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Roots of 'Parametric Thinking' in Palladio's Villas. Surveying, interpreting and visual programming the plates from *I quattro libri di architettura*

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Abstract **– In this work we want to link the considerations relating to the rectangular ratios and harmonic proportions of Palladio's plans, through the automation of the Shape Grammar rules rewritten here in Visual Programming Language. This operation allows to program generalized automatisms for the construction of some Palladian villas (e.g. Villa Thiene, Villa Sarego, Villa Poiana), cataloguing them in families mainly linked to the size of the tartan grid used (e.g. 5 x 3). This experimentation could show how algorithmic thought has distant roots, finding in the contemporary era a new digital life through software and procedures now available to the designer.**

I. INTRODUCTION (RS, MC)

When in 2008 Patrik Schumacher launched *Parametricism as Style,* the Parametricist Manifesto, a largely antagonistic response from historians, critics, theorists, and scholars, arose. They aimed to demonstrate the presence of a "parametric thinking" in the architecture of the past: it could be say that parametricism was an intrinsic feature of architecture. More recently, some scholars started to analyze both architectural treatises and historical artifacts using the new tools of parametric modelling and visual programming language (VPL) offered by the digital revolution. These analyses based themselves on real survey operations, whether they refer to existing buildings, or archaeological rest, or archival sources, or architectural treatises. The researches carried out by parametric modelling and VPL about these historical architectures have to be referred to the so called "form-making" modelling strategies.

The same path is proposed in the present paper aiming to discover the parametric relationships in Palladio's villas [1]. Starting from the algorithmic survey, with the visual programming tools we are now able to rewrite a new compositional algorithm of the shape, exploiting the potentialities expressed by a programming language, which is also visual, but able to take advantage from the digital representation methods. The added value of writing the shape using the VPL is mainly to be found in the responsiveness of the models created at the end of the process. By varying the initial inputs, new forms are generated that are linked only to

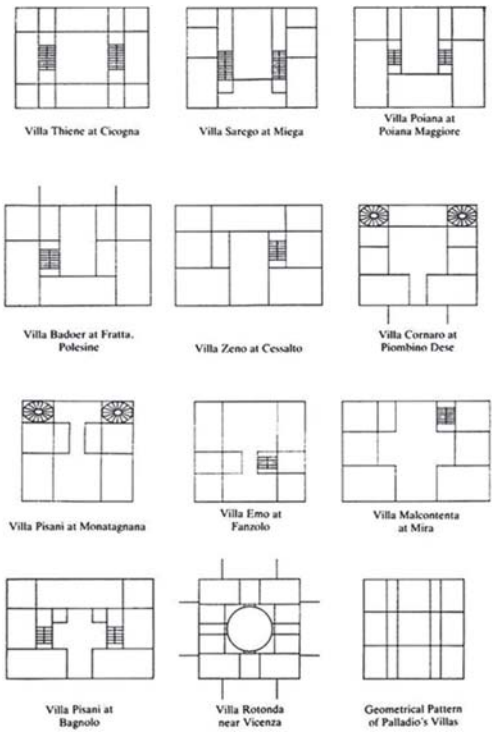

Fig. 1. Schematized plans of Palladio's villas. Source: Wittkower 1949.

the writing of the algorithm, allowing the identification of generative families.

The aim of the present phase of the research is to demonstrate the presence of parametric rules in the plans of Palladian villas, i.e. "the necessary truth, that is mathematical and immutable" [2], that in the words of Wittkower underlain their ideation.

Moreover, the experimentation broadens to achieve three-dimensional results, through the combination of VPL and BIM tools. Among the Palladian villas a case study is carried out until this outcome, aiming to realize an interpretative model applicable to the other villas.

II. Knowledge Bases and Working Methodology (RS)

From the Forties, several scholars found and interpreted the parametric thinking in Palladio's treatise, "I quattro libri di Architettura" [3]. Many of them inspire the present phase of our research, others will be taken in consideration in the future research developments, using the obtained result.

