Reconstructing Palladio's Villas: A computational analysis of Palladio's villa design and construction process

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Abstract

This project is ongoing research focused on finding a method of reconstruction, using computational devices to build, represent and evaluate Palladio's un-built villas in three-dimensions. The first of *The Four Books of Architecture* contains text and images explaining Palladio's design and construction systems in the form of rules. These rules were written for masons and craftsmen of the 16th century, offering one and two-dimensional data on each of Palladio's villas, palaces and churches. The Four Books offers a general treatment of the villas; however, it is missing most of the physical construction data needed to execute a full reconstruction of an un-built building.

Many architects and historians have attempted to reconstruct Palladio's work in drawings, wooden models and computer imagery. This project presents a new method of reconstruction through the definition of construction rules, in addition to shape and proportional rules defined by previous scholars. In also uses 3D printing and texture mapped renderings as design tools. This study uses the Villa Trissino in Meledo as a test case for the process. The end product is a presentation of a method for reconstruction in the form of a three-dimensional analysis of Palladio's design and construction rules. The goal is to recreate all 24 of the villas found in the *Four Books* with the same method and rules as a demonstration of qualitative and quantitative input and output from a computational device.

Keywords

Palladio, Computer Modeling, 3D Printing, Computer Rendering

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1 Introduction

This project is a follow up of two papers written by Wittkower and Stiny, on methods for reconstructing Palladio's villas by rules, shape and computation [1]. This paper adds to the theory by reconstructing the villas in three dimensions verses two, using computer modeling and three-dimensional printing. The process requires information beyond the programmatic line representations presented by Wittkower and Stiny. This paper will demonstrate the process used to reconstruct 30 of Palladio's villas in the form of computer modeling (Figure 1). Each resulting villa was represented using a variety of output devices such as computer rendering, conventional plans, sections and elevations on paper and three-dimensional printing. This paper will also demonstrate how Palladio's text could be applied to the reconstruction of an entire villa exclusively by rules, from the foundation to the roof. Most important is that the rules used to reconstruct each villa have been rewritten here in a format that allows for a direct application to a computer program or shape grammar. This paper does not claim that Palladio's rules will lead towards a perfect reconstruction. Instead it is a discussion of a process of qualitative and quantitative evaluation and design choice.

2 Villa Design: The First Two Books of Architecture

From 1538 to 1570 Palladio designed over 30 villas throughout the Veneto, twenty-four of which are recorded in the form of drawings in the *Four Books of Architecture*. Bertotti Scamozzi recorded the remaining six villas in the 18th century in the form of etchings. Most important is that Palladio wrote the rules and drawings for the Four Books after the villas were built. The drawings reflect what he wanted the buildings to be - not the built

Figure 1. Process of sketch to CAD to three-dimensional product representation (3D Print)

condition. Of the thirty drawings, only 19 were built, and of those only two resemble any of the drawings. Most of the built work differed dramatically from the drawings found in the *Four Books* or in Scamozzi's text [2]. Some of the built works are missing the barns, towers or porticos. Again the goal here is to reconstruct Palladio's ideal intentions (the drawings in the *Four Books*) and not the built conditions, by the rules expressed in Books One and Two. There are three facts relating to the drawings that make reconstructing Palladio's villas a challenge:

- Palladio created the drawings and text in the Four Books of Architecture after the buildings were built. So the drawings in the text are a representation of how Palladio wanted the villas to be and not a representation of the built condition.
- The drawings are in constant conflict with themselves. Dimension strings do not add up to over all sizes, and the drawings contain little information on the buildings' physical construction or how the rules were applied.
- It is difficult to define the rules: what are they, how do they work in construction and design; what are the unit measurements that Palladio uses to define sizes of objects, and how do these objects work by the rules in a space or spaces.

Of the twenty-four villas (Figures 2 and 3) there are two types - the country villa or farm villa, and the urban villa. The country villas were composed of a main house and barns, set at the outer ends of the site. The barns extended from the main house towards the front of the property ending with a wall and a small opening aligned with the entry of the main house. Country villas were farms, whose income offset the costs associated with owning such an expensive piece of property in the countryside. The area within the barns was used to grow expensive crops and care for livestock. Urban villas such as the Villas Foscari and Rotunda were used for entertainment and as an escape from the hectic pace city life. They did not have barns (Figure 4).

