Constructing a shape grammar. The Ducal palace façade

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This paper shows the way the Ducal palace façade shape grammar was built, evidencing some steps involved in the process, its derivation and partial outputs gained from the grammar evaluation.

Keywords: *Alberti, shape grammar, rule base design, design automation, transformation in design*

INTRODUCTION

After 4 decades of shape grammar research there is not (m)any document showing systematically the process of shape grammars construction. This article aims to trigger the subject in this particular field, showing not just its relevance in terms of enlightenment of a procedure (if it is possible), but also, the necessity to provide future grammarians with a synthesis of others approach. To illustrate it, a brief presentation of the main steps taken to achieve the Ducal palace façade in Vila Viçosa, Alentejo, Portugal grammar and its interpretation is presented.

The construction of the Ducal palace façade in Vila Viçosa, Alentejo, Portugal took place circa 1532/1537 extending the existing palace called Paço de D. Jaime (after 1513).

It was commissioned by D. Teodósio I, having 110m long facade with 23 bays, being one of the longest in Iberic peninsula of its times. According with its patron, the formal and ornamental solution should be in romano style.

Several of the architects and builders involved in the design, such Nicolau de Frias, Pero Vaz Pereira and Manuel Pereira Alvenéo (Teixeira, 1997), may have knowledge of the Renaissance style.

Theresearch present in this paper was part of Alberti Digital research project finished in September 2013. The goal of the project was decoding Alberti's treatise De Re Aedificatoria (Alberti, 2011) by inferring the corresponding shape grammar using the computational framework provided by description grammars (Stiny, 1981) and shape grammars (Stiny and Gips, 1972) and the transformations in Languages of designs (Knight, 1994) and the formalism involved in such transformations.

The main propose was to compare the grammar of the treatise with the grammar of actual buildings to determine the extension of Alberti's influence on Portuguese architecture in the counter-reform period, comparing the grammar of the treatise with the grammar of existing buildings to determine the extension of Alberti's influence on Portuguese architecture in the counter-reform period (Kruger, 2011). The Ducal palace façade shape grammar is part of a wider grammar named column systematization shape grammar.

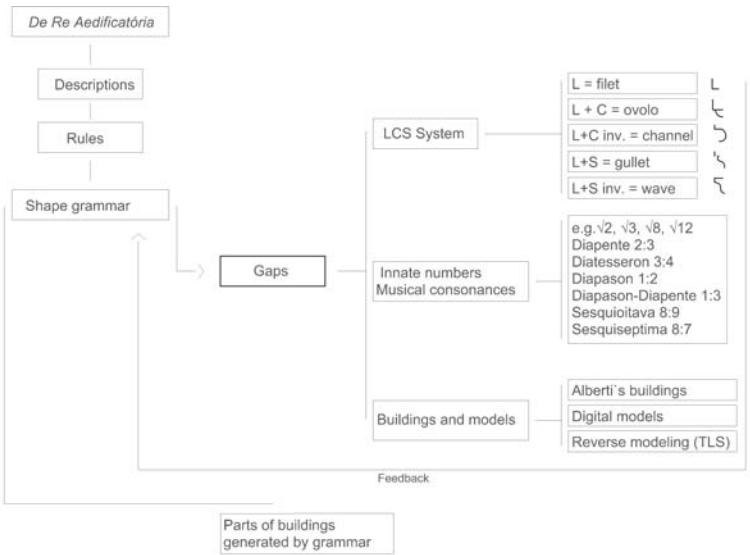


Figure 1
Fill in the gaps diagram.

