Thonet Chair Design Grammar: A Step towards the Mass Customization of Furniture

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Abstract. The ultimate goal of the present research is the design and fabrication of mass customized chairs using a beech forming process. This paper describes the first stage of the research which is concerned with the development and implementation of a grammar-based design system for Thonet chairs. A corpus of six different chairs designed in the second half of the 19th century was used to infer the grammar, which can account for the design of existing and new chairs in the style. The chairs are composed by four connected beech parts—backrest and rear legs frame, backrest inner area, front legs, and seat, shaped by a forming process. Constraints on the shapes of parts and positions of connections, linked to fabrication and structural performance, respectively, are determinant in the definition of the style. The grammar was converted into a parametric design model to enable its implementation in CATIA. Rapid prototyping of new and existing designs was used to fine tune the parametric model. Results illustrate the potential of a digital design process based on shape grammars, parametric design, and rapid prototyping to enable the mass customization of chairs.
1. Introduction

The paper presents the first phase of a research currently under development that is focused on encoding Thonet chair design style into a generative design system using a shape grammar. The ultimate goal of the work is the design and production of customizable chairs using computer assisted tools, establishing a feasible practical model of the paradigm of mass customization [1].

The current research phase encompasses the following three steps: 1) codification of the rules describing Thonet design style into a shape grammar; 2) convert the grammar into a parametric design model to enable its implementation in CATIA; and 3) rapid prototyping of customized chair designs within the style to fine-tune the model. Future research phases will be concerned with linking the model to structural analysis software to enlarge the range of solutions while assuring structural performance; developing a CNC forming process to make the chairs; and transforming the grammar to create new chair styles using a similar fabrication process.

The shape grammar formalism is used first to capture the rules of formal composition of the Thonet design style and then to generate new designs through a creative application of the same rules. Subsequently, the developed shape grammar is converted into a parametric model and then encoded into a computer tool. The use of computer tools aims to enable both the generation and production of mass-customized chairs. From the design viewpoint, the use of these tools aims to support the designer in the conceptual design phase by facilitating the exploration of design solutions. In the current stage of development, the tool does not include performance evaluation capabilities, but the goal is to include them in the future.

The novelty of the described research is threefold. First, it proposes the use of shape grammars as the basis of a methodology to support the conceptual phase of furniture design. Shape grammars are used first to encode the rules of an existing style and later to transform it by changing the rule set. The designer may explore alternative design solutions by applying the rules and by varying its parameters to meet individual user’s needs. Second, it uses a formalized method to convert the shape grammar into a parametric design system, thereby facilitating its computer implementation. The resulting tool is used as a generative device to augment the designer’s ability to define and explore the universe of design solutions. Third, it aims at linking to digital prototyping and fabrication. This is accomplished by encoding constraints related to the envisioned fabrication system into the grammar so as to enable the direct production of chairs from the output of the tool, which will be described in a future paper. The result is a system to use in the in the design and fabrication of customizable furniture.

This paper is organized into six sections. Section two provides an overview of the context in which Michael Thonet chairs were designed. Section three provides
basic background information on the shape grammar formalism. Section 4 describes the proposed grammar and the application of its rules in the production of new designs. Section five explains the conversion of the proposed shape grammar into a parametric design model and its subsequent implementation in CATIA. It also describes the production of physical models using rapid prototyping. Section six closes the paper with a discussion on the research methodology and results, providing insights for future work.

2. Thonet chairs

In the 1830’s, furniture designer Michael Thonet began experimenting with forming steam beech to produce lighter furniture with fewer components, when compared with the standards of the time. Using the same construction principles and standardized elements, Thonet produced different chairs designs with a strong formal resemblance, creating his own design language.

The kit assembly principle, the reduced number of elements, industrial efficiency, and the modular approach to furniture design as a system of interchangeable elements that may be used to assemble different versions of the same object, enabled him to become a pioneer of mass production [2].

The furniture designed by Thonet presented a formal unity similar to the furniture designed by Hepplewhite, Sheraton, and Adam in the eighteenth century, although with a stronger emphasis on simplification and functionalism closer to the tradition of Biedermann style, which was widespread in the Austrian Empire and a few German states in the nineteenth century [3].