For both the county and urban villa, the main house contained three levels of service. The main level, or the one elevated from the street level known as the piano noble, was used for entertainment, and as sleeping quarters for the patron. The second floor contained apartments for ser-
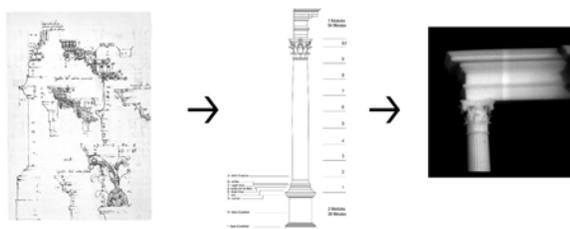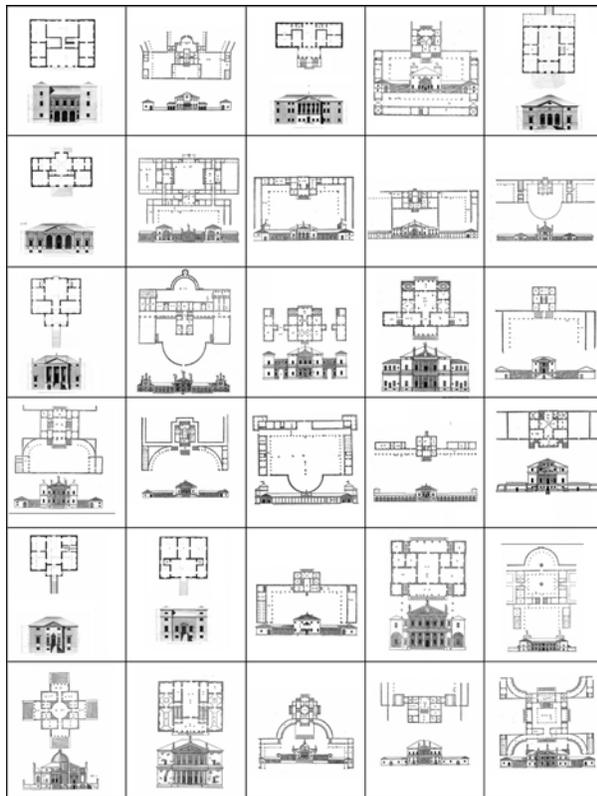
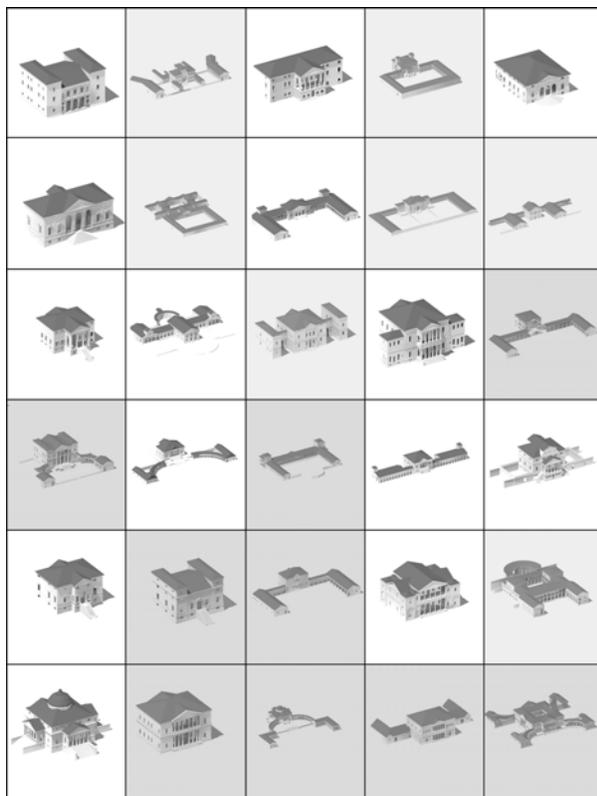*Figure 2. Palladio's original drawings*

Figure 3. Villa models: built in white, partially built or unbuilt in gray
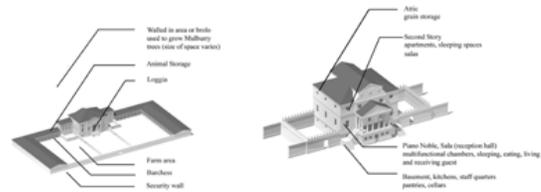

Figure 4. Country villa (Pojana) and an urban villa (Foscari)

vants and storage space for grain. The lower level was used for cooking, storage and cleaning. Spaces were organized symmetrically around a hall, such that all spaces on the right were the same as those on the left [3]. Principal spaces (loggias, halls, and courts) were seen as the most beautiful, to be placed in full view upon entry [4].

3   The Construction Process

The construction of walls, ceilings, roofs and basements requires information not always found or clearly determined in the *Four Books of Architecture*. Materials are acquired through surveys of the built conditions, measuring and documenting the built conditions and interviews with noted historians [5]. In addition to determining the construction material, the process must also contain methods for checking rule application during the process and in the resulting model. In summary, the process involves qualitative and quantitative methods for evaluating and testing the process and resulting model.

The process used here involves three steps starting with a *villa manual* and concluding with a three-dimensional representation known as a *villa model*. The villa manual is a clarification of rules from the *Four Books*, rewriting and illustrating each rule in the form of a simple line of text. This manual contains all of the programming, construction and ornamental rules needed to reconstruct a villa from a site plan. The first step is to reconstruct the site and villa plan in the form of a line drawing (Figure 5). The second step is to apply construction rules to the line representation of the plan in order to create a digital representation of Palladio's design intensions. The third step is to reconstruct a digital representation of the elevation from the previous digital plan and the elevation drawing in the *Four Books*. Finally, three dimensional *construction rules* and *ornamental rules* are applied to the plan and eleva-

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Figure 5. Reconstructing the Villa Pojana plan in line form from the site and barn on the left to the reconstruction of the final plan in line form on the right

tion drawings leading to a *villa model* representing of half of the final villa (Figure 10). The villa model is used to create plans, sections and elevation drawings for measurements, in addition to a three dimensional print and renderings of complex spaces. Throughout the process each rule taken from the villa manual, or rule invented by the author or others is recorded on a spreadsheet.

