Advances in Intelligent Systems and Computing 975

Massimo Di Nicolantonio
Emilio Rossi
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Advances in Additive Manufacturing, Modeling Systems and 3D Prototyping

Proceedings of the AHFE 2019 International Conference on Additive Manufacturing, Modeling Systems and 3D Prototyping, July 24–28, 2019, Washington D.C., USA

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10th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences

Proceedings of the AHFE 2019 International Conference on Additive Manufacturing, Modeling Systems and 3D Prototyping, held on July 24–28, 2019, in Washington D.C., USA

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Advances in Additive Manufacturing, Modeling Systems and 3D Prototyping	Massimo Di Nicolantonio, Emilio Rossi and Thomas Alexander

Preface

The AHFE International Conference on Additive Manufacturing, Modeling Systems and 3D Prototyping focused on cutting-edge design and manufacturing processes; it welcomes papers that cover articles, case studies and multidisciplinary studies specifically focused on ergonomics research, design applications, engineering processes, experimental purposes and theoretical methods applied the themes of Digital Modeling Systems and Additive Manufacturing and their cross-sectorial convergences. This book presents the results of recent research work. We believe that the findings presented in this book can either inspire or support others in the field of manufacturing and process control to advance their designs and implement them into practice. Therefore, this book is addressed to both researchers and practitioners.

The papers presented in this book have been arranged into ten sections, as shown below. The first five sections cover topics in modeling and 3D prototyping. Sections 6 to 8 deal with issues in additive manufacturing, while the last two sections are concerned with digital human modeling.

Section 1	Design and Innovation for 3D Printing
Section 2	3D Printing Technology
Section 3	Research on 3D Printing, Design and Digital Modeling
Section 4	Algorithmic Design and Rapid Prototyping For Cultural Heritage
Section 5	Recent Developments in Rapid Prototyping for Assistive Technologies
Section 6	Smart Additive Manufacturing: Sensing, Data Analytics and Process Control
Section 7	New Materials and Industrial Processes for Additive Manufacturing
Section 8	Additive Manufacturing and Industrial Production
Section 9	Digital Human Modeling and Applied Optimization
Section 10	Digital Human Modeling by Women in Human Factors

The presented chapters depict the influence of worker experience and the technology used to improve work effectiveness. Next, the comparison of non-expert and expert work is studied to find patterns that can be used to improve the technique of performing different tasks by less-skilled employees. The third section deals with outcomes ergonomics have on industrial quality and safety, while the fourth and final section of this book is focused on ergonomic design of future production systems.

The editors would like to thank Sudhakar Rajulu for his contribution to co-organizing the Digital Human Modeling program and Sofia Scataglini for her contribution to organizing the Digital Human Modeling by Women in Human Factors.

The contents of this book required the dedicated effort of many people. We would like to thank the authors, whose research and development efforts are published here. Finally, we also wish to thank the following Editorial Board members for their diligence and expertise in selecting and reviewing the presented papers:

Additive Manufacturing, Modeling Systems and 3D Prototyping

Digital Human Modeling and Applied Optimization

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July 2019

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Procedural Modelling as a Tool for Morphological Analysis of the Design Idea

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Abstract. In recent years, generative modeling has assumed a very important role in the training of the designer. The generative approach, in fact, educates to a conscious and rigorous representation of the form through a logical process that describes its geometric genesis by making explicit the dimensional and proportional relationships between the parts that compose it, information that can always be accessed to verify the quality of the project reading and with which it is possible to interact. Through the exposure of selected case studies, drawn from the tradition of interior design, we will see how the generative model is able to express in a summarized and comprehensive form the information necessary and sufficient to define the genesis of the shape of an object and, in as such, to educate the student to a conscious and controlled design of the form.