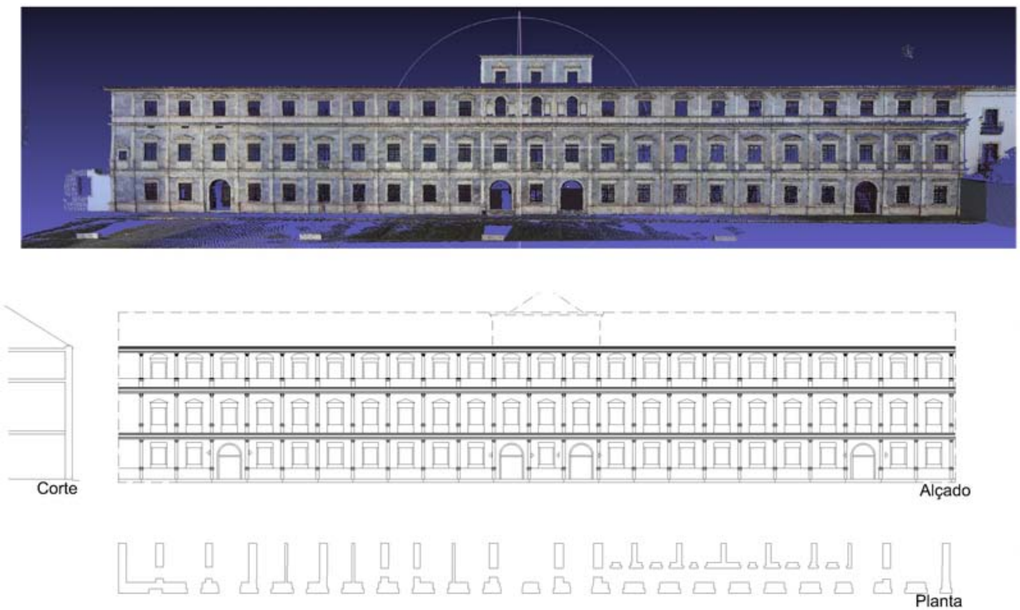


Figure 2
Point cloud model. Elevation, plan and section of the Ducal palace façade.

METHODOLOGY

The Ducal palace façade shape grammar is a parallel grammar that used different grammars to establish part of their rules. Two of those grammars rules were extracted from Alberti`s treatise (the column system and the intercolumn shape grammars). A third generic grammar was constructed to provide rules specifically to apply those grammars.

This paper will briefly show 4 different phases of work. Structurally they are organised as: 1) The elements used to construct the grammar; 2)The generic rules used in to generate Ducal palace façade; 3) Computational implementation and visualisation of the grammar; and finally 4) Evaluation process.

NOTES ON THE SHAPE GRAMMAR CONSTRUCTION.

The treatise can't provide all the information needed to build a grammar able to generate the desired facade. By that fact a strategy was adopted to full fill those blank spaces in the treatise. That is the passages with contradictory descriptions or even erased passages or even lack of information. A strategy was prepared called fill in the gaps (FITG). Looking closer to FITG it is possible to see diagrammatically (see Figure 1) the steps needed to build such a grammar. Ducal palace in Vila Viçosa was the building mentioned to be generated with the grammar. There was a previous survey of the building using a phase based laser scanner (FARO Focus 3D) and 24 different stations were considered from which 8 point clouds were done. A merging of all this point clouds may be seen in Figure 1.

Constructing a grammar is all except a straight pass. In this process it was used the LCS system, the musical consonances and the numbers descripted in the book IX, chapters 5 and 6. Finally, information was gained from real buildings and models made out of those buildings. See diagram 1.

The LCS system is a system described by Alberti at Book VII Chapter VII. It represents the way to generate the ornament mould with letters, like: an L that does a Fillet, a L+C does an ovolo, a L + C (reversed) does a channel. A L+S does a gullet, and finally a L+ S (reversed) does a wave.

The numbers represented in the Book IX that where taken in consideration are the ones from musical consonances representing a system of proportions, like: 2:3 (Diapente); 3:4 (Diatesseron); 1:2 (Diapason); 1:3 (Diapason-diapente); 8:9 (Sesquioitava) e 8:7 (sequiseptima). Also taken in consideration were the Innate proportions represented by the roots $\sqrt{2}$, $\sqrt{3}$, $\sqrt{8}$, $\sqrt{12}$ e $\sqrt{16} = 4$.