3.1 Reconstructing the Floor Plan

Palladio's villas can be constructed from a two - dimensional line drawing once the construction procedures are known. This part of the system is a based on the use of a set of parametric shapes, systematically applied to the plan diagram (Figure 5) once the proportions and line drawing representing the plan has been constructed (Figure 6-1 – plan diagram). The construction system is used to create a finished plan of walls, ceilings, porticos and stairs. These shapes are plan views of construction items and new rules created by the author. New rules must be written to fill the gaps for general rules written by Palladio. These rules are scalable, stretchable rules representing the design or construction that are dependant on the completion of the previous set of objects on the plan for their parametric assignment. The process requires the assignment of nine steps, each with a series of rules from the villa manual that can be applied to the plan. The final representation is a quantitative representation from Palladio's plan drawing in the Four Books.

Plan Reconstruction Steps (Figure 6)

1. Assignment of spaces to the plan diagram
2. Ceilings notation
3. Wall thickness notation
4. Portico
5. Columns and arches
6. Stairs and stair pedestals
7. Door notation
8. Window notation
9. Detail notations

3.2 Reconstructing the Elevation

Palladio's elevations are pictorial representations of the plan, projecting and adding elements from the piano noble. A closer look at the plan and elevations demonstrates that the two drawings do not match. Elevation lines are off from the floor plan or sometimes drawn differently from the plan. This part of the system for reconstructing the elevation is focused on transforming to a digital representation in nine steps, each representing some aspect of the construction, such as wall height variation and column location. Most are focused on a pictorial representation of the parts by locating windows, doors, pediments, moldings and entablatures. Finished sizes are not of the
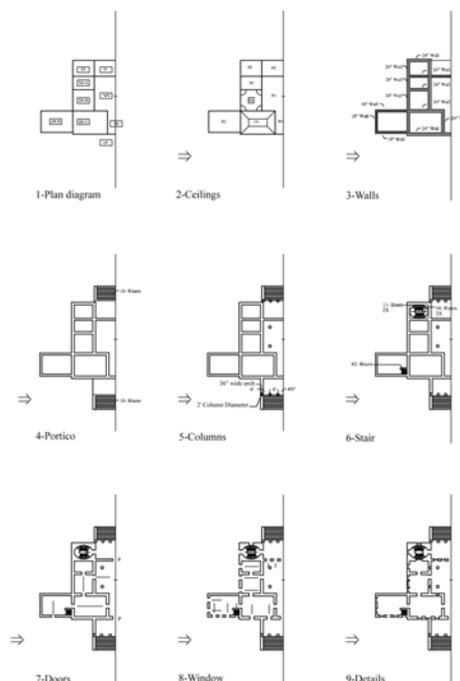

Figure 6. Reconstruction of the Villa Cornaro plan drawing from a line representation (Figure 6-1)

highest concern. Here the goal is to create a pictorial reference for heights and object locations.

Elevations Reconstruction Steps (Figure 7)

1. Initial Shape
2. Walls and Floors
3. Cornices
4. Portico Steps
5. Columns
6. Moldings
7. Doors and Windows
8. Roof and Pediment
9. Details

3.3 Constructing the Villa Model

The *Queen Anne Grammar* [6] and the *Frank Lloyd Wright Grammar* [7] use parametric grammars to specify shapes related to the style of the architect. The difficulty with the use of these grammars here is that the origin of the sizes for the shapes used in the grammar is unclear. There is little documentation defining the sizes of the objects and the reasoning behind their fitness requirements. To address the issue, this study has created a manual containing variables missing from Palladio's drawings (see 4.0 Villa Manual).
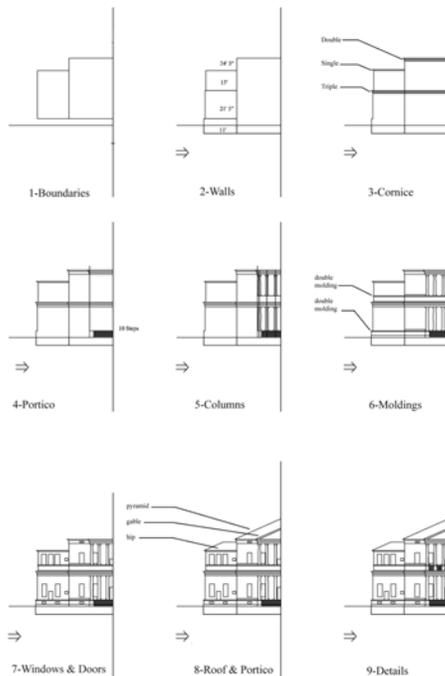
There are twelve steps toward constructing the final villa model. Each step requires sizing and location information from the reconstructed plan and elevation drawings. The part is created in three dimensions from information found in the villa manual. A building part is assigned a set of variables also listed on the spreadsheet from rule variables defined in the illa manual. The rule application is not formed from pre made objects combined to make a final product, but formed from procedures and profiles in Palladio's style (fig 8).

