lexicon. Following the classification method of Tzonis and Oorschot [24] the architectural space is subdivided following their level of **abstraction** (clustering, topological and metric).

As reference, the semantic classification work applied to 3D digital modeling and developed by Paul Quintrand et al. [25] was used. They stated that the association of semantics and architectural shape is possible only considering the building as a system of knowledge: the model is extracted from its description while its representation is defined according to the objectives of the analysis. The use of this information system then let the users perform studies based on context and semantic content, providing a quick and efficient solution to the problem of presentation of aggregated and hierarchical data. Due to the different typologies of objects we defined two different groups of interpretation and structural formulation for the final architectural complex:

■ **24**
Alex Tzonis, Luc Oorschot, Frames, Plans, Representation Conceptdictaat Inleiding Programmatische en Functionele Analyse, PhD diss., Delft University of Technology, 1987.

■ **25**
Paul Quintrand, Jacques Autran, Michel Florenzano, Marius Fregier, Jacques Zoller, La CAO en architecture, Paris 1985.

A first group (2D-to-3D modeling) consisting of individual elements derived from pure geometric primitives (architectural lexicon) and built up using unambiguous logic. The primitives were put together mechanically in a pre-ordered manner to become objects like bases, capitals, shafts etc. and when assembled co-axially, they appear as a column or a series of columns supporting an entablature, etc.;

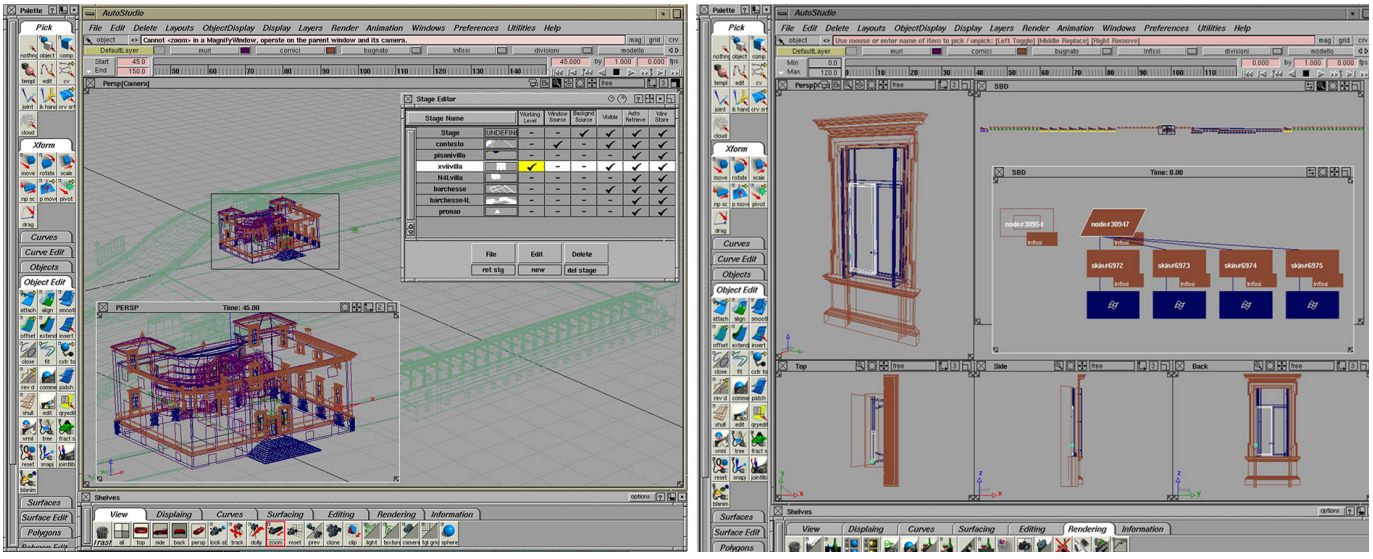
A second group (reality-based modeling) referred to the construction of complex parts, i. e. an architectural whole (a cornice, window, basement, internal and external volumes etc.). Any complex system comprising similar elements was hierarchized to determine which parts should undergo transformations.

The method was implemented using Alias Studio graph system called Scene Block Diagram 26 08 and extensively used since 1993 approaching many other cases 27.

■ 26
This was a NURBS modeler state-of-the-art, still on market and known as Autodesk Alias.

■ 27
Marco Gaiani, Translating the architecture of the real world into virtual reality and vice-versa: 7 years of experimentation with »conservation and representation«, in: Canada – Italia Workshop, Heritage Applications of 3D Digital Imaging proceedings, CD-Rom, Ottawa 1999, pp. 30–46.

☐ 08
Villa Pisani at Bagnolo: two different levels of interpretation and structural formulation of semantics defining the architectural complex (Marco Gaiani)



At the time, the 50 Mbyte 3D model of the villa did not allow any interactive visualization. We just remember the file opening time on the powerful Silicon Graphics Maximum Impact used was 7 hours. However, this solution allowed to switch quickly between the three different versions of the Villa Pisani, reusing most of geometry and materials implemented as simple variants of the 3D model scene graph. Typical example is the solution of the façade toward the courtyard.