The data used to analyse the different buildings from Alberti was based in photographic surveying, 2D drawings and some measurements taken in the site. The same procedure was taken at the Portuguese architecture in the counter-reform period. Two of those buildings were surveyed in detail using a reversed modelling process. With that a cloud point model was obtained from a Terrestrial Laser Scanning (Figure 2).

TRANSFORMED AND GENERIC RULES

The grammar was obtained with the column system and the intercolumn grammars and few other rules. The goal of this research is to see the degree of coincidence between the rules in use on the two grammars mentioned before and ones of the Ducal palace façade shape grammar. Some rules had to be transformed, that is, added, subtracted, and changed (repositioned and resized).

To generate the facade some of the rules of the treatise had to be transformed with immediate impact on their parameters. These parameters were then compared with the ones from the treatises. . In Figure 3 some transformations were made in order to achieve a corinthian capital similar to the one existing in the Ducal palace façade. The corinthian capital described by Alberti has 8 leafs spread in 2 levels. The one existing in the Ducal palace as 3 leafs. A transformation was operated resulting in a new configuration and new proportions, namely, its height that changed from 1/3D (that is 2parts of the entire height) to 1D (that is 6parts of the entire height).

As the treatise does not fully specify how to

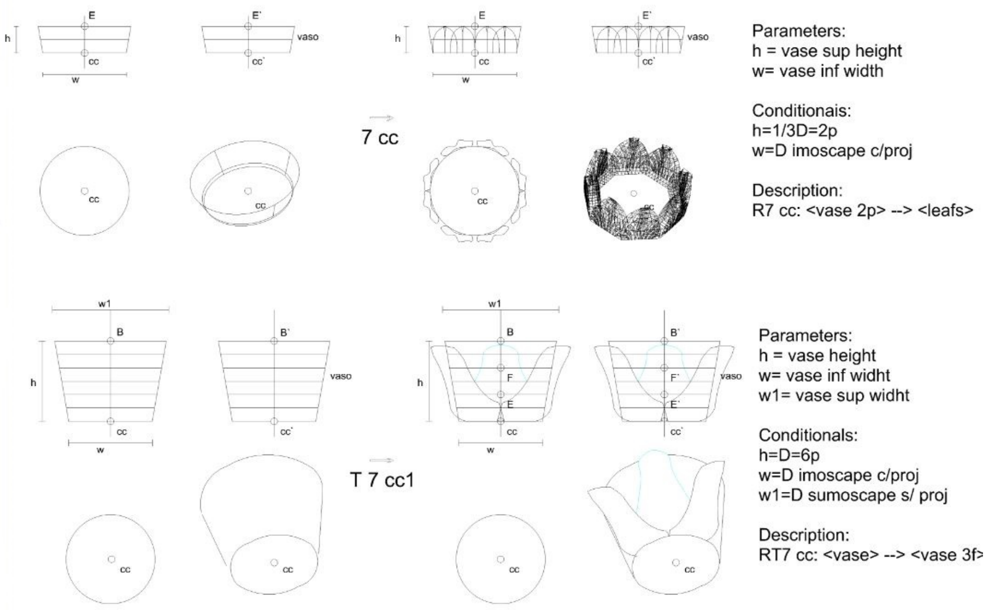


Figure 3
Transformations of the rule 7 cc of the Corinthian capital