Villa Construction model Steps (Figure 8)

1. Initial plans
2. Walls
3. Ceilings
4. Cornice
5. Portico
6. Staircase
7. Columns
8. Moldings
9. Doors
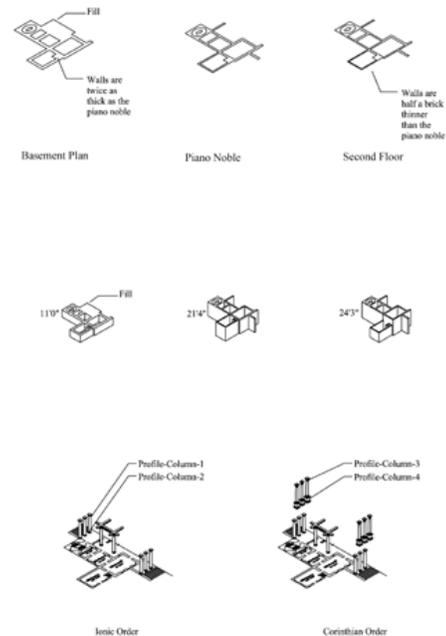10. Windows
11. Details
12. Roof

Figure 7. Reconstruction of the Villa Cornaro elevation

Figure 8. Three steps within villa model reconstruction (initial plan, walls, columns)

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4 Input - Manual of Rules

The *Four Books of Architecture* breaks rules up by object, proportion and spatial ordering. The villa manual is written in a similar format with more illustrations and more simplified representations of the rules. It is broken into 16 sections based on the Vicenzentine brick, (means of measuring objects such as walls) and mathematical rules used to define ceiling heights or window opening sizes. Within each section of the manual is a rewriting of the rules from the *Four Books* or a new rule needed to construct a detail or a space not mentioned in Palladio's text. A typical series of rules from the villa manual is written in the following format:

Rules for stairs (Figure 9)

8.1.pa - Staircases may not obstruct other places, nor be obstructed by them [8]

8.2.1.pa - They should be hidden from those that enter the house[9]

8.2.2.pa - They should be in a place so that the most beautiful part of the house is seen first [10]

8.3.1.pa - Three openings are required in staircases [11]

A typical rule contains three sets of numbers and text. The number on the right of the rules indicates the rules section, and rule division within that section. The "pa" refers to a rule written by Palladio. A rule labeled "ls" or "sm" is a rule authored by someone else. In this study the manual of rules is based on three rule types: *plan programming rules*, *construction rules* and *ornamental rules*.

5 Output - Representation

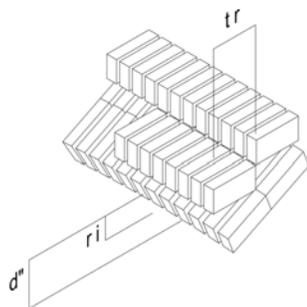The case study at the end of this paper is presentation of the reconstructed villa using four methods of representation and evaluation, each method addressing qualitative and quantitative issues [12]. These representational methods address Schon's points on action-in-reflection in that this process is one of learning by doing [13] The concept of representation is that the more opportunities offered to visualize the design, the better the design results. Filmmakers and artists follow a similar process by changing the viewer's position in relation to the artificial world with devices from stereoscopic glasses to virtual reality. Their mission is to visually engage the viewer in the subject matter by changing the viewer's point in relationship to the object being viewed [14]. Here the four methods of representation include rule graphs, also known as spreadsheets, used to record object variables and rule equations, 3D printing of the model file (Figure 11) from the 3D model (Figure 10), followed by 2D documentation and fi-
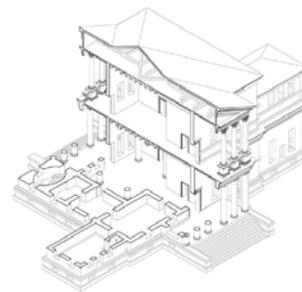

Figure 10. CAD representation of the completed Villa Cornaro villa model

Figure 11. 3D printing techniques used to view models in physical form. Smallest model is a sketch representation with very little detail; largest model is a detailed representation of the villa showing column and ornamental details

Figure 9. Rules for a stair construction, D = riser height & brick thickness, tr = tread depth

nally renderings (Figures 30 and 31) used to visualize areas of spatial conflict.

6   Case Study: Reconstructing The Villa Trissino, Meledo

This case study is a presentation of four attempts to reconstruct the un-built villa Trissino in Meledo (Figure 12), reflecting how the villa would have been built using the rules in the villa manual. The three previous reconstruction attempts were evaluated in renderings or 3D print form only. Result from each study differed slightly based on different interpretations of the rules by different people. The first attempt was a simple representations constructed for a CD-Rom project (Figure 3). The villa model had no interiors or details such as column or cornice moldings. The second reconstruction was undertaken in a workshop the following year. Students reconstructed parts of the villa, later combining those parts to create a full villa model. The final results were composed of interior and exterior renderings and a three-dimensional printed model. There were no attempts to record decisions or a documentation of the final model. The third version, completed by Isaac Persley, an undergraduate architectural student, was a research project focused on building by the rules and recording the steps in graphic and textural form. The rules used in this study were recorded on a spreadsheet along with a drawing file defining the application of the rule visually in the form of step-by-step pictorial documentation. It was also printed three-dimensionally. The fourth and final version was created using methods defined in this paper. There are one, two and three-dimensional records of all decisions used to reconstruct the fourth villa model as well as a three-dimensional print and renderings of the central space.
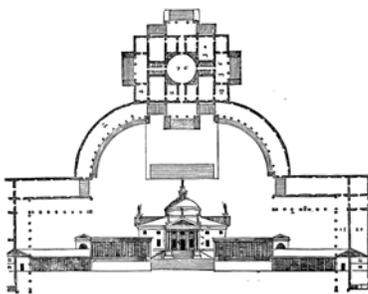