The user was able to switch between the three different solutions simply checking different stages in the Alias stageset windows 09. Over time, the semantic organization of the 3D models allowed to generate outputs for several different uses:

simulation of many villa's features for the multimedia CD-Rom **Andrea Palladio — Le Ville**, in the **Exhibit** section able to show six themes related to the architecture of the Palladian villa: villa, site, project, architectural language, construction, and life at the villa 28 10. The user is able to leaf through texts illustrated by drawings, maps or a range of other documents contained in the database, including animated digital reconstructions and virtual visits;

interactive studies of Palladio's constructive and design villas solution by Howard Burns for the exhibition Andrea Palladio e la Villa Veneta da Petrarca a Carlo Scarpa held in Vicenza in 2005 and its catalog 29;

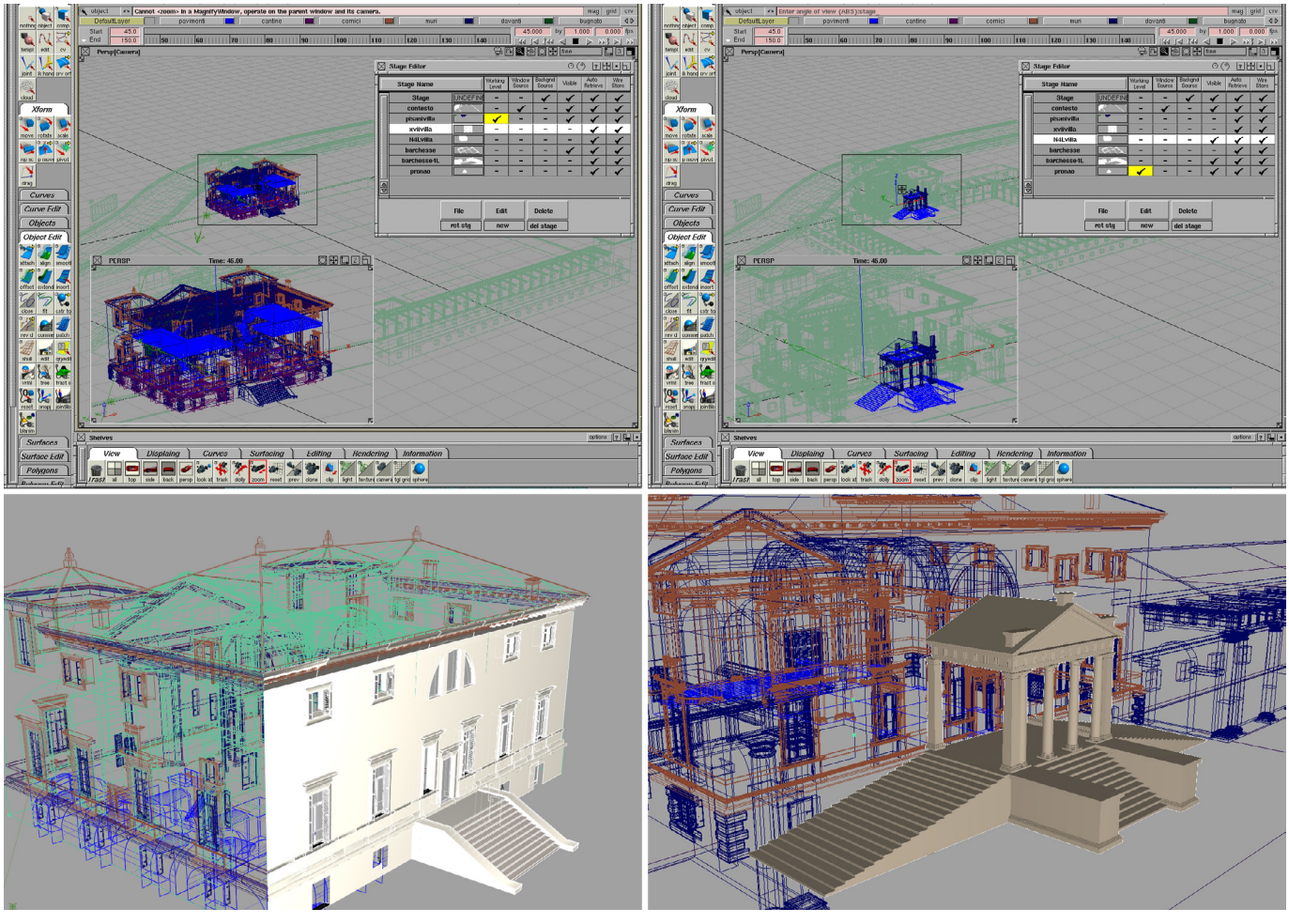
real-time rendering (RTR) side-by-side comparison of different design solutions 30.

■ 28
Guido Beltramini, The Multimedia CD-ROMs of the CISAP: A resource for the study of architectural history and for the scientific examination and promotion of the works of Palladio, in: VSMM 2002 proceedings, Seoul 2002, pp. 791–799.

■ 29
Guido Beltramini, Howard Burns (eds.), Andrea Palladio e la villa veneta da Petrarca a Carlo Scarpa, Venezia 2005.

■ 30
See paragraph: RTR techniques for design analysis and a Palladian 3D geodatabase.

☐ 09
Villa Pisani at Bagnolo: solution of the façade toward the courtyard in the two different versions. The user was able to switch between the three different solutions simply checking different stages in the Alias stageset windows (Marco Gaiani)



☐ 10
A screenshot of the Exhibit in the multimedia CD-Rom Andrea Palladio – Le Ville (Marco Gaiani)

Al di sopra del basamento si imposta il piano nobile, organizzato intorno ad una sala centrale, affiancata da gruppi di stanze minori, di dimensione e forme diverse, ma usualmente rettangolare quadrata e un'altra rettangolare più piccola.

L'accesso dall'esterno è sempre mediato da una loggia, connessa alla sala centrale, spesso compresa all'interno dell'edificio, ma a volte configurata come un pronao di tempio applicata al corpo di fabbrica. Pur essendovi ville a due piani (come villa Cornaro a Piombino Dese, progettata infatti per due fratelli) nella maggioranza dei casi il piano nobile è unico.