The structure of Thonet chairs includes the following elements: backrest and rear legs frame, backrest inner area, front legs, linking-leg torus, and seat structure.

Thonet chair style is characterized by the light and elegant structure. The backrest and rear legs are made in a single steamed beechwood profile, with an organic shape. This element rises from the bottom in a delicate curve that is narrower in the seat. The curve is observed both from front and sideways. The seat is a wooden or rattan coated ring. Some versions have a second ring, positioned lower, connected to the four legs. However, the distinguished feature between models is the backrest area design. It is defined by the use of one or two beech profiles, bent in oval or "S" like shapes. They may be connected to the backrest frame, to the backrest and the seat, and with each other. Thonet chairs are functional and have no ornamentation, but the structure.

The most paradigmatic example of his vision of furniture design is chair No. 14 produced in 1858, which was composed of six structural elements, excluding connective elements, as shown in Figure 1. Due to its simplicity, lightness, ability to be stored in flat and cubic packaging for individual or collective transportation,
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respectively, chair No. 14 became one of the most sold chairs worldwide, and it is still in production nowadays [4].

![Thonet chair No. 14](image)

*Fig. 1. Thonet chair No. 14*.  

3. **The shape grammar formalism**

Shape grammar is a formalism developed in the 1970s by Stiny and Gips [5]. Having as reference Chomsky’s generative grammar, shape grammars permit one to describe design styles through four key concepts: a set of geometrical shapes, a set of spatial relations between them, a set of composition rules that recreates such spatial relations, and an initial shape to which these rules can be applied recursively to generate different designs. Shape grammars have been used with success both in the analysis and synthesis of designs at different scales, from product design [6] to building [7] and urban design [8]. Shape grammars have been particularly successful in the characterization of design styles and in the generation of new designs within the same style, and in representing design knowledge in a way amenable to computer implementation [9, 10]. The literature includes one other example of a grammar for chair design, the one for Heplewhite chairs developed by Knight [11].

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4. The shape grammar

The Thonet shape grammar was developed to account for the generation of existing chairs, as well as allow for the generation of new chairs in the style. Due to the wide variety of chairs designed by Thonet, six chairs (Figure 2) were chosen to infer the grammar and then this was fine-tuned by checking whether it could account for the generation of other existing designs, not in the original corpus. The six chairs were selected so as to represent different perceivable chair types within the style.

After selecting the chairs, the following step in the development of the grammar was to identify the key elements in the formal description of the chairs. As mentioned above, these elements are: backrest and rear legs frame, backrest inner area, front legs, and seat. The description was then detailed by identifying the number of structural profiles, their relative position, the number of connections between them, and the characterization of the backrest inner area, which is determinant to guarantee structural stability to the backrest and rear legs frame. Subsequently, the corpus was analyzed to determine the essential spatial relations between these elements, concluding that pairs No. 1 / No. 4, No. 16 / No. 18, and No. 14 / No. 15, shared similar features concerning the design of the backrest inner area, and the connection of the backrest frame to the seat. These similarities were taken into account when inferring the shape grammar rules.

The definition of the shape grammar schemata is based on a simplified representation of the backrest structure—frame and inner area, because its design was considered key to the definition of the Thonet design language. The simplified representation was obtained by abstracting curves into rectilinear lines and representing just half of the backrest structure due to its symmetry properties.
The initial shape is a simplified representation of the backrest structure, and it is a common element to all the grammar rules. In order to control the positioning of subsequent elements, the initial shape also includes the axis of symmetry $s$ and a horizontal segment $h$ that indicates the position of the chair seat. To facilitate the understanding of the relative position of labels (points and segments) it was used an auxiliary $4 \times 4$ grid, as shown in Figure 3.
Any shape grammar is developed in an algebra $U_{n,m}$, where $n$ is the dimension of objects and $m$ is the dimension of the space in which objects are combined. Points have 0 dimensions, while lines have 1 dimension, planes 2 dimensions and solids 3 dimensions. For instance, the algebra $U_{0,1}$ consists in the arrangement of points along a line and the algebra $U_{1,2}$ consists in the arrangement of lines on a plane. A shape grammar might be defined in the Cartesian product of different algebras, each containing different classes of elements, such as shapes (U), labels (V), and weights (W) [12, 13, 14]. Labels are used to control the application of the rules, and weights can be used to represent the properties of shapes, such as functional and material properties, graphic expression, and so on.