Firstly, using as documental source Palladio's treatise, it has been interlaced with the fundamental researches by Rudolph Wittkower [2]. Eleven schematized plans of Palladian villas, the same recognized and compared by Wittkower as different statements of the same geometrical formula (fig. 1), has been analyzed. They have been put in scale using the measurements found in the treatise, and the ratio between the sides of each room are highlighted. In each room, the seven ratios stated by Palladio, and that inspired by the harmonic ratios, that permeate the Renaissance culture, are also recognized. Moreover, following Wittkower, the harmonic proportions between the sides of rooms put in sequence, are evidenced. If Wittkower discovered the scientific foundation of Palladian architecture, and his pupil Colin Rowe spoke of Mathematics of the ideal villa [4], more recently George Stiny and William J. Mitchell found a parametric shape grammar generating the plans of Palladio's villas [5]. This last work has been the base for experimenting the new digital tools offered by the digital revolution to the interpretation of Palladian villas. Stiny and Mitchell's analysis is a skilful work of a Palladio's project deconstruction, Villa Malcontenta, in which the algorithmic recomposition takes place using a language to make explicit the shape's grammar. They used a visual language that progressively expresses the actions (transformations) that, starting from a point, progressively cumulate until arriving at the final shape: the planimetric layout of the villa. Their text clearly expresses a method of survey, not in terms of shape, but in terms of the logic of construction of the building, limiting itself to the planimetric aspects.

The following book of Mitchell, "The logic of architecture", published in 1990, deepened the meaning of Palladian grammar about the villa plans [6]. Mitchell highlighted a design process organized in eight main stages, from the grid definition to the positioning of walls, rooms, openings, to the ornamentation. Mitchell reasoned about 3 by 3 and 5 by 3 layouts, discovering a lot of resulting possible configurations. This method has been applied in our work by a digital algorithmic process for the determination of uniaxial symmetry. The researches of Moretti [7], carried out from the Forties, and Eisenman (2015) [8], expanded the analyses to the third dimension. Moretti, who coined the definition "Architettura Parametrica", took up Wittkower's research, and deepened the study of Palladio's Rotonda. In this regard, he proposed to graphically represent the spaces of the sequence pronaos, vestibule, and main hall, as spheres corresponding to the volumes of each room and whose center coincides with the barycenter of the volume itself [7].

Eisenman analyzed twenty of Palladio's villas from a different point of view in relation to Anglo-American critics. Indeed, he hypothesized the breakdown of unitary villas volumes into a series of partial villas elements and their important positioning in the landscape by comparing the possibility of two states: first the relationship in space of potentially ideal organizations; and second, the possibility of virtual topological conditions that arise out of a careful reading of each villa. This reading in turn fuels the discussion of each villa, producing a new theoretical trajectory from a previously thought static geometric volume to a dynamic topology of partial figures [8]. Our approach faces the passage from the analysis of the plans to that of the volumes linking VPL and BIM tools.

III. Interpreting the Treatise and the Critics by Digital Drawing (RS)

Wittkower wondering about what Palladio's intentions were while experimenting incessantly with the same elements, hypothesized that he, once he had found the basic geometric pattern for the problem "villa", he adapted it as clearly and simply as possible to the special requirements of each commission. Yet this grouping and re-grouping of the same pattern was not a simple operation, as it may appear. Palladio took the greatest care in using harmonic proportions not only inside each room, but also in the relation of the rooms to each other, and this need for the right ratio is at the center of Palladian architectural conception [2]. The scholar, through a careful analysis of the plates of "I quattro libri di Architettura", observed the importance of the written measures through which Palladio seems to want to establish proportional relations of general and universal value. The way to systematically link one room to another by means of harmonic proportions constituted the fundamental novelty of Palladio's architecture. These proportional ratios, which other architects had used in correspondence of two dimensions of a facade, or three dimensions of a single room, were used to integrate an entire building [2]. Palladio, actually, never refers to harmonic proportion as rules of architectural composition. Instead, following Alberti and Serlio, in Book I of his treatise, he established a sequence of seven rectangular ratios between the sides of the room, 1:1, 1:√2, 3:4, 2:3, 3:5, 1:2 that shape the plan of the most beautiful and proportioned rooms. It is necessary to remember that three of them, i.e., 3:4, 2:3, 1:2, are also harmonic ratios, Moreover, Palladio's reasoning widens to the heights of the rooms that could be in arithmetic, or geometric, or harmonic

Fig. 2. The seven rectangular ratios in Palladio's villas. Source: Palladio 1570. Drawing: Roberta Spallone

proportion related to the sides of the room. This expansion of Palladio's theory inspires the phase of our research devoted to the three-dimensional analysis of the case study of villa Poiana (1549), selected for testing the transition from 2D to 3D survey.