Il progetto

villa Pisani a Bagnolo

CREDITS
ABOUT
BIBLIOGRAFIA

EXHIBIT

LA "VILLA"
IL SITO
IL PROGETTO
IL LINGUAGGIO
LA COSTRUZIONE
LA VITA IN VILLA

CATALOG

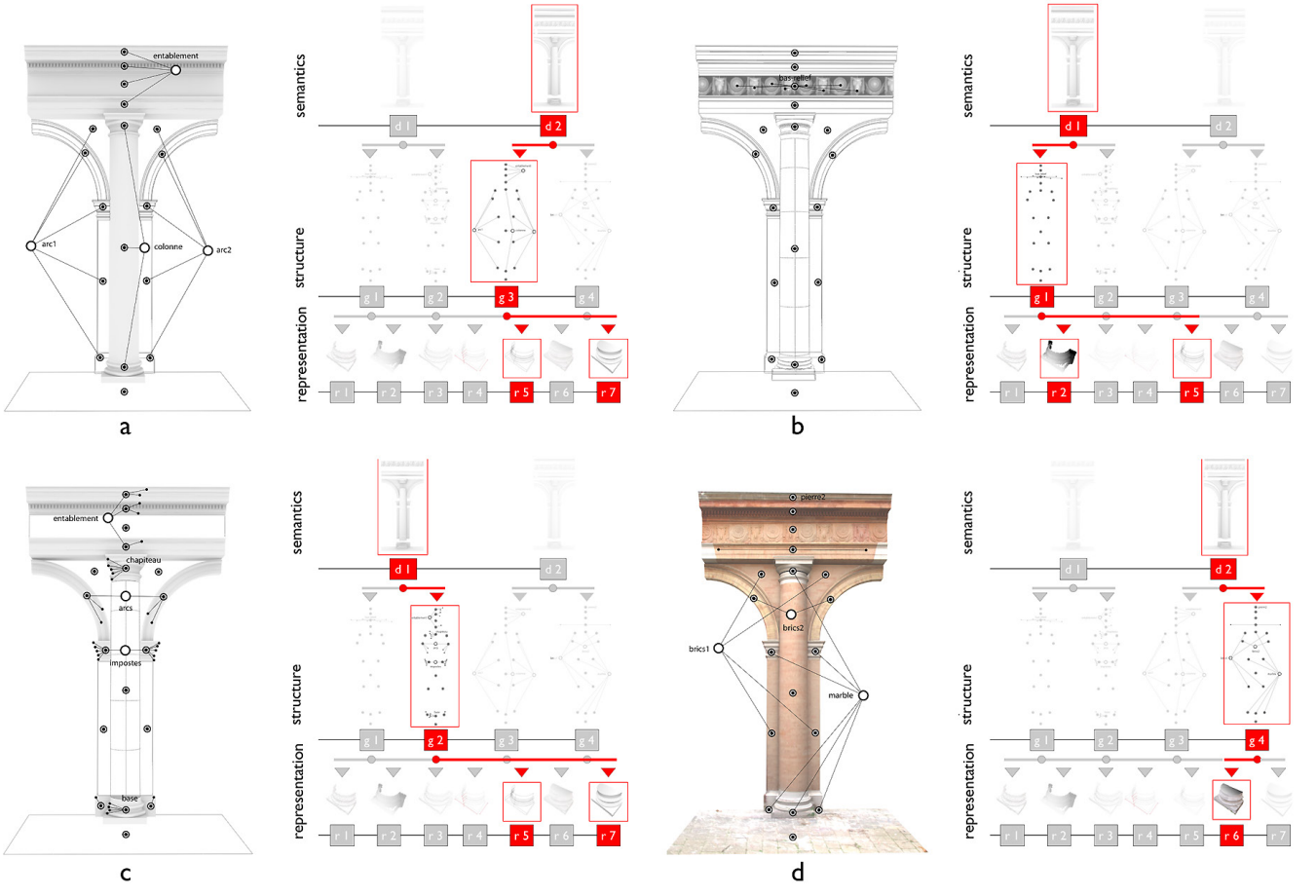
HELP
STAMPA
QUIT

■ 31
Livio De Luca, Paul Véron, Michel Florenzano, A generic formalism for the semantic modeling and representation of architectural elements, in: Visual Computer 23, 2007, pp. 181–205.

■ 32
Livio De Luca, Chawee Busarayat, Chiara Stefani, Noemie Renaudin, Michel Florenzano, Philippe Véron, An Iconography-Based Modeling Approach for the Spatio-Temporal Analysis of Architectural Heritage, in: Shape Modeling International Conference (SMI '10), Washington 2010, pp. 78–89.

Ten years later the Villa Pisani work, Livio De Luca 31 presented a methodological approach to the semantic description of architectural elements completely coherent with Ferrara's techniques but much more consistent and easy to use [11]. De Luca, furthermore, in a later work, extended the method to the structuring of heterogeneous information, including the documentation of the state of conservation, the indexation and retrieval of iconographic sources, and the analysis and representation of spatiotemporal changes 32. This will be also the development line of the 3D models developed in collaboration with the CISAAP by the group of the University of Bologna who collected the Ferrara experiences.

□ 11
3D model construction based on semantics: four »points of view« on Convento della Carità in Venezia detailed starting from the same morphological cutting. Analysis of the order (a), analysis of sculptures (b), analysis of mouldings (c), analysis of materials (d) (Livio De Luca)



II.4 RTR techniques for design analysis and a Palladian 3D geodatabase

The works at MIT, at the University of Ferrara and other around the world (we just recall studies by Livio De Luca, Alberto Sdegno 33 12 and Paolo Clini 34) demonstrated consistent techniques to study the Palladio's design strategies and many unclear key steps of his work.

However, they did not provide response to the key issues of the organization of the large amount of Palladian relevant data (Palladio drawings dispersed in several archives around the world, the largest existing photo library devoted to Palladio (over 5,000 photos), approximately 1,200 survey drawings, Palladio's writings), nor allowed a quantitative approach to the analysis in 3D of the whole **corpus palladianum**: 54 constructions spanning houses, public buildings, palaces, churches, bridges.