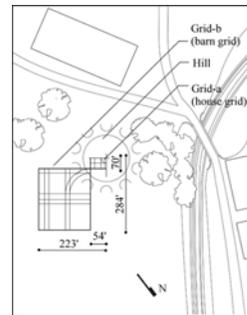*Figure 12. Palladio's plan of the Villa Trissino in Meledo*

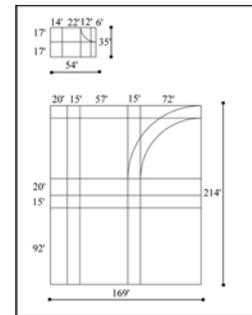*Figure 13. Site plan of the Villa Trissino with grid-a and grid-b*

Figure 14. Grids-a and grid-b

6.1 The Reconstruction

To start, the reconstruction an initial grid (a & b of Figure 13) for the main house was placed atop the hill along with a barn grid at a lower point. These grids are used to define the spacing of the walls and columns. The measurements for the villa plan were taken from Palladio's drawing (Figure 12), while the barn grid was an interpretation of the dimensions (Figure 14) from the drawing there are no measured drawings of any kind for this building. The barns are divided into two sections, one circular and the other half square. There are two methods that could be used to find the center point of the circular barns. The first method is to add the distance between the columns and the diameter of the column defining the barn circumference.

The second is to measure the distance from the edge of the steps leading to the lower terrace to the first column in the circular barn. The length of the barn is found by adding the columns and their diameters. Bertotti Scamozzi's drawing was referenced for the number of columns and the spacing between the columns to define the length of the barns. The villa barns also sit alongside of a thin waterway, specified in Palladio's description of the villa [16]

Once the basic layout for the wall grid along with dimensions was established (Figure 14), the process of adding reconstruction begins starting with the plan (Figure 15). The only area of conflict within the plan reconstruction was in the connection between the house and the circular barn. It is unclear how the two were connected in the Palladio's drawings. In this solution, the attempt
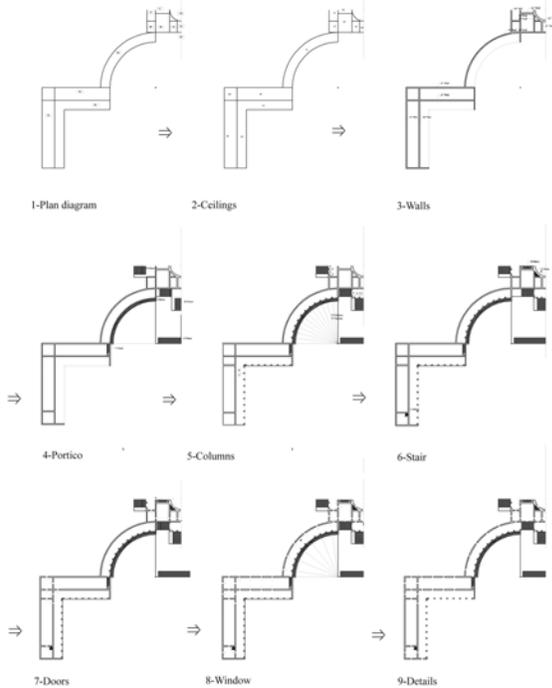
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Figure 15. Plan reconstruction derivation

Figure 16. Elevation reconstruction derivation

was made to join the barns to the outer wall of the main house.

The elevation did present some problems in height definition, which varies substantially between the two barns and the main house (Figure 16). In addition to the variation in heights of the barns, the dome became as much of a construction issue as it was a design issue. The dome is drawn in the *Quattro Libri* with a straight line at its base, where the roof of the villa meets the dome, similar to the drawing of the Rotunda. There are no rules for the height of the dome, nor rules for its construction. Here again, another conjecture is made to define the height of the dome. In this case the guess is set at 72' to the top of the dome, the same dimension as the inside radius of the barns (Figure 15).

Model construction is broken into 12 parts as mentioned earlier. Here the main conflict expected to be resolved in the modeling process is the construction of the large dome over the central space. Additional areas of conflict are the stair construction, basements, junction between barns and the house and the roof of the main house.
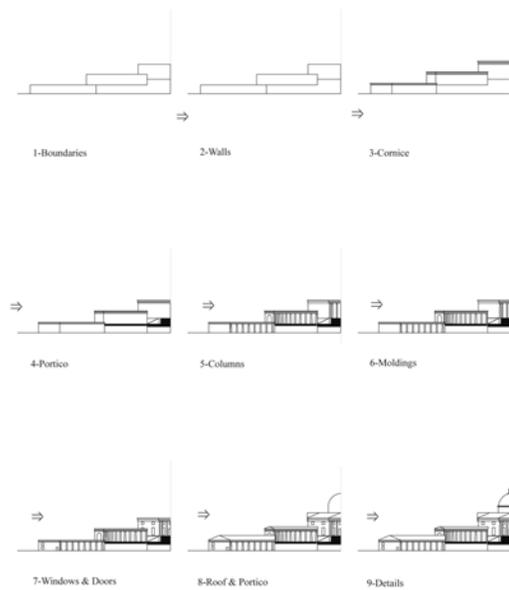
6.1.1 The Initial Plan
Although the first level of the plan shows the barns and the basement as one piece, the site separates the villa and its into three separate pieces: the basement, the upper barn and the lower barn. The walls at the basement of the villa follow the rules system for walls, which states that they are to be twice the thickness of the walls at the piano noble. (Figure 17).