Keywords: Geometric analysis · Parametric generative modelling · Educational methodology · Morphological algorithm · 3D modelling

1 Introduction

The design process, both on the architectural scale and on the smaller one of the industrial product, underlies a rigorous process of definition of the form. Although in recent years digital technology is evolving towards sculptural and intuitive modeling tools, the substantial part of the design activity still follows a traditional logic, which sees the final form as the final product of a long and skillful process of integration, transformation and articulation of geometries, from the simplest to the most complex ones [1]. The ability to manage this form generation process, being also an expression of the quality of the project itself, is therefore of primary importance in the training of designers [2].

The teaching tradition in this area has followed various training methods. Among all, a particular role was taken by the reading of form aimed at the knowledge of pre-existing products, already made by skilled designers. Before the introduction of new technologies, this process was conducted in the form of graphical analysis [3]; thanks to the introduction of three-dimensional modelers, graphic analysis has evolved and more properly transformed into geometric analysis. The limits of the first one, affected by a strong interpretation linked to the reduced applicative rigor of the instruments and the use of only two-dimensional representations, were partially solved with geometric

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analysis [4]. However, with traditional digital tools we obtain a three-dimensional representation of the object which, although rigorous, does not allow us to record and transmit intrinsically the genesis of the project and the consequentiality of the steps that make up the process.

Therefore, the generative modeling [5], aimed at reproducing a process of defining the shape of the project, acquires the role of an instrument that verifies the quality of the project reading and implies its knowledge. Consequently, it is configured as a perfect tool in the training of the designer, capable of recovering the methodological rigor that has been a unique basis of reference for management of form complexity and for expression of project quality [6].

The research focuses on some sample models describing this process of analysis.

2 Case Studies

To demonstrate the peculiarities and advantages of the generative approach, we have chosen two case studies, both at the design scale: two furnishing elements designed by Alvar Aalto. In both cases, we previously conducted a graphic analysis based on the interpretation of drawings and images collected for the purpose [7, 8].

2.1 X600 Stool by Alvar Aalto

The first case study concerns the X600 Stool by Alvar Alto (Fig. 1), an object that is well suited to this purpose because, despite its simple formal purity, it presents interesting ideas.

We begin to recognize the main parts of the object, making a decomposition aimed to its understanding and then to its subsequent digital recomposition. The stool consists of a circular seat to which three legs are connected, arranged according to a radial symmetry with respect to the seat axis. Each leg consists of five parts arranged radially with respect to its own axis.

From a geometrical point of view, the seat consists of an extrusion solid: specifically, it is a circular profile interrupted by three circular arcs, in continuity of position, extruded in a direction perpendicular to it. These three circular arcs define the contact edges between the legs and the seat (Fig. 2a). It is therefore evident that the different parts influence each other in their geometric genesis. First of all, as is immediately perceptible, the axis of the seat coincides with the axis that defines the polar series of the legs. Next, we note that each arc of concave circle that belongs to the profile of the seat is defined by the convex edge of the contiguous leg, generated by revolution of a profile around an axis that belongs to one of the three symmetry planes of the stool. this axis does not touch the main circumference that defines the seat, but is external to it: this causes the side profiles of the leg not to be tangent to the outer cylindrical surface of the seat, but to be in continuity of position (Fig. 2b). Finally, the thicknesses of the seat and of the leg are congruent and therefore define each other; this, combined with the nature of the circular arches that define the profile of the leg, whose tangents at the upper extremities are horizontal, allows the continuity of tangency between the intrados and extrados surfaces of the seat and leg (Fig. 2c).

Fig. 1. X600 Stool by Alvar Aalto. Picture of the stool (to the left) and some representations of a digital model of it.

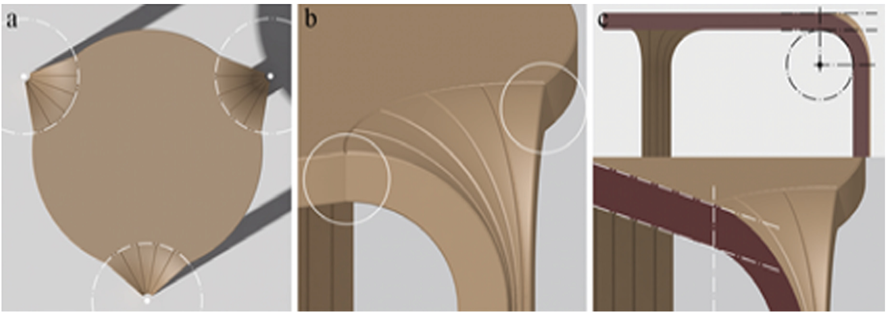

Fig. 2. Main geometrical relationships between the different parts of the X600 Stool.