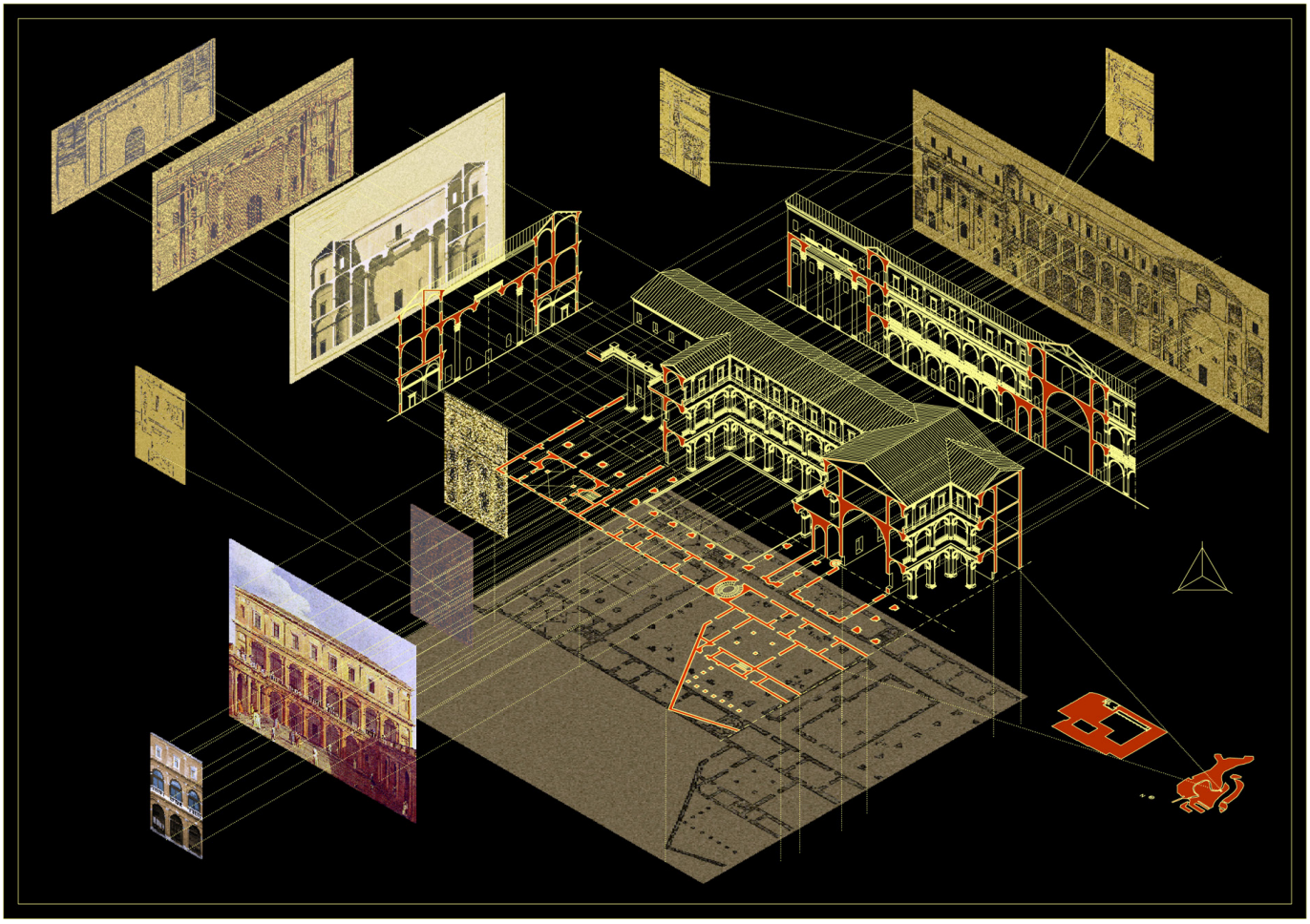
To give solution to these problems, CISAAP activated **Digital Palladio** project in 2002 with the aim to digitalize the whole Palladio's works documentation 35.

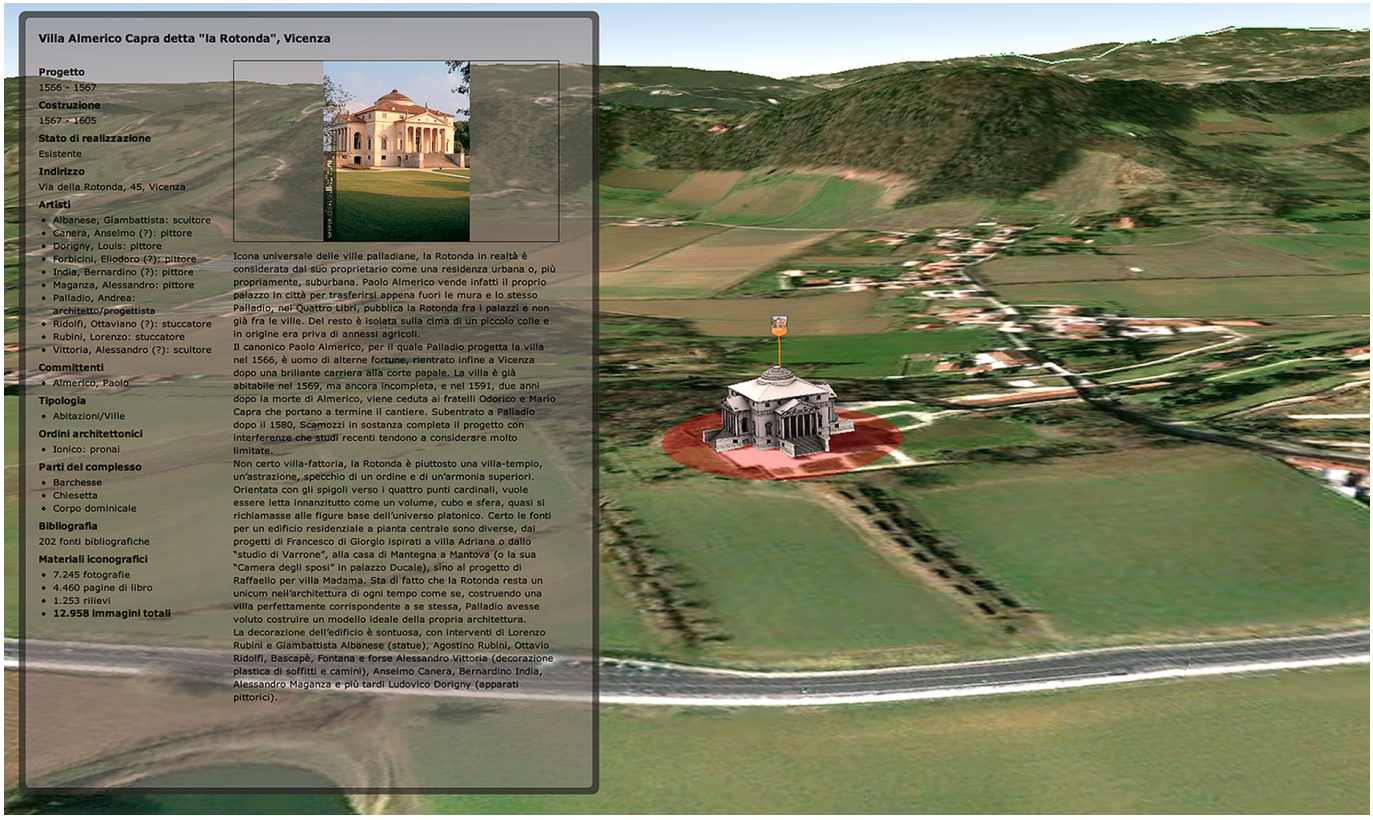
■ 33
Alberto Sdegno, Digital Palladio, Venezia 2005.