The interpretative work starts with the recognition of the compositional scheme of the eleven plans of villas identified by Wittkower. It reveals the overcoming of the radiocentric models that prevails in the mid-Renaissance treatises, as the VII Book of Architecture by Serlio [9] in favour of the models symmetric with respect to the central axis. Moreover, the dimensions written inside the rooms (that are in Vicentine feet, about 35,7 cm), allow to reduce all the plans at the same scale and compare their composition. Nevertheless, the measurements given in the plates not always are consistent with those written in the texts. Sometimes the text declares the intention of using the ratios above mentioned, but the dimensions deny this. Another important feature of the plan drawings is that Palladio attributed the same thickness to the walls, so that the scholars affirmed that it could be considered as an idealized thickness [10] [11], also observing Palladio's schematic drawings preserved at RIBA [12]. Surveying the drawings, it has been established that the wall thickness measure 2 feet. Furthermore, Rosci noted that in the designs of Palladio the written dimensions include half of the wall thickness, so the overall dimensions of the villas are the exact sum of the dimensions of each room [13]. Assumed these statements, firstly the seven ratios are highlighted on the plans (fig. 2), then other harmonic ratios: 4:9, 9:16, 1:3, 3:8 etc. highlighted by Wittkower have been pointed out.

The deepening of the analyses to the 3D features of the villas, by the case study, raises some issues related to the architectural elements, as the vaults, the stairs, the openings, and the decorative apparatus. The related discourse is developed in the Book I of Palladio and follows the orders' description.

Palladio reserved a single page for the theme of the vaults, listing six types of vaults: "There are six different forms of Arches, viz. cross'd, fasciated, flat, (those are call'd so, which are but a Section of a Circle) round, grinded, and shell-like, all which have in height one third of a breadth of the Room" [14]. Observing the figure accompanying the text, he relates the geometric shape of the vaults with their rise that is linked to the planimetric dimensions of the room and exemplifies their typologies to hypothesize different proportional relationships between the two sides of the rooms. In villa Poiana cross vaults, and shell-like vaults have been recognized. These last, are generated by four round quarter of cylinders on each side joined with a flat rectangular surface in the middle. Moreover, these vaults have a more complex shape in two lateral square rooms, where four cuts in the corners were done and were completed by two rampant groins for each corner (fig. 3).

About the stairs, Palladio stated that the minimum rise of a step has to be four ounces (about 11,9 cm), the maximum six ounces (about 17,85 cm), the minimum tread one foot (about 35,7 cm) and the maximum one foot and half (about 54,45 cm). The stairs in villa Poiana are, using the Palladian classification, straight stairs without internal wall.

Then, Palladio established that the doors must have the minimum area of 2x5 feet (about 71,4x178,5 cm) and a maximum of 3x6,5 feet (about 107,1x232 cm). The windows have to range from 1/5 and 1/4 of the rooms' length and their height must be double and 1/6 of the window's length.

The example given by Palladio considers a room 18x30 as the lateral ones in villa Poiana and states that the length of the room has to be divided in 4 and 1/2 parts to obtain the length of the window (i.e. 4 feet). The resulting height will be 8,67 feet. These measures seem consistent to those of the villas' windows.
Finally, the cornices are described by two possible solutions that have been assumed as basis for our modelling.

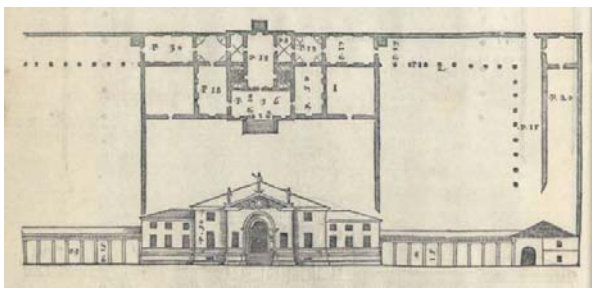

Fig. 3. Villa Poiana. Source: Palladio 1570.