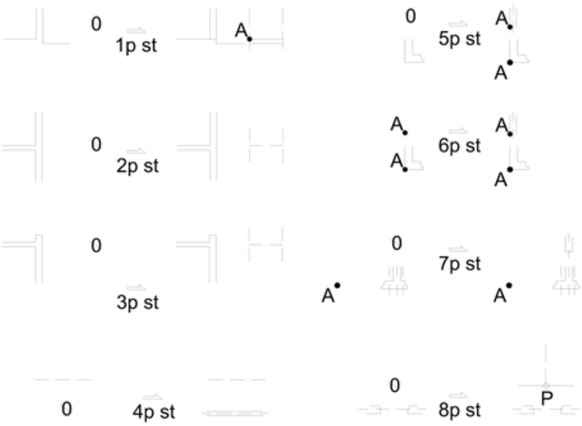
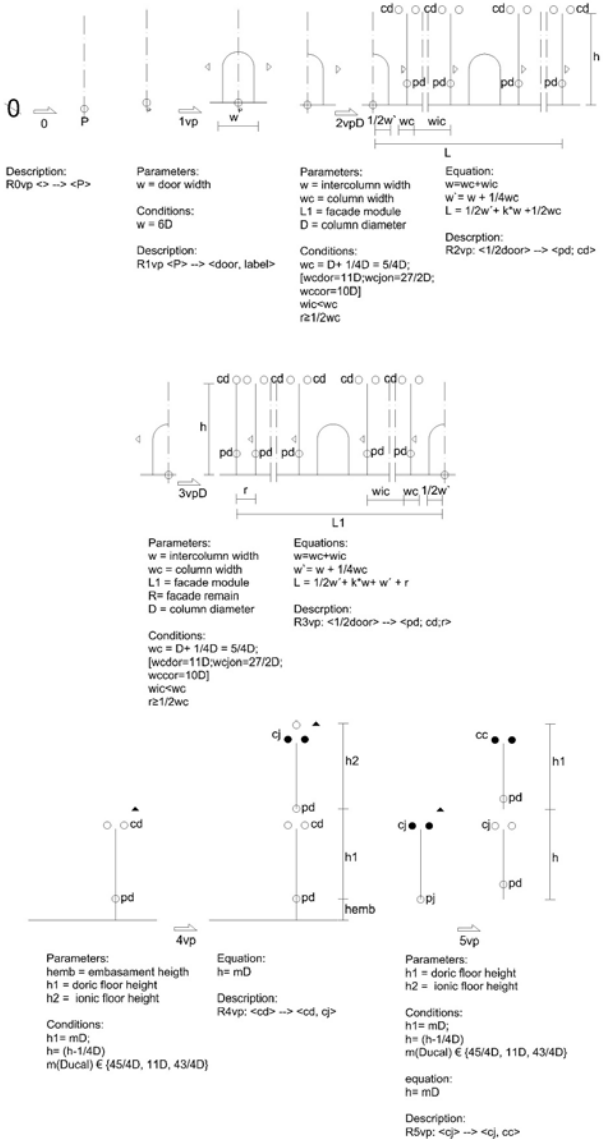


Figure 4
Set of rules of recognition

Figure 5
Meta-structure rules



generate a facade, some rules had to be produced. These rules are generic rules and they comprehend specifications for different generative process scales. Those scales are large (e.g.related to site plot and/or pré-existing structure recognition), medium (focused on the elements of the column system), and small (regarding the constituent parts of the elements of the column system), leading to 5 different derivation stages organizing the subsequent generic grammar that as:1 - Recognition rules; 2 - Meta structure rules; 3 - Rules to collocate windows and doors; 4 - Intercolumn grammar (set of descriptions to transform columns in pilasters); 5 - Rules to collocate column system elements.

Recognition rules maps some generic elements of a building such as parts of walls, floors and other pré-existing structural elements. Figure 4 shows rule 1st that recognise the interior and exterior floors placing a label A; rule 2st places a dashed line related with an interior slab, rule 3st add a dashed line related with an interior slab and a cornice, and rule 4st add a slab at previous dashed lines. Rule 1st, 2st, 3st works in two views (elevation and vertical section) and rule 4st in one view (elevation). Rule 5st inserts a label A and a wall, rule 6st maintains the label A and inserts a wall, rule 7st introduces a wall between two openings, and rule 8st introduces a label P related to a door. Rule 5st, 6st and 7st works in two views (plan and horizontal section) and rule 8st in two views (plan and elevation)