■ 34
Paolo Clini, Andrea Palladio. Per un catalogo critico dei rilievi. Storia e prospettive, in: Palladio 15208–2008 – II simposio del cinquecentenario, Venezia 2008, pp. 405–412.

■ 35
Guido Beltramini, Marco Gaiani (eds.), Una metodologia per l'acquisizione e la restituzione dei giacimenti documentali dell'architettura. I materiali per lo studio di Andrea Palladio, Milano 2003.

□ 12
Digital reconstruction of the on Convento della Carità in Venezia and iconographic sources (Alberto Sdegno)





□ 13
Andrea Palladio – 3D Geodatabase: interface with a descriptive card
(Marco Gaiani)

Mainly, CISAAP launched in 2010 the **PALLADIOLibrary** project [36], a new Information System (IS) that, using new information technologies now available to all, aimed at the unification and display of all the key materials for understanding and appreciating Andrea Palladio's work.

The core application of **PALLADIOLibrary** is **Andrea Palladio – 3D geodatabase** (AP3D), a complete 3D web geo-database based on GoogleEarth [37], where 3D models rendered in real-time support the whole IS [13]. The application was conceived as the preferred interface of the Palladian database from different output devices and working at different levels of iconicity, giving an easily and user-friendly access to individual buildings and whole information system to different types of users: tourists, architecture historians, architects, curators, and managers.

The most complex issue faced in the development of AP3D was the construction of the 3D models, core of the representation and description of Palladio works. To solve this problem, a new standardized process was developed to construct, manage and visualize the 3D models, keeping a substantial homogeneity of representation and data quality and ready to be used by different operators and researchers at different places and times.

■ **36**
Guido Beltramini, Marco Gaiani, (eds.), Palladio Lab – architetture palladiane indagate con tecnologie digitali, Vicenza 2012.

■ **37**
Micheal T. Jones, Google's Geospatial Organizing Principle, in: Computer Graphics and Applications, 27, 27 (4) 2007, pp. 8–13.

The evolved pipeline is based on three mutually linked modeling aspects (subdivisions into literally defined and / or constructed parts and visualization) that allow the construction of high-definition models, their classification, and the allocation of additional information to each architectural element, besides the geometrical-dimensional details. 3D models could be obtained from multiple and sometime integrated sources and technologies: 2D drawing plot of manual survey, photogrammetry, laser scanners [38]. Finally, we focused on the quality procedures assessment to ensure consistency and reliability of data throughout the whole pipeline, as well as a new semantic reality-based structure.

Semantic construction method used is basically described in Apollonio et al. (2010) [39] integrated with the De Luca observations [40]; it refers to the real built object and can identify highlights and describe not only the scheme but also the constructive rules.