IV. VISUAL LANGUAGES FOR WRITING SHAPES (MC)

Wittkower's studies of Palladio's plans reveal the parametric construction vein of the Venetian architect. Some of his architectural works, in this study, can be traced back to typological systems with a common functional program, forming families of architectures. It is therefore possible to describe some planimetric systems starting from a scheme with variable data. The scheme is composed of lines representing what we will call the geometric framework of architecture. It is that composition of primitive shapes that schematize the architectural typology. Procedures in Visual Programming Language are particularly suitable for the representation of typological models. The construction of the geometries and the introduction of variables allow to design a genesis of shape able to represent the architectural type and its variations [15]. The digital operation made possible by the new representation tools, is similar to that carried out by Wittkower in an analogical way, representing the parametric systems of some Palladian villas, where the common compositional characteristics are evident. Moreover, the vision of the different planimetric schemes highlights some dimensional variables of the environments and gives a dynamic vision of the distributive elements that slide in different positions but respectful of the typological scheme. The workflow for the construction of a parametric model of some Palladian villas includes the following operations:

1. definition of the model's geometric framework by surveying the construction algorithm derived from Wittkower's graphic diagrams;
2. parametric definition of standard and customized architectural elements to provide the volumetric consistency of the building;
3. association of the parametric elements of point 2 with the geometric framework.

The procedure described above allows the entire volume of the building to be reconstructed in parametric mode but thinking that we want to start with the planimetric system, we can articulate point 1 with the digitisation of the algorithm proposed by Stiny and Mitchell [5]. In their extremely clear contribution, the construction of the plan is marked by the following actions: grid definition, exterior-wall definition, room layout, interior-wall realignment, principal entrances-porticos and exterior-wall inflections, exterior ornamentation.

In this text we want to link the considerations relating to the shape of Palladio's plans expressed in the previous paragraph, through the automation of the Shape Grammar rules already expressed by Stiny and Mitchell and rewritten here in VPL. This operation allows to program generalized automatisms for the construction of some Palladian villas (e.g. Villa Thiene, Villa Sarego, Villa Poiana), cataloguing them in families mainly linked to the size of the tartan grid used (e.g. 5 x 3). This experimentation could show how algorithmic thought has distant roots, finding in the contemporary era a new digital life through software and procedures now available to the designer. The construction rules that enrich the algorithm are organized hierarchically in such a way that the first level of construction influences the subsequent constructions, passing from a general parametric control (e.g. the spaces between the grids) to a detailed parametric control (e.g. the thickness of the walls). The definition written in VPL respects the workflow expressed in the paper taken as a reference, but trying to make it "efficient" by exploring the peculiarities of the new grammar adopted (fig. 4). Therefore, the axial symmetry of the planimetric system is guaranteed during the input management phase. The data initially introduced are the lists of the module dimensions according to the proportions deduced from Palladio's drawings of the villas chosen (e.g. Villa Thiene, Villa Sarego, Villa Poiana). Along the dimension x, perpendicular to the vertical symmetry axis, the sequence of the modules is not complete, the dimensions of the modules present on one side of the axis and half of that straddling the axis itself (semi-list) are collected. The uniaxial symmetry can be rewritten in the new algorithm adopting the properties of list management, speculating the semi-list in a negative semi-list that summed returns the complete list. On the contrary, the sequence of modules along the y-direction is described completely. As we write the algorithm in the VPL language it is possible to identify several nodes where the new grammar allows variations to ensure greater efficiency and guarantee future automatisms. The relationship between the numerical sequences, identifies the grid with variable parameters, where the input parameters are lists of numbers that define the villas in their proportional relations so that, replacing the input lists and maintaining the definition, it will be possible to obtain plans of architectures that belong to the same typological family.

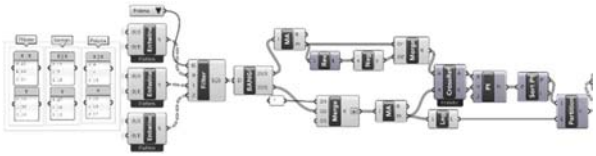

Fig. 4. Portion of the digital algorithmic process for the determination of uniaxial symmetry. Coding: Michele Calvano

V. EXPERIMENTS (MC)

More broadly, Mitchell in his 1990 book [6] expresses the need to establish a possible shape grammar. The book presents an ante litteram computational logic with which to explain systems of rules using diagrams. A grammar to detect the existing relational systems within classical architectures. Mitchell with his language is able to reveal the compositional genesis of projects through the explanation of constraints and transformations. Operation that facilitates the conception of the mental model, but which are limited to a static sequence of graphs. An original writing that follows the compositional rules established by the grammar he experimented with within the text.