Let's see in detail the steps that characterize the genesis of the X600 stool model.

Let's start with the seat (Fig. 3). As we said above, first of all we define on a horizontal plane placed at the appropriate height, through a center and a radius, the circle from which the profile of the seat originates. Subsequently, at the first axis of symmetry that we choose, we construct a circumference of smaller radius, proportioned with respect to the first, positioning the center on the axis, at a given distance to the outside of the first circumference. This circle, which will serve to define the solution of continuity between the leg and the seat, must then be replicated two more times through a polar series (Fig. 3a). Finally, we complete the profile by eliminating the circle portions which are no longer necessary (Fig. 3b). We then create the solid of the seat by extruding perpendicularly upwards the profile obtained and we complete the model by applying a homogeneous chamfer to the edges of the object (Fig. 3c).

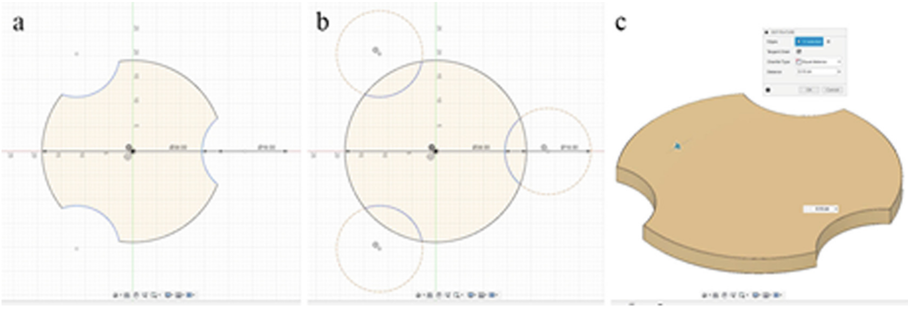

Fig. 3. Main steps of the construction of the X600 seat.

Now let's move on to modeling one of the legs (Fig. 4). First of all, we choose as work plane, on which to build the leg profile, the first of the three vertical symmetry planes of the stool, passing through the horizontal axis previously created. We directly insert a further vertical axis on this plane, passing through the center of the smaller circumference made on the horizontal plane: this will be the axis of revolution of the leg itself (Fig. 4a).

According to the proportions detected, we construct the profile of the leg on this plane, taking care to construct in an appropriate way the centers of the circles to which belong the two curves which define the intrados and extrados surfaces of the leg. In fact, the tangents of the two curves, in the upper ends, must be horizontal and therefore coplanar to the lower and upper surfaces of the seat already made, thus ensuring the continuity of tangency between the surfaces, as mentioned above (Fig. 4b).

Completed the profile, appropriately sized, we make the first of the five congruent portions that form the leg through a revolution operation, choosing as axis the vertical line previously introduced: the revolution, of a given angle, occurs symmetrically with respect to the inserted construction plane (Fig. 4c). After we applied a chamfer to the edges of the solid thus obtained (as we did for the seat), we complete the model of the leg through four polar copies of the same, introducing an appropriate angle to guarantee the contiguity of the portions (Fig. 4d).

The two polar copies of the first leg with respect to the stool axis complete the construction (Fig. 4e).