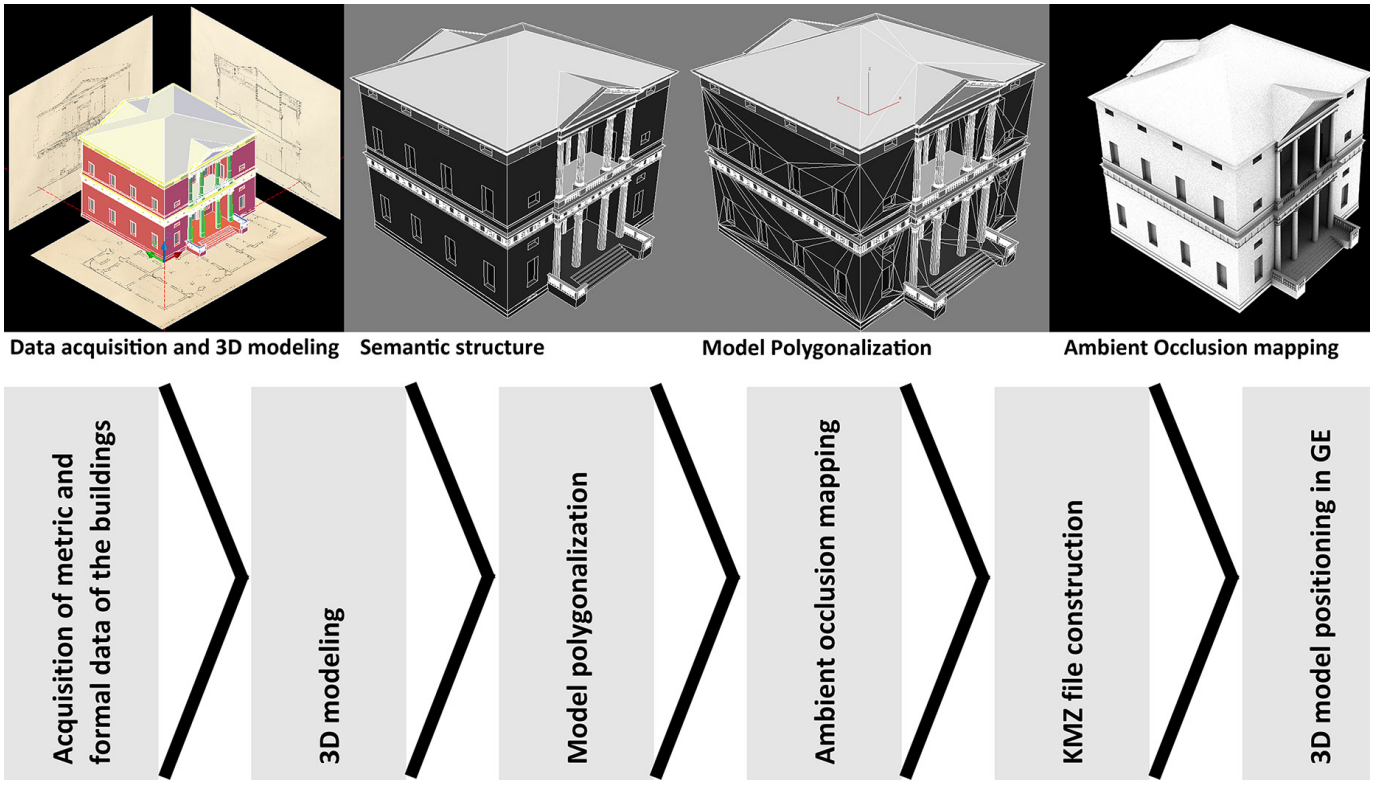
■ **38**
Fabrizio I. Apollonio, Simone Baldissini, Paolo Clini, Marco Gaiani, Caterina Palestini, Camillo Trevisan, The PALLADIOlibrary geo-models: an open 3D archive to manage and visualize information-communication resources about Palladio, in: ISPRS Archives, XL-5/W2, 2013, pp. 49–54.

■ **39**
Fabrizio I. Apollonio, Cristiana Corsi, Marco Gaiani, Simone Baldissini, An Integrated 3D Geodatabase for Palladio's Work, in: The International Journal of Architectural Computing, 8, 2010, pp. 107–129.

■ **40**
Livio De Luca, Methods, formalisms and tools for the semantic-based surveying and representation of architectural heritage, in: Applied Geomatics, 6 (2) 2014, pp. 15–139.

The final visual appearance of 3D models was conceived as a reinterpretation of the Palladian graphics evolving the contour techniques employed for the engraved plates of its treatise, excellent for 2D drawings to a solution reflecting the Palladian **adumbratio** more appropriate for the 3D visualization. AP3D 3D models are rendered using the Ambient Occlusion (AO) shading technique. 41 14

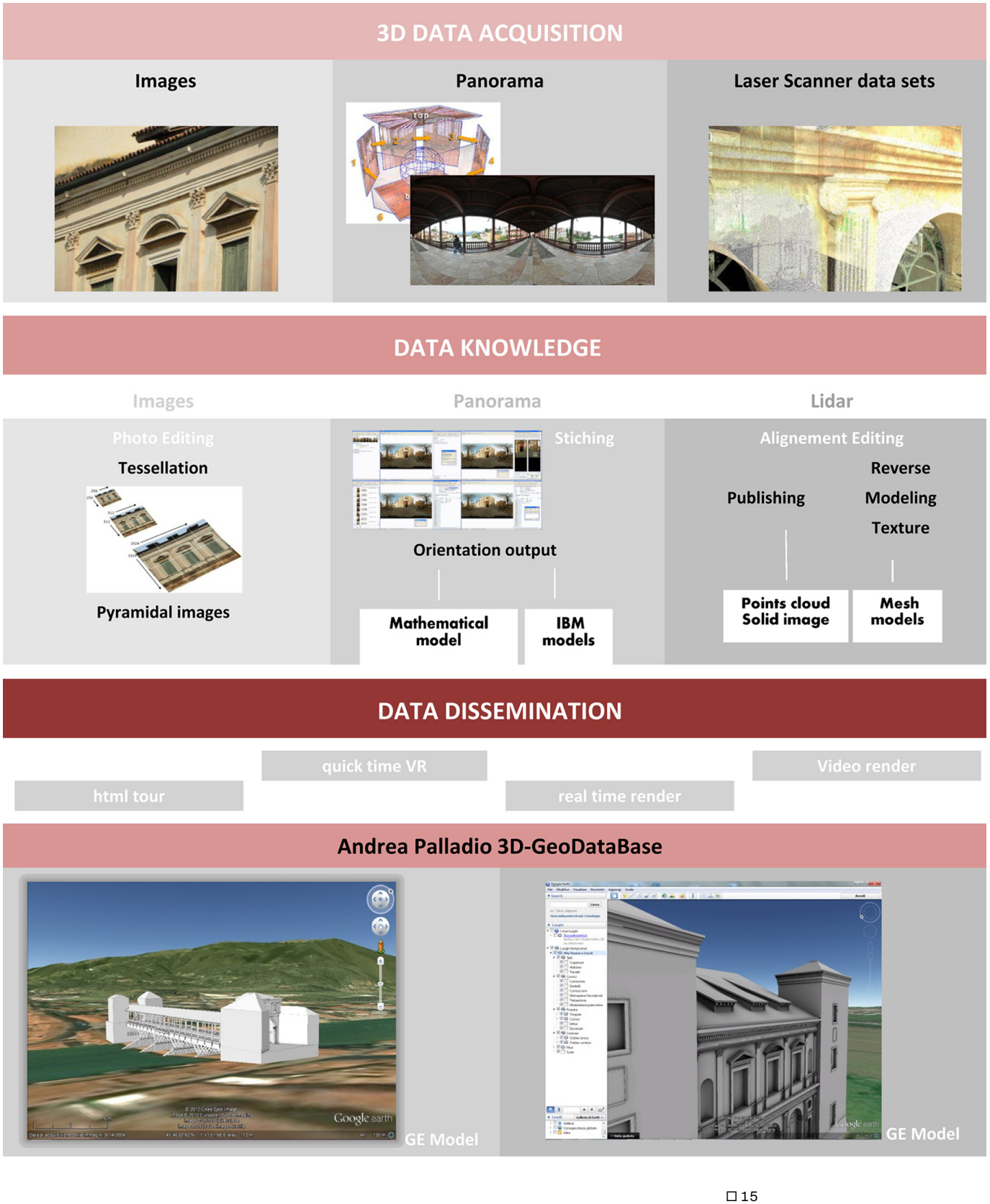
■41
Martin Knecht, State of the Art Report on Ambient Occlusion, TR, Wien 2007.