The proposed Thonet chair grammar is developed in the Cartesian product of different algebras. Shapes are defined in the algebra $U_{1,2}$ and to control certain aspects of shape generation the labeled algebras $V_{0,2}$ and $V_{1,2}$ are employed. To assign different thickness to beech profiles and to permit the choice of different cladding materials in closed backrest areas, the algebras $W_{1,2}$ and $W_{2,2}$ are used, respectively.

Different shades of grey match different weights. Black segments have more weight than dark grey ones, and these have more weight than light grey ones. Different weights have a physical match in the diameter of lathe-machined beech. Weights used in the generation of model No.15 are intended to allow for the choice of rattan or beech sheet as a cladding material.

4.1. **The Rules**

The initial shape is a schematic representation of half chair. When the generation process is complete, the design must be reflected along the symmetry axis $s$ to
obtain the complete chair design. Then, \( s \) and the horizontal segment \( h \) are removed.

Fig. 4. Rules 1 to 3.

Rules 1 to 3 introduce the initial shape and they feature different labels, as shown in Figure 4. The placement of these labels complies with the following principles:

- \( a' \) is a labeled segment embedded in the horizontal segment \( h \). It starts at \( 5/8 \) of the backrest’s basis width and its length is \( 1/4 \) of the same width.
- \( a'' \) is a labeled segment embedded in the backrest frame. It starts at the frame’s turning point and it ends at the midpoint of its horizontal part.
- \( a''' \) is a labeled segment embedded in the symmetry axis \( s \). Its length is \( 1/4 \) of the total height of backrest.
- \( b' \) is a labeled segment embedded in the backrest frame. Its endpoints are at \( 1/4 \) and \( 2/4 \) of the total height of the backrest.
- \( b'' \) is a labeled segment embedded in the symmetry axis \( s \). Its endpoints are at \( 1/4 \) and \( 2/4 \) of the total height of the backrest, as in segment \( b' \).
- \( b1' \) is a labeled segment embedded in the backrest frame. Its endpoints are located at \( 2/4 \) and \( 3/4 \) of the total height of the backrest.
- \( A1 \) is a labeled point embedded in the symmetry axis \( s \) that is located at \( 3/4 \) of the total height of the backrest.
Rule 1 allows for the application of Rules 4 to 10 (Figure 5). In this set of rules all points will be embedded in one of the labeled segments a', a'', or a'''. The application of rule 7 permits to add a less weighted segment t' whose length is 1/4 of the width of the backrest’s basis.

Rules 8 to 10 remove labeled points. Rule 8 is intended to constrain the removal of labeled points when the shape has at least one of points P1, P2 and P3. This rule prevents the generation of an incomplete inner backrest area.
The application of Rules 11 to 25 (Figure 6) is possible after if Rule 2 was applied. Points Q1, Q2, Q3, and Q5 are the points of connection between backrest parts and they can only be embedded in any of the labeled segments a’, b’ and b”. Point Q4 can only be positioned in the top half of the segment Q1Q3.
Rules 20 to 25 permits the removal labeled points, granting the generation of chairs like *No. 1* and *No. 4*. There are a maximum number of points that may be removed at one time in Rule 20.

The application of Rules 26 to 34 (Figure 7) is possible after the application of Rule 3. Points S1, S2, S3, and S4 can only be on labeled segments a”’, b”’ and b1’.

Rules 29 and 30 can be used to specify the cladding material for the inner area of the backrest. Rule 29 specifies rattan and Rule 30 wood sheet.

The applications of Rules 31 to 34 erase labeled points. Similarly to Rules 8 and 20, Rule 31 permits the removal of a maximum set of points at one time.