6.1.2 Walls
The floor-to-floor height is missing from the original Palladian drawing for the piano noble and the barns. However he does give dimensions for the height of the walls from the piano noble to the bottom of the roof cornice. Here 17' was given to the first floor, one to the floor thickness and 8'-0" was given to the upper story. In this case the conjecture for the basement wall height was taken from previous studies defining the basement at 11'-0" in height. The barns were given heights of 15' for the lower barn and 15' for the upper (Figure 18)

6.1.3 Ceilings, Vaults and Floors
The only ornate ceiling in the villa is a barrel vaulted entry hall. It turns out that there are two

rooms with the potential of supporting a vaulted ceiling-the entry room and the small outer room, adjacent the connection to the barns. The middle space is a double height space similar to a large palace space with a flat ceiling. Basement vaults are semi-elliptical vaults (Figure 19).

6.1.4   Cornice

The cornice is the most complicated part of the assembly. Each cornice type (c1, c2, etc.) is composed of three design conditions - an extrusion of the profile, a cap condition at the corners where two cornices meet and a reverse cap condition where two cornices meet in a corner. Composed of two parts, the Corinthian order is customized in four different ways. The first of the Corinthian orders is used for the balcony projection under the portico (c2); the second is used at the rotunda (c3), the third is the most ornate (c4), in this case placed under the pediment; the last is a flattened version with the least ornamentation, and it is used under the roof (c5). The most complicated connection or joint is at the portico. Here Palladio extends the ornate entablature (c4) over the columns away from the flattened cornice (c5) that surrounds the walls (Figure 20).

6.1.5   Portico and Steps

There are three different portico stairs, each with its own function and layout. Types (s1) and (s2) are formal types leading to the porticos of the villa. Types (s3) and (s5) are service stairs leading to the upper and or lower barns. Type (s5) is a formal stair dividing the two gardens. The greatest conflict is in (s5) which is modeled differently than Palladio's original drawing. Palladio's drawings showed a set of stairs heading into the lower barns. This gave little room for a landing. The solution here calls for a switch back stair leading to the lower barn (Figure 21)

6.1.6   Staircases

There are three types of stairs, each made of the standard brick supporting system, but there is question as to how the formal stair might have been constructed. Palladio shows the stair as a wrapping rectangular stair without an inner wall. It is not clear how it would support itself with out a wall, so one was added in this study (Figure 22)

Figure 17. Plan Reconstruction using wall notations from the plan reconstruction
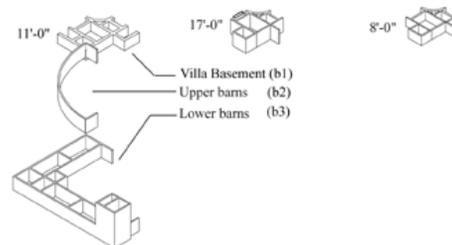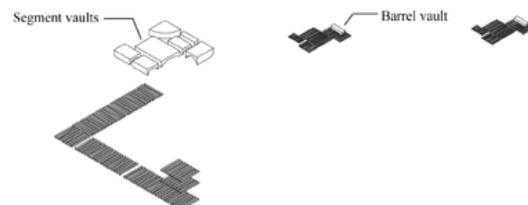

Figure 18. Wall derivation
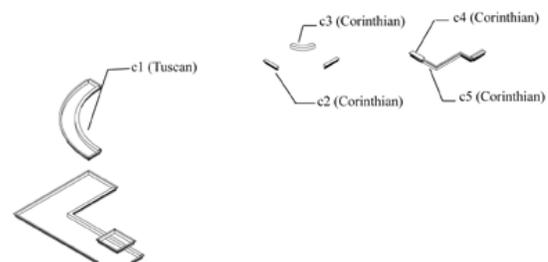

Figure 19. Ceiling derivation

Figure 20. Cornice types

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6.1.7   Columns and Arches

It is unclear as to what orders Palladio might have used for the barns, and for the main villa. Palladio specifies that the loggias are to be of the Corinthian order and that the barns are Tuscan. Bertotti Scamozzi challenges this by saying that the upper barns were designed by Palladio to be of the Ionic order and that the lower barns were meant to be of the Tuscan Palladio does not assign an order to the half columns in the dome. In the Four Books he states "*There are some half columns in the hall, that support a gallery, into which one goes from the rooms above; which by reason they are but seven feet high, serve for mezzati* [17] " Bertotti Scamozzi lists the order under the dome to be Corinthian. It is most likely that the real challenge is the dome and not the orders (Figure 23)

6.1.8   Moldings

There are two molding types (double and single) surrounding the lower levels of the villa and barn (Figure 24).

6.1.9   Doors

Room doors worked fine when installed by Palladio's rules. The formula for the principal doors did not work at the second story, the top of the doorway conflicted with the ceilings. The height of the opening and archway at the colonnade level of the barns had to be altered to compensate for the large entablature (Figure 25).

6.1.10   Windows

The generic window size generated by the rules was used in the upper and lower barns. Windows at the upper level of the house was not generated by a Palladian rule (Figure 26).