Meta-structure rules as 5 rules that may be seen in Figure 5.Rule 1vp inserts a door in the point P from previous rules and two labels (triangles) that show the direction next rules are going to take. Rule 2vp inserts column system elements labels (pd - doric pilaster and cd - doric capital). This rule as a set of equations such as $L = \frac{1}{2}w' + k_1 \cdot w + \frac{1}{2}wc + w^{\backprime}$, where w = intercolumn width, w` = ½ door width, wc = column width; L = facade module. This rule drives to the right side of the facade. Rule 3 vp is similar maintaining the same equations except the $L_1 = \frac{1}{2}w^{\backprime} + k_2 \cdot w + 2w^{\backprime} + \frac{1}{2}wc + r$, where r = facade remain. This rule drives to the left side of the facade. These 2 rules as the expression

$$\left(\sum_{j=1}^{k1+k2} w\right) + 4w^{\backprime} + wc + r;\ \forall w^{\backprime}, wc, w, r\ \epsilon \mathbb{R} \wedge k \epsilon \mathbb{N} \quad (1)$$

as the sum of the two sides of the façade.

The rule 4vp adds a doric pilaster and a ionic capital labels at second floor. Finally rule 5vp adds a doric pilaster and a corinthian capital labels related to third floor and erases the triangle label.

Rules to collocate windows and doors may be seen in Figure 6. Rule 1jp, 2jp, differentiates the bays with doors from the ones without doors, adding labels to insert windows or doors. Rules 3jp and 4jp

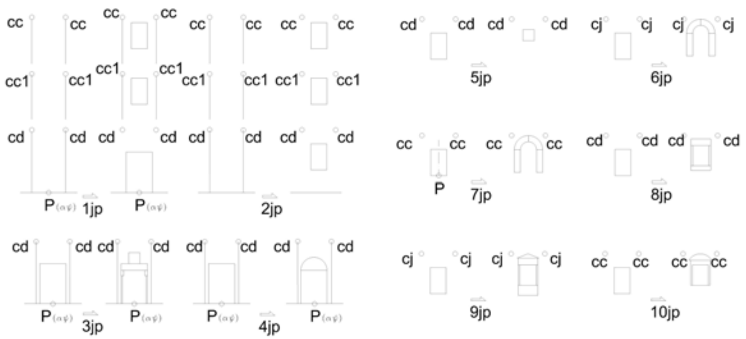


Figure 6
Rules to collocate and detail windows and doors

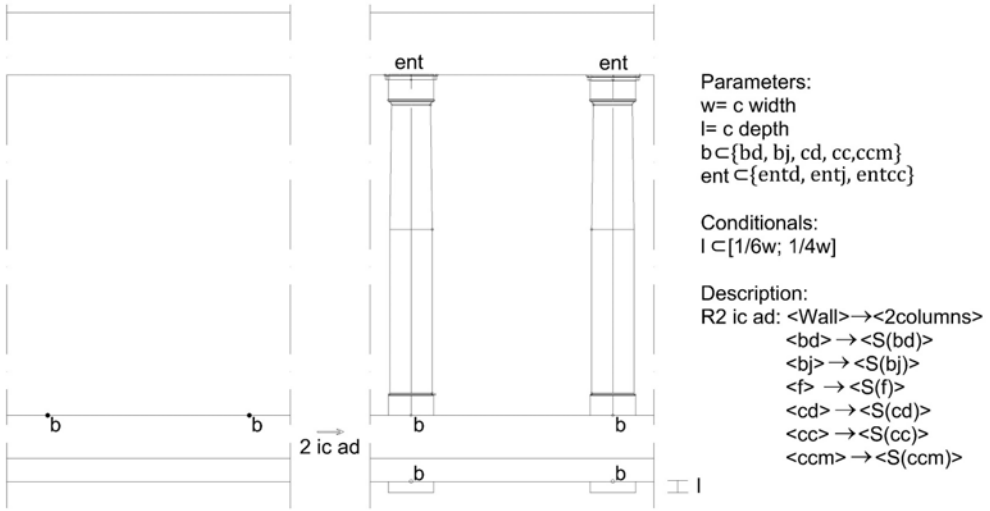


Figure 7
Rule 2ic from Intercolumn grammar transforming columns in pilasters.

are related to doors detailing, and rules 5jp to 9jp are related to windows detailing.