The generation of chairs in the corpus according to the proposed shape grammar is diagrammed in Figure 8. The first step branches off into three
different design families, each characterized by the style of the connection element in the backrest area. The first is characterized by one connection element between the backrest and the seat. It generates chairs No. 16 and No. 18. The distinguished features in the second family are the existence of double "S" shapes, two connection points between them, and four connection points to the backrest structure. It allows the generation of the chairs No. 1 and No. 4. In the third family there is one connection element on the backrest area that is connected to the outer frame in two points. When the central element is closed, it may have a cladding material. It leads to the generation of the chairs No. 14 and No. 15.

![Tree diagram showing the key steps in the generation of chairs in the corpus.](image)

Fig. 8. Tree diagram showing the key steps in the generation of chairs in the corpus.

4.2. The application of rules

4.2.1. Generation of new chairs

The developed shape grammar describes the formal composition of Thonet chair design style. A creative application of the shape grammar rules allows for the generation of new chairs, not included in the corpus. Figure 9 shows the derivation of a new design and Figure 10 a sample of other new designs after the grammar. The application of the rules with embedding could lead to designs with intersecting profiles, such as the design at the bottom of Figure 10, which could make it difficult to encode the grammar into a parametric model and be hard to fabricate. Rules were, therefore, constrained to avoid embedding, thereby turning
the grammar into a set grammar. When the fabrication process is addressed in a future research phase, such a possibility might be studied.

Fig. 9. Derivation of a new chair design.
5. Computer implementation

5.1. Parametric design model

After defining the Thonet chair grammar, the goal was to implement it into a computer program. This program was intended to assist the designer in conceiving and producing customized chairs using the grammar. As the development of a shape grammar interpreter involves a large amount of programming to enable shape recognition and embedding [10], the grammar was converted into a parametric design model to facilitate its computer implementation using an existing CAD package. Parametric design supports design exploration based on interdependencies established between different geometric elements [15].
The parametric model was implemented in CATIA after converting the grammar into an equivalent parametric design model. This type of model is considerably more restrictive than a grammar is; for instance, it does not permit one to generate different designs by defining different rule application sequences. To convert the grammar it was necessary to encode the label features of each design family into a different parametric design model, which becomes a specific design when values are assigned to the parameters and then is saved into a *.CATPart file.

As a result of the use of a parametric design model instead of a shape grammar interpreter, the developed computer implementation does not support shape emergence and so the possibility of obtaining surprising results was considerably reduced. For the user of the parametric model, shape exploration does not occur through shape computation, but rather by assigning different values to the parameters in predefined parametric models. In this sense, easiness of implementation is safeguarded at the expense of creativity. On the other, complying with Thonet style is easier to guarantee.

The reduced number of rules and the simplified rectilinear representation used facilitated computer implementation by making it possible to convert the grammar into a parametric model. This model includes two linked geometric models: an auxiliary wireframe model and a rendered surface model for visualization purposes (Figure 1). The rectilinear representation foreseen in the shape grammar was converted into an auxiliary wireframe geometric model, in which control points and equations used in parametric design permitted to encode the geometric dependencies defined in the grammar. The definition of the parametric model included three steps. First, the simplified geometry of the backrest is defined on a vertical plane, thereby defining the basic wireframe model. Second, points on this geometry are projected onto three planes, the first corresponding to the top part of the backrest, the second to the side and inner parts of the backrest, and the third to the rear legs. Third, the projected points become the control points of spline curves that are used to generate the surface model. In short, the curvilinear representation is using 3D splines directly constrained by the wireframe model.
Once the basic 3D geometric model was defined by imposing dimensional and topological constraints on features of chair parts, such as length and cross section diameter, as well as angles between them, and parallel and perpendicular requirements, the range of values for the corresponding parameters was established to allow for variations of the output. The set of relations among parameter values defined in the parameterization process took in account the general morphology of Thonet chairs. The independent parameters are: backrest outer frame diameter; seat height; seat diameter; seat thickness; backrest height; backrest width; backrest angle; legs angle; backrest inner frame diameter; and position of the initial shape points. Additional parameters, related to the shape grammar labels features were defined as dependent from features of the initial shape representing the backrest to ensure variation according to the shape grammar rules. A design table containing all the parameter values constraints and dependencies was created as an Excel spreadsheet (*.xls file) when the parametric model was initially defined.