Once the model has been completed, we can see how its structure allows us to retrace and show in detail the construction process and the relations between the parts, to the point of making possible hypothetical transformations: the hierarchies, ratios and constraints - positional and dimensional - described in the model structure can generate infinite similar models, changing the values of the various associated parameters (Fig. 5). Let's imagine that we want to start from the stool model to make other pieces of furniture that are coordinated with it, such as a table. We could first intervene on the

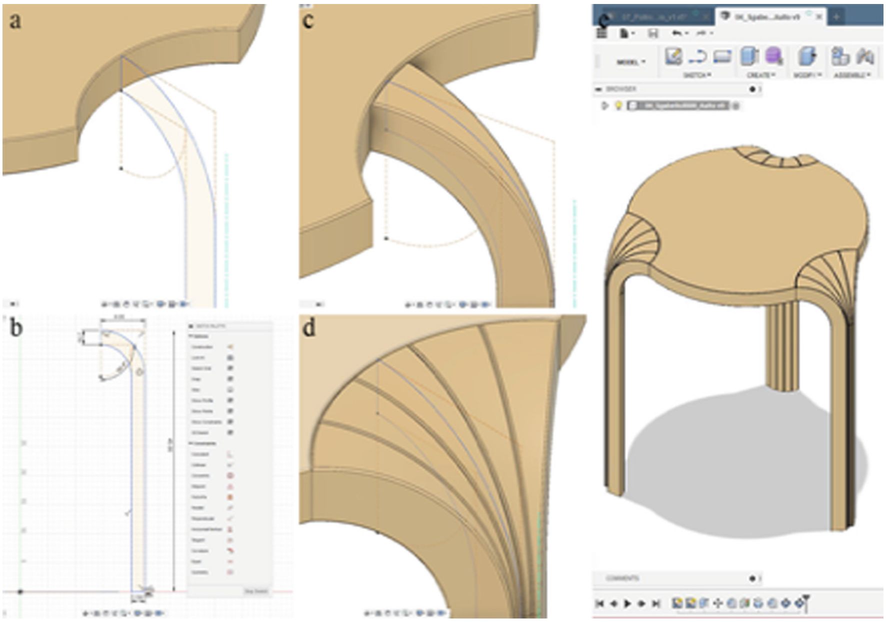

Fig. 4. Main steps of the construction of the X600 legs.

dimensions, through scaling or modifying the individual dimensions, and we could even decide - acting only on the initial representation of the seat profile - to vary the number of legs, increasing the number of secondary circles from which the models of the legs connected to them depend directly.

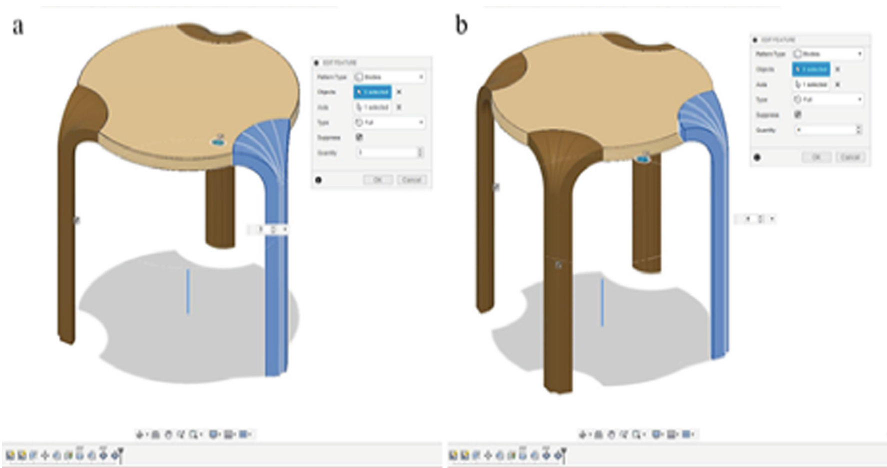

Fig. 5. An example of editing of the model by the modification of some parametric values.

2.2 Paimio Chair by Alvar Aalto

Let's now address a second case study. Always remaining within the furnishing elements designed by Alvar Alto, we have chosen the Paimio Chair, which offers interesting insights into the relationship between the genesis of the ideal model and the effective construction (Fig. 6).

Fig. 6. Paimio Chair by Alvar Aalto. Picture of the chair (to the left) and some representations of a digital model of it.