The Intercolumn grammar rule 2ic, seen in Figure 7, is applied to transform columns in pilasters and it comprehends a set of descriptions as:

```
<wall> → <2colunas>;
<bd> → <S(bd)>;
<bj> → <S(bj)>;
<f> → <S(f)>;
<cd> → <S(cd)>;
<cc> → <S(cc)>;
<ccm→><S(ccm)>.
```

In order to fill the facade with ornament, it's evoked the column system shape grammar applying all the elements needed. (Coutinho, 2011).

Note that in an advanced stage of construction of a shape grammar the rules transformed are going to be integrated in the grammar rules showing a dialectic process of reconstruction of the grammar simultaneous to its derivation. That is that the grammar derivation is not the end of the process until being obtained a satisfactory and meaningful result. Figure 8 shows the Ducal facade derivation. Drawings are being generated and detailed in elevation, plan and section simultaneously trough a parallel grammar application.

IMPLEMENTATION AND VISUALISATION OF THE PALACE FACADE GENERATION

The application of the parameters and descriptions of the grammar, using the software Grasshopper (GH), allowed the automatic implementation of the grammar.

The GH program allowed achieving different formal solutions through the manipulation of those predefined parameters.

The implementation of shape grammars in GH environment corresponds to a parametric system that simulates the generative capacity (derivation) of the grammars inferred from the treatise.

This GH program created a set of medium scale and small scale that were applied simultaneously generating different solutions, allowing some degree of flexibility. See Figure 9.

This set of systems aimed to contribute to an in-

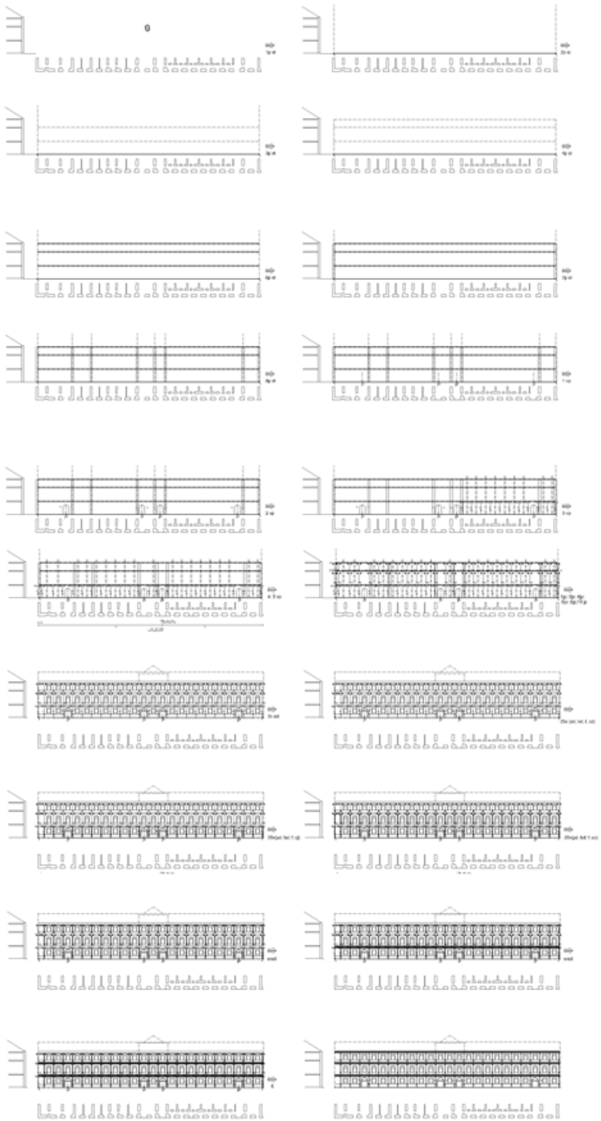


Figure 8
Ducal palace façade shape grammar derivation.