□14
Andrea Palladio – 3D geodatabase: 3D Model Construction Pipeline (Marco Gaiani)

51 high resolution semantic 3D models were made resulting as an extensive Palladian landscape able to be continuously updated with the advancement of studies. Many of the fifty-one 3D models were constructed starting from the so-called **Corpus dei rilievi delle fabbriche palladiane** drawn up in the 70s by Andrei and Ewa Soltan and Mario Zocconi. Drawings consist of a set of tables at different scales depending on the type of representation and detail (1:100 – 1:10). The 3D models of the Venetian churches (San Francesco della Vigna, San Pietro di Castello, San Giorgio Maggiore and Redentore) were made from an integrated laser scanner and photogrammetric survey carried out by the IUAV in Venice. The 3D models of Villa Valmarana in Vigardolo, Villa Trissino in Meledo, the wing of Villa Thiene in Cicogna, the bridge on the Tesina in Torre di Quartesolo and the Ponte Vecchio in Bassano, are the result of a new surveying method based on **all in one** instruments, and the integration of spherical panoramas photogrammetric and laser scanning data. 42 15

■42
Marco Gaiani, Fabrizio I. Apollonio, Paolo Clini, Ramona Quattrini, A mono-instrumental approach to high-quality 3D reality-based semantic models application on the PALLADIO library, in: 2015 Digital Heritage, Granada 2015, pp. 29–36.



☐ 15
Andrea Palladio — 3D geodatabase: a mono-instrumental approach to high-quality 3D reality-based semantic models (Marco Gaiani)

The use of 3D RTR techniques, enabling real-time side-by-side visualization comparison and interpretation of different variants and solutions, introduce new analysis and interpretation techniques of architecture exploiting two separate but complementary directions.

The first involves photorealistic images using global illumination rendering techniques; nothing more than a progress of Renaissance painting techniques and, to a certain extent, a continuation of the desire of 15th and 16th Century artists and intellectuals to investigate the world and nature using the drawing.

The second direction is the use of rendering for data visualization and involves a work more interpretative than philological, based on the idea of simplification rooted in the **model construction** operations.

The use of interactive consultation techniques RTR-based with the aim of comparison and interpretation of different variants and solutions was introduced in 2008 43. The application, reusing the Villa Pisani 3D models made in 1997, by means of the original construction techniques which fostered a long-term preservation, was intended to allow the real-time assessment of the differences between the three Palladio projects side-by-side and at a photorealistic quality of the image with a resolution twice of the original. 16

■ **43**
Marco Gaiani, Modelli di Palladio – modelli palladiani, in: Palladio 1508–2008, il simposio del cinquecentenario, Venezia 2008, pp. 396–400.

□ 16
Side by side RTR visualization of two different façade solutions of Villa Pisani at Bagnolo: left, today solution, right solution from Palladio's RIBA XVII/17 drawing (Marco Gaiani)

Among several works carried out over the years using RTR techniques certainly one of better successful is the verification of the Guido Beltramini theory that the Palladio's drawing conserved in London at RIBA and classified XVII/15r represents the first nucleus of the Villa Contarini at Piazzola sul Brenta is certainly one of the most successful. 44 17

The 3D model built to demonstrate Beltramini's hypothesis 45 allows:

→ comparison between the original drawing and the 3D model;
→ analysis of the geometric and proportional features of the 3D model;
→ photorealistic visualization of the Palladio's design into the surrounding.

■44
Guido Beltramini, Andrea Palladio, Plan and elevation of a villa for two brothers (Villa Contrarini at Piazzola?), in: Charles Hind, Irena Murray (eds.), Palladio and His Legacy, A transatlantic Journey, Venezia 2010, pp. 75–76.

■45
Fabrizio I. Apollonio, Guido Beltramini, Giacomo Fabbi, Marco Gaiani, Villa Contarini a Piazzola sul Brenta: studi per un'ipotesi di attribuzione palladiana servendosi di modelli tridimensionali, in: Disegnare Idee Immagini, 42, 2011, pp. 42–55.

□ 17
Villa Contarini reconstruction based on the RIBA XVII/15r drawing: RTR visualization of the comparison between the model and the design of the façade (Marco Gaiani)

Through the semantic structure of 3D models and the use of RTR techniques, the application is not only meant to show a realistic rendered solution of Palladio's work [18], but also to visually assess the level of knowledge of each solution used to coherently construct the model, with its flaws and lacunae [19]. Semantics specifically describe: the relationship between the existing building and a 3D image of Palladio's drawing; the features and limits of the graphic framework provided by Palladio's drawing RIBA XVII/15r; possible reconstruction theories not linked to the drawing itself; the solutions that cannot be univocally solved and their possible variants; and finally, the way in which the most plausible reconstruction theory could interact with the surroundings at the time of the design.