The ability of the past to express a grammar of the parts through proportions and transformations is easily described by contemporary visual programming systems. Today we are able to constitute a continuous flow of information assuming variable parameters within the algorithm; therefore, the output is not unique but changeable into a family defined by the code. The plurality of the output images contrasts with the grammar of the

new language; the attention of the modeller moves from the output to the process that leads to the generation of the set objective: the process is explicitly designed in a digital environment. In other words, by explicit drawing we mean the procedures useful for the representation of the algorithms that lead to the construction of the models [16]. The model can be considered a three-dimensional image of dynamic entities, changeable because parametric. The explicit digital representation of the procedure allows the attention to be focused on the generating archetype and not only on the generated architectural object.

Also, in Mitchell's book there are examples of semantic reading of the parts constituting the building; the grammar generated reveals the functional relationships between the elements. Overall, these rules are useful for synthesising the shape, functions and attributes of architecture into a synthetic structure that can be interpreted; a written language that can be easily stored [6]. A sort of information enrichment whose storage did not take place directly with the digital model of form, which is what happens today with Building Information Modeling. The grammar used by Mitchell as a coding tool can be used in the opposite way to decode a synthetic language, an experiment carried out in this text working on Palladio's Villa Poiana. The procedure adopted by us involves the following operations.

- Data survey

The database for the reconstruction of the parametric 3D model of Villa Poiana was Palladio's treatise: the graphic works are those shown in fig. 4. For the morphological and dimensional aspects of the parts not represented in the figure, but also for further confirmation of the information on the image, we referred to the parts of the text in which the architect describes the relationships between the architectural elements that make up the buildings. For all the parts of the villa not adequately described in the treatise, we used the 1978 survey tables preserved by the Centro Internazionale di studi Andrea Palladio and drawn up by A. Soltan, E. P. Soltan, M. Zocconi.

- Modeling of parametric objects and architecture recomposition

The ordinary procedures for creating parametric objects in BIM software do not cover most of the classical elements present in past architectures. The experimentation carried out on Villa Poiana has therefore led to the study of digital construction algorithms composed for the definition of new families of parametric objects. In figure 5 we see the parametric 3D model of the vault that covers the square rooms on the ground floor of the villa. The main body is a cloister vault intersected, on the four angles, by pairs of cylindrical rampant groins. The geometric construction processes were written in VPL, automating an algorithm that divides the parameters into two groups, the one relating to the dimensional characteristics of the cloister vault (main parameters) and the one relating to the dimensional characteristics of the groins. Palladio's rules for the construction of this architectural element are now saved in a BIM modeller (VisualARQ); the object can be adapted to cover different rooms, simply by modifying the parts of the element and respecting the construction conceived by the architect. The collection of families that can be modified has made it possible to quickly

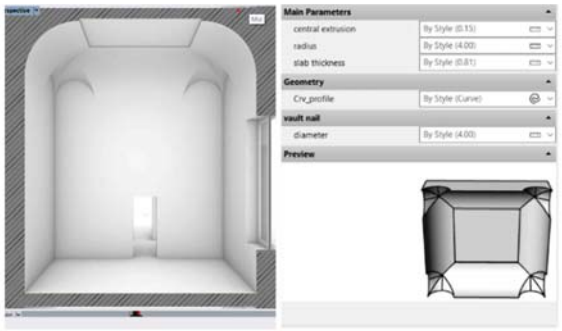

Fig. 5. Customized parametric element. Coding: Michele Calvano

resolve the architectural recurrences present in the building, as the cross vaults, by changing the parameter values (fig. 6). The use of customized objects (serliana, column, lintel, cornices, friezes, etc..) and standard objects (wall, window, slab, roof, door, staircase, etc..) has allowed the 3D reconstruction of Villa Poiana (fig. 7). Remember that the BIM process is based on the drawing of entities (points and lines) for the insertion of architectural types. Each element will relate to the path with modes defined during the process: alignment with respect to the entity, angle of rotation along the axis and other parameters that change in relation to the inserted objects.