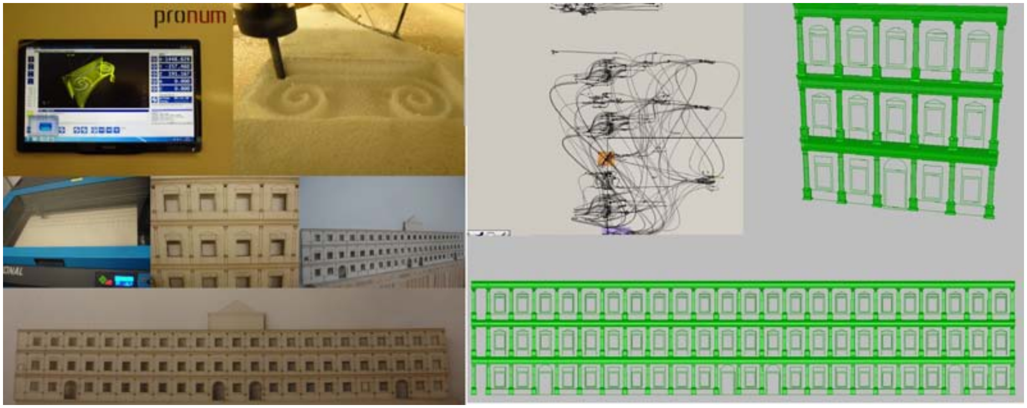


Figure 9
Ducal palace façade physical models made with digital fabrication technics and virtual models from a GH program.

terpreter, which is a system of applying a rule set automatically generating new elements with grammar, denoting a behavior with semantic and syntactic value providing shape emergence (Stiny, 2011).

Several physical artefacts were fabricated. First experiments comprehended an ionic capital milling using a 3 axis milling machine Pronum 4020. Models were milled from an expanded polystyrene (EPS) block.

The CNC machining strategies consisted in one rough passage using a 10 mm milling cutter and two diagonal finishing passages using a 3mm cutter, thereby allowing a better definition of the physical model.

The final Ducal palace facade physical model was fabricated with a laser cutter.

This technique was elected due the large proportions of the facade. The aim was to manufacture a prototype with a reasonable scale without losing the definition of the elements of the column system. The final facade prototype has about 80cm width and 15cm height.

This technique enabled both the cut of empty windows and doors, such as the engraving of the different column elements. The constructed models as well as some stages of manufacture can be seen in Figure 9.

There`s evidence that Alberti`s treatise influenced Ducal palace facade design?

The column system shape grammar allowed compiling the resulting treatise rules in order to generate different buildings providing them with ornamentation.

However, it was not always possible to directly use those rules, so new rules were found through transformations. This new rules were then used to understand the impact of the treatise in the design of Ducal palace façade.

The simple linear regression method (SLRM) was chosen to perform the analysis of the rules applied in the facade design and construction, measuring the degree to which the treatise has influenced the design and construction of buildings. To implement SLRM was used the statistical software SPSS..

For verification of the degree of influence two variables were used. The independent variable (IV) that is the values of the column system from the treatise, and the dependent variable (VD) consisting on the rules applied in the Ducal palace façade values.

The SLRM was chosen to understand the relationship between the two variables, and if the IV positively influenced or not the DV. With this method is possible to describe the relationship between the two variables. This relationship may be seen through the line

$$Yi = 0 + 1 \cdot Xi + i; \tag{2}$$

where X is the independent variable; Y is the dependent variable or predict; β 0 is the constant which represents the intersection of the straight line and the vertical axis; β 1 is a constant representing the slope of the line; and εi is the residual factor.