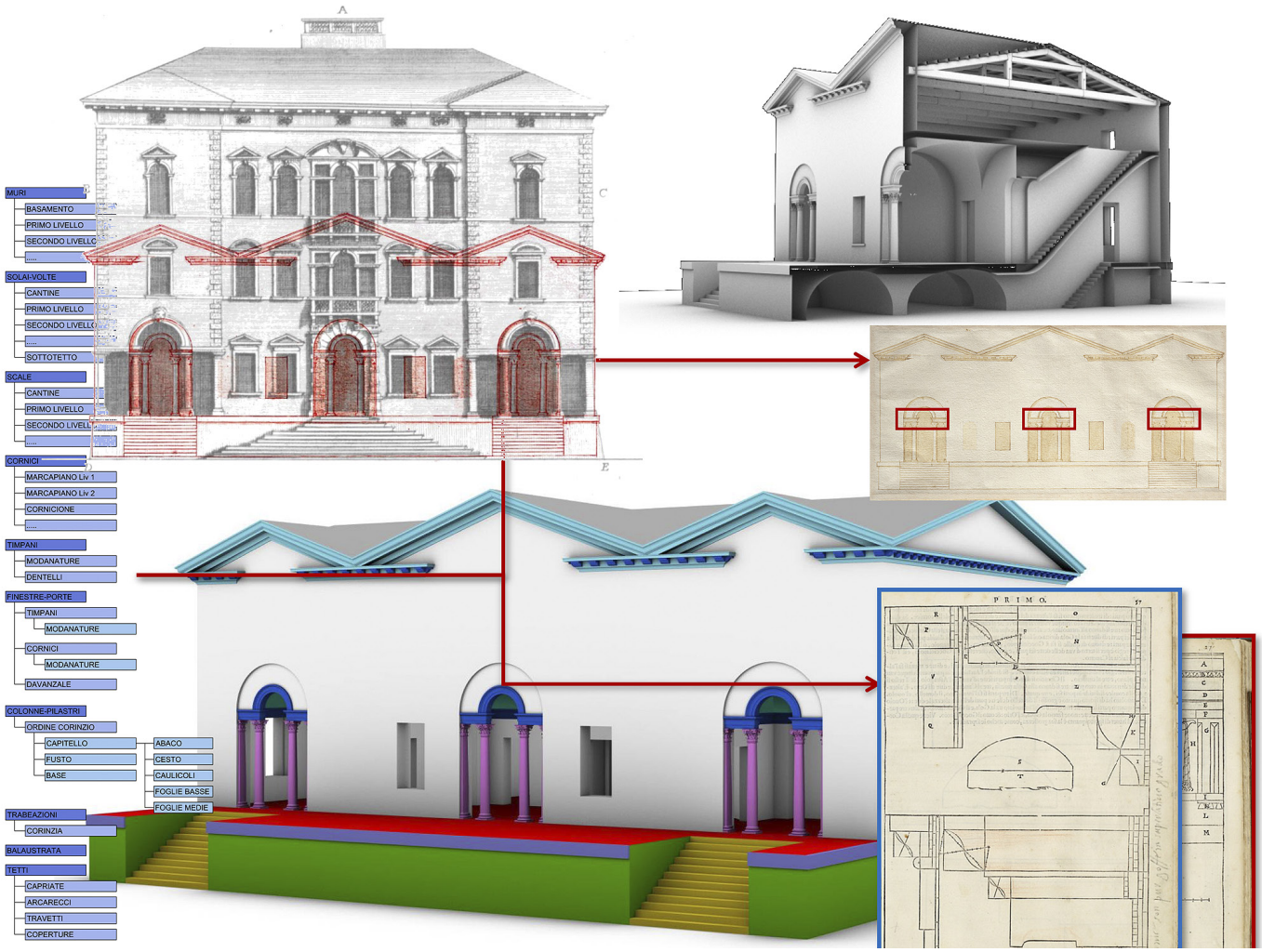
The Villa Contarini work focus also on the quality assessment procedures adopted to ensure consistency and reliability of data throughout the entire 3D model construction process, trying to face a major problem of the 3D reconstruction from multiple sources and exploiting typical proprieties of digital systems. Beyond the analysis specifically conducted (ex-post), digital systems allow the collection and systematization (ex-ante) of operations to determine the geometry of the elements that contribute to the definition of an architectural work, becoming themselves explanatory values of the geometric-formal genesis of that building.

□ 18
Villa Contarini reconstruction based on the RIBA XVII/15r drawing: RTR photorealistic visualization of the main façade (Marco Gaiani)

Further details on the data model (knowledge representation) allowing to fully understand the construction and the features of the 3D model are in this same book [46].

■ 46
See Fabrizio I. Apollonio, Conceptual modelling and cognitive process in 3D virtual reconstruction, in: Conference on Cultural Heritage and New Technologies, 8–10.11.2017, Vienna 2017.

□ 19
Villa Contarini reconstruction based on the RIBA XVII/15r drawing. The reconstruction process of Palladian drawing with its sources and face the today building (Marco Gaiani)



II.5 Conclusions

We think that William Mitchell well summarized problems, aims, goals, solutions described in this paper in one of his last essays:

»The use of three-dimensional digital modelling software, combined with rapid prototyping to create physical models, enables a more disciplined and scholarly approach to reconstruction than has been common in the past. The outcome of the reconstruction process must be a logically consistent three-dimensional object; there is no room to fudge. And a carefully structured digital model provides a framework for documenting the evidence and arguments supporting a reconstruction choice, and for showing possible variants — much as with scholarly footnotes in the editing and reconstruction of ancient texts.« 47

■47
William J. Mitchell, Larry Sass, From Drawing Collections to Virtual Museums Representing, Preserving, and Studying Architecture in the Digital Era, in: Palladio 1508–2008: il simposio del cinquecentenario, Venezia 2008, pp. 401–404.

Palladio's architecture and Palladian drawings and texts are, in this context, an extraordinary field of experimentation with their clear design thinking and their measurable and observable solutions. They provide a detailed language of architectural form, a specification by means of formal grammars, an easy interpretation, and a specific role in structuring design thinking. It's possible to observe not only specific Palladio's architecture, but to reexamine central issues of design theory giving a comprehensive and systematic treatment of the logical foundations of design thinking.

The forty years long illustrated path demonstrated these sentences from both point of view of technologies and media developed and used and of findings of investigations carried out.