The generation process of different design solutions consisted in first selecting the *.CATPart model and the respective *.xls file and then assigning values to the various design parameters using the spreadsheet. In the *.CATPart model, the desired configuration was selected and the 3D model updated (Figure 12).
5.2. Rapid prototyping

To study the process of digital materialization and to test the solutions generated by the parametric design system, physical models of existing and new chair designs were produced using rapid prototyping, namely, the 1/8 scale models using 3D Print by ZCorp shown in Figure 13. As the models are produced using an additive process and the result is monolithic unlike the real chairs, this technique is not suitable for studying some tectonic aspects of the real chairs, such as the part bending process and the connections between parts. However, the models were useful in helping to perceive errors in the parametric model linked to tectonic properties, like the generation of intersecting parts when they should just abut, or possible inadequacies, like a part with a section that is too thick to be
produced by bending. As a result, the rapid prototyped models helped to fine-tune the geometric parametric models, including topological features and parameters values ranges. The parameters ranges were fine-tuned to guarantee that design exploration was compliant with Thonet style and to guarantee feasibility in the production of solid beechwood frames. However, these ranges maybe changed to permit the generation of chairs in slightly different styles that may still be produced.

Fig. 13. Rapid prototyped models of the chair designs in Figure 11 produced using 3D Print by ZCorp.

6. Conclusions

This paper describes the first phase of a research aimed the mass production of chairs. The main goal of this phase was to codify the language of Thonet chairs into a shape grammar, so they could be formally explained and reproduced. The shape grammar permits the generation of all the chair designs included in the corpus, as well as of new ones that result from different applications of the rules.

The developed shape grammar shares some features with the grammar of Hepplewhite chairs developed by Knight [11], particularly, the simplification of backrest shapes using rectilinear lines and symmetric properties. This is possible because in both styles – Hepplewhite and Thonet – the chair-back design varies while other structural elements remain similar. The use of rectilinear lines provided a less complex method for describing curvilinear shapes and led to the reduction of the overall number of grammar rules. This simplification also
facilitated the effective use of the shape grammar as a useful tool in the conceptual design stage by providing a clear, easy to apprehend set of rules for generating new designs. In addition, such a simplification constituted the means for developing computer implementation of the grammar as a parametric design model by providing an auxiliary geometry that permitted to define topological and dimensional features. As a result, it also permitted to map the parameters onto a table, the so-called CATIA’s design table, which facilitated the generation of designs. Although at the end the grammar was implemented as a parametric design model, its development was useful for representing design knowledge in a systematized way, amenable to computer implementation.

Some geometrical inconsistencies occurred when defining dimensional dependencies between elements. Following a series of tests, it was possible to realize that the number of inconsistencies occurring when assigning values to parameters is smaller when using the rectilinear geometry as the generator of curvilinear surfaces than when a curvilinear model was directly used instead. In addition, when it was necessary to correct errors in the parametric design model, the use of a simplified rectilinear wireframe made it easier. In conclusion, the use of two different levels of geometry provided a straightforward way of avoiding errors and correcting them when these could not be avoided.

The use of rapid prototyping in the production of physical models generated by the proposed parametric systems enabled us to detect errors in the model, namely, in the definition of dimensional and topological constraints, and assess the degree of design freedom permitted by such constraints. Future work will be concerned with the linking the parametric design model to structural evaluation software to relax parametric constraints while maintaining structural stability; to the manufacturing of chairs using a computer aided beech forming process; to the transformation of the Thonet grammar to create new design styles based on the same manufacturing process, and the development of an interface, possibly Web-based, that permits the use of the parametric model by the client, instead of the designer. The Thonet grammar and the parametric model developed in the present research may be extended to generate other Thonet chair types, such as armchairs, canapés and rocking chairs. It may also be manipulated to permit the generation of new styles, which will be the subject of future research.

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