The objectives of SLRM are: perform measurement on how much one variable is explained by another, that is how much DV is explained by IV; quantify the intensity and direction of the linear relationship between two variables; predict the DV from the IV, and; infer that the model is adequate to explain the linear relationship between two variables.

The dispersion model gives the quality measures of the model where the correlation coefficient (R) measures the intensity and direction of the linear relationship.

R2 is the coefficient of determination which measures the proportion or percentage of variation of the DV that is explained by IV. This varies between [0, 1]. Where R2 = 0, DV cannot be explained by IV.

If R2 = 1 means that the DV can be 100% explained by IV. The coefficient of determination then varies between 0% and 100%. It is assumed that 50% means that the DV can moderately be explained by IV. In this analysis we focus on the readings R2.

To apply the SLRM is necessary to assess 5 presupposition (Carvalho, 2008): Linearity of the studied phenomena; Random variables with null value: E (ε i) = 0; Constant Variance of residual random variables: Var (ε i) = σ 2; Independence of residual random variables: Cov (i ε, v j) = 0 i ≠ j;- Normal Distribution of residual random variables: ε i ⊠ N (0, σ2).

The treatise and transformed rules proportion parameters represented by height h of the column system element were selected to be analysed with SLRM. These proportions are dependent on a constant diameter D which represents the measure of the column imoscape projection.

The 98 rules of the column system contains: 8 rules from shaft grammar; 7 rules from doric base; 7 rules from ionic base; 18 rules from doric capital; 18 rules from ionic capital; 10 rules of the corinthian capital; 2 rules from composite capital; 13 rules of the doric entablature; 17 rules ionic entablature; 1 rule from corinthian entablature and 5 rules from the pedestal.

The rules which contain more than one parameter are divided into sub rules. For example the rule of the shaft Rshaft 6 has h = 1/8D, h1 = 7D and h2 = 27/5D and was treated in sub rules like Rfuste6 h = 1/8D, Rfuste6A h1 = 7D, Rfuste6B h2 = 27/5D to facilitate the data base management.

The sample had 261 x 2 (different building) = 522 parameters. That is N = 522, were N is the number of observation.

The result of the Constant Variance of residual gave an abnormal result, being the large majority of the data divergent with the line (seen in Figure 10) not revealing that the DV can be explained by IV. This result suggests that the rules used in the design of Ducal palace facade are not the from Alberti`s treatise.

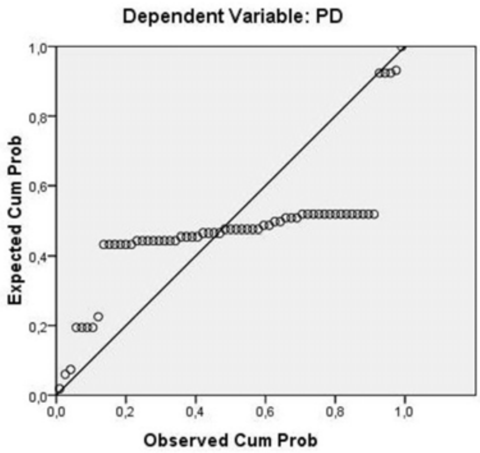


Figure 10
Figure 10. Regression Standardized Residual

CLOSURE

The grammar presented lead us to conclude that there is no evidence of Alberti`s De Re Aedificatória descriptions use on the design of the Ducal palace façade.

The experiment showed in this paper is part of a wider research that analyzed 3 other building, 2 from Alberti (Rucellai palace in Florence and Sant`Andrea church in Mantua) and another Portuguese building, São Vicente de Fora in Lisboa using the same methodology evidencing different results.

The shape grammar proved to be efficient in providing and organizing the data to be evaluated with SLRM.

This paper also had the goal to expose, as much as possible, the process of construction of this specific grammar, contributing to a better understanding of its specificities and extension of such generative tool.

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