6.1.11   Details

Here, two principal door types are used, the scroll being the most formal of the two. Balustrades and newel post are used at the balcony level (Figure 27).

6.1.12   Roof and Pediment

The pediment is of the Corinthian type angled at 23.2 degrees,(Figure 28).

6.2 Results and Conflicts

With the exception of the internal workings of the dome, the final model was a successful representation of the Villa Trissino (Figure 29). An
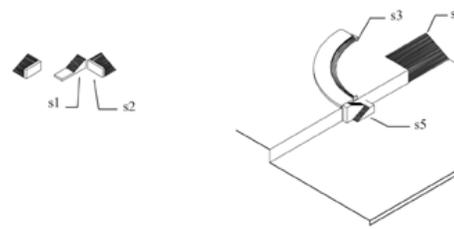

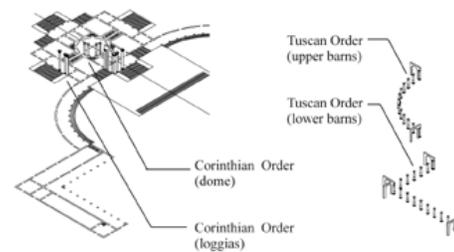*Figure 21. Porticos and exterior stairs*

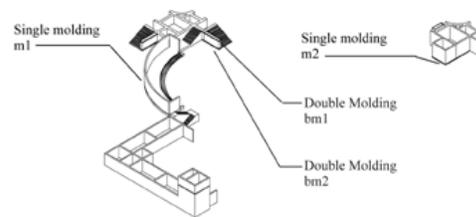*Figure 22. Interior stairs*

Figure 23. Columns and arches

Figure 24. Molding Reconstruction

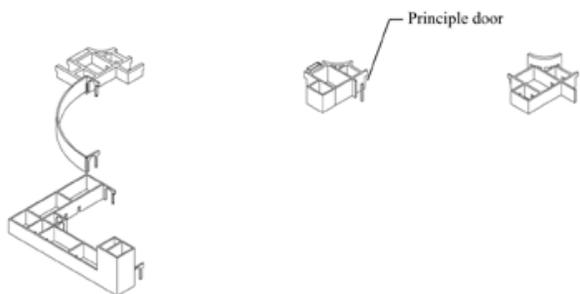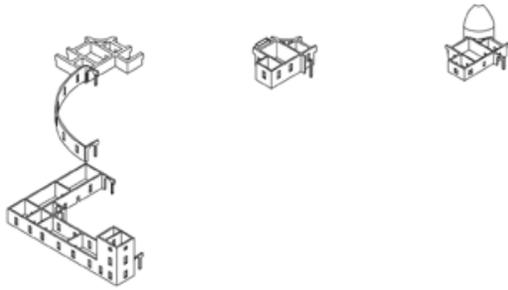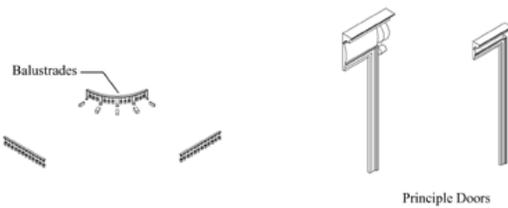*Figure 25. Doors*

Figure 26. Windows

interior study presented two complications (Figures 30 and 31) in the construction of the dome and details. First, there are no rules for defining the height of the dome. Although the Villa Rotunda is rendered with a similar dome, the two cannot be compared in construction or design. The Rotunda's dome is drawn almost as if it were metal with little wall space between the base of the dome and the top of the villa roof. The
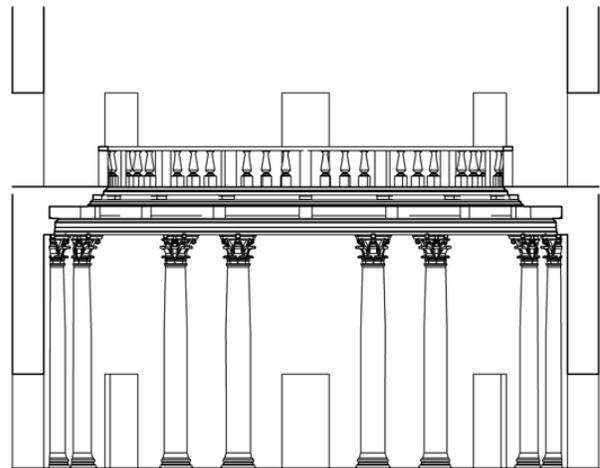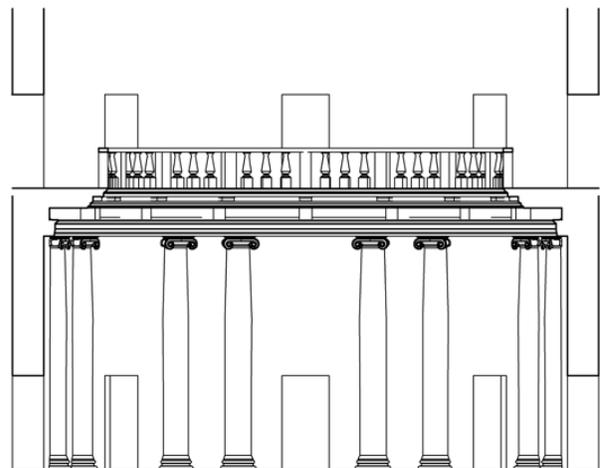

Figure 27. Details

Figure 28. Cornice, roof truss and roof

Solution - A
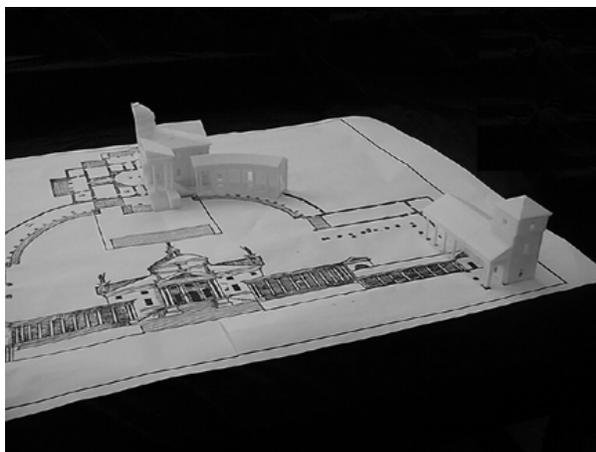
Figure 29. Three-dimensional print from the CAD model

Solution - B

Figure 30. Proposals for the Corinthian and Ionic orders at the dome

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Trissino dome has walls extended far above the roofline for the main house and the dome has a radius lower than that of the Rotunda. Palladio's drawing shows the Villa Trissino dome with moldings and details around the upper portion of the dome, which could mean that the dome was composed of brick not metal. Here the height was defined as 60' from the rotunda floor to the ceiling of the dome. The second conflict is over the half columns in the central space. Palladio does not specify an order. Scamozzi speculates that the columns are of the Corinthian order while Burns defines the order to be Ionic. The two possible orders are tested in this next section.

Figure 31. Rendering of the central hall with half columns in the Corinthian Order

6.3 Interior Study

The question here is what was the order of the half columns? The possibilities include the Ionic and the Corinthian orders as mentioned by Scamozzi and Burns. There are two references that can be taken from other dome spaces similar in composition to this villa. The first is the Tempietto Barbaro at Maser, which happens to also have a portico of the Corinthian order and a domed space articulated with half columns also in the Corinthian order. These half columns support a balcony of thin balustrades, above with no supporting newel post. The second space is similar to the design of the Villa Rotunda, which is of the Ionic order on the outside and frescos with columns of no particular order on the inside. The inner wall below supports the balcony, lined with balustrades and newel posts but not columns. Here the two are tested qualitatively. In conclusion, there is not a logical reason behind the selection of column types. These choices cannot be reduced to a purpose in the design based on structure, construction or visual satisfaction.

7 Summary of Findings from the Villa Trissino

As simple as it sounds, fitness served as a major conflict in the execution of the rules. Conflicts were the project's greatest asset as they lead to design investigation or invention. Palladio's designs thrived on conflicts between the rules. Adhering to major design rules while breaking lesser rules forced him to invent new design solutions to classical design problems. Design occurs at the junction of conflicting rules. Unfortunately computational rules are much more rigid, containing many fitness requirements. Little has been written on the issue of fitness and rule, also referred as a constraint model [18] If the process of reconstruction were a linear rule operation, starting with the site and ending with a pyramid style roof set atop villa walls, each rule would define a new object that must be aligned precisely with the previous component. As the model is constructed the program would be able to calculate each component and adjust the size or insertion for each component automatically through fitness extensions to each rule. Fitness challenges the extent of the rule by requiring a certain amount of flexibility in the execution of a rule. But if the rule is too

flexible is cannot be defined as a rule of a certain category or type. The challenge and creativity is in writing the rule, not in its execution. In this study fitness pertains to two or more objects that come in contact with other objects, requiring that one or more objects fit inside, next to, along side of or between two or more objects [19]. The question here is how to break down rule conditions based on fitness and degrees of fitness.

8   Future Work
In conclusion, this paper is a presentation of an un-built villa in many dimensions constructed by Palladio's rules. These rules will also be used to create 29 other villas at the same level of detail. The process will also help to examine the rule conflicts as well as add to rules established in this study. This project also demonstrated that a re-construction needs two types of rules - construction and design. Construction rules are predominately parametric instruments used to construct objects once origin points have been defined. Design rules in this project are used to organize the plan and ornamentation application. At both the level of construction or design, real design decisions happen when rules conflict. What makes the process even greater has been the methods of representation used to construct and evaluate each conjecture. Three-dimensional printing of objects calls for more information on the side of the architect leaving little room for ill defined conjectures.

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Notes

1. Stiny/Mitchell 1978 p. 6
2. Scamozzi, B., 1976
3. Palladio, A. 1965 Book I, Chapter 21 par. 1
4. Palladio, A. 1965 Book II, Chapter 2 par. 1
5. Most of the interviews were conducted on Howard Burns from the University of Venice or James Ackerman of Harvard University
6. Flemming, U. 1987
7. Koning, H., 1981
8. Palladio, A. 1965 Book I, Chap 28, par 1
9. Ibid., par 2
10. Ibid.
11. Ibid.
12. Tufte, E R, 1997
13. Schon 1987
14. Crary, J. 1990 p.39
15. Mitchell, W J., pp. 137-153
16. Palladio, A. 1965 p.54
17. Ibid, p. 51
18. Gross, M 1987
19. Ibid., p. 95