The object consists of two main parts: the seat and the structure that supports it. This structure is composed of two symmetrical lateral supports constituted by a closed mixtilinear profile, connected to each other by three straight and transversal elements, one posterior, the other two also functional to connect the structure to the seat that rests on it. The seat consists of a continuous element, alternating flat parts with cylindrical parts, which defines the support surface of the user.

In this case too, in order to obtain a correct and well-structured model, it is necessary to detect the geometric relationships between the parts (Fig. 7).

Firstly, it is necessary that all the profiles useful for defining the parts are built on vertical planes, parallel to each other and appropriately spaced. The main transversal element that connects the two supports of the structure admits as generating line a profile whose center must coincide with the center of the rear upright of the structure and as a directrix a straight line perpendicular to the profile itself (Fig. 7a). The other two transversal elements will instead be appropriately matched to the lateral elements of the structure at specific points in which rectilinear parts begin (Fig. 7b). The flat ends

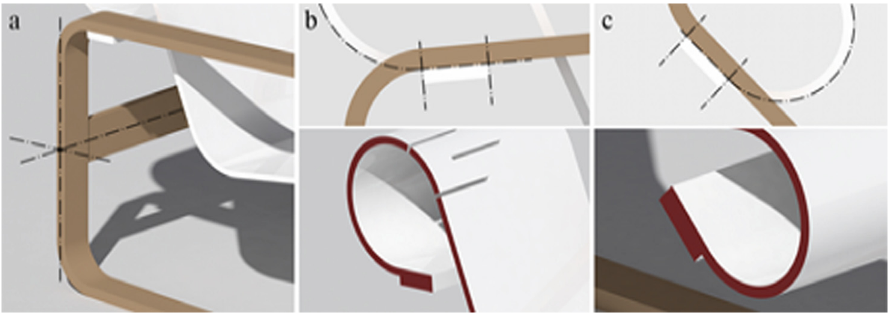

Fig. 7. Main geometrical relationships between the different parts of the Paimio Chair.

of the cylindrical solid defining the seat will depend on such transverse elements, to which they are aligned (Fig. 7c).

Let us see in detail the steps for the construction of the structure.

First of all, most of the time available must be dedicated to defining the external profile, on a vertical plane, which generates the lateral elevation of the structure (Fig. 8). The profile consists of a series of segments and circular arcs in continuity of tangency. Let us begin by drawing the lines to which these segments belong, placing them in a parametric relationship with each other through dimensional constraints - both linear and angular (Fig. 8a). We then create the arcs of a circle through operations of connection between the segments, defining fillet radii and proportioning them with respect to the structure. Now we make an offset of the profile, at a certain distance, and thus we obtain the generatrix that, by an extrusion perpendicular to it, makes it possible to generate the side element of the structure (Fig. 8b). We copy the element thus created at a given distance to obtain the opposite side of the structure (Fig. 8c).

Now we are going to construct the rectangular profiles that define the transversal elements of the structure (Fig. 8d).

The first element, the posterior one, has a rectangular profile, whose axes are aligned with those of the rear upright: therefore we constrain the center of the rectangle to the center of the structure upright profile. The extrusion height of the profile, to make the element, is equal to the internal distance of the side elements of the structure.

The extrusion height of the profile, to make the element, is equal to the internal distance of the structure side elements. The rectangular generatrices of the two solids are aligned with straight internal edges of the structure, starting from points where the curved parts end. The seat will be supported by these elements.

So we come to the main part of the model, the seat (Fig. 9).

First of all, we draw the profile on the vertical plane, in accordance with the support elements already made. It consists of arcs of circles and lines, defined by angular dimentions proportioned to each other (Fig. 9a). An offset of the line thus created allows the profile to be completed and leads to the subsequent extrusion phase, which gives form to the seat (Fig. 9b). The model is completed by creating the holes at the top of the seat. Here we can identify two main operational solutions. The first consists in making cuts by subtracting the solids made on the model of the enveloped solid seat,