- Encoding

Now let's think about the reverse process, moving from the 3D model to its maximum discretization in points and lines. According to what has been described, we can extract, from the semantic model, the insertion paths of the architectural objects: the walls are represented by fragmented lines in the plane, the lintels by their own axes, the cornices by polylines that move in space; the pillars are reduced to vertical segments while doors and windows become points. (fig. 8). With this procedure we obtain a light "elementary representation", useful for the process

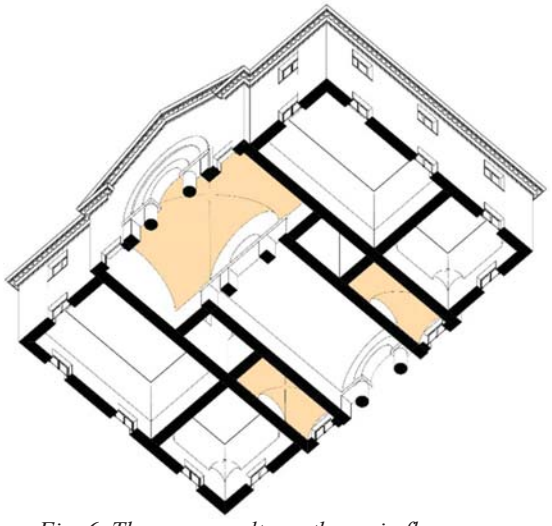

Fig. 6. The cross vaults on the main floor are represented by the same object varying the size parameters. Modeling: Michele Calvano

Fig. 7. 3D model of Villa Poiana made up of customized and standardized architectural types. Modeling: Michele Calvano

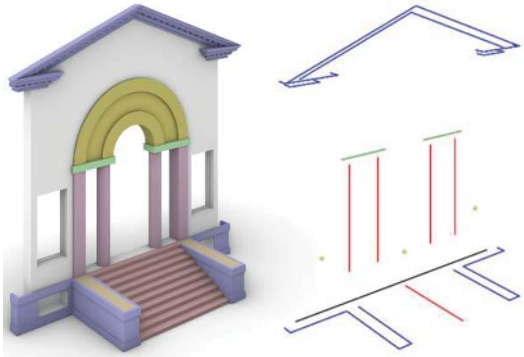

Fig. 8. Elementary representation of Villa Poiana's semantic model. Modeling: Michele Calvano

of archiving and transferring the shape. In addition, this representation allows an easier reading of some architectural qualities such as the rhythm of the parts and the density of the elements that make up the examined artifact. Then we combine the geometrical path with a system of meta-data, for this reason the procedure provides for the enrichment of the curves and points, associating to each extracted geometry an alphanumeric string that collects all the parameters useful for the restitution of the objects in space. In figure 8, the horizontal black line is the trace of the wall, identifying the start, the end and the path. We associate to the curve the following text string described by an ordered grammar:

wall|{18, 0, 0}&{-18, 0, 0}|2&35|External

filled out according to the following rules:

Obj | {A}&{B} | a&b | Style

Obj is the architectural category (wall, stairs, window, floor...);
A and **B** are respectively the start and end points of the path;
a and **b** are the relationship between the architectural object and the path (inside, centred or outside) and the maximum height of the wall;
Style is the set of characteristics that define the architectural category.

The paths enriched with this information represent a new shape grammar that communicates directly with the needs of the BIM environment.

VI. Conclusions (RS, MC)

The scalability of the process on other Palladian villas could be the immediate challenge of our research. Moreover, this study allows to represent in an elementary way the parametric models of the architectures through a related system of signs and texts. Writing can be done directly by enriching the graphic entities with notes, following the grammatical rules set in advance, or using a code capable of deconstructing architectural objects in synthetic paths enriched with parameters written according to the described rules. The experience focuses on possible developments of the method by hypothesizing a semantic survey of the architectures for the reproduction of the model in BIM environment. Each element that composes the building could be described by parameters that relate the object to the graphic entity. At the same time, it is necessary to provide a description of the different architectural categories to be associated with the paths and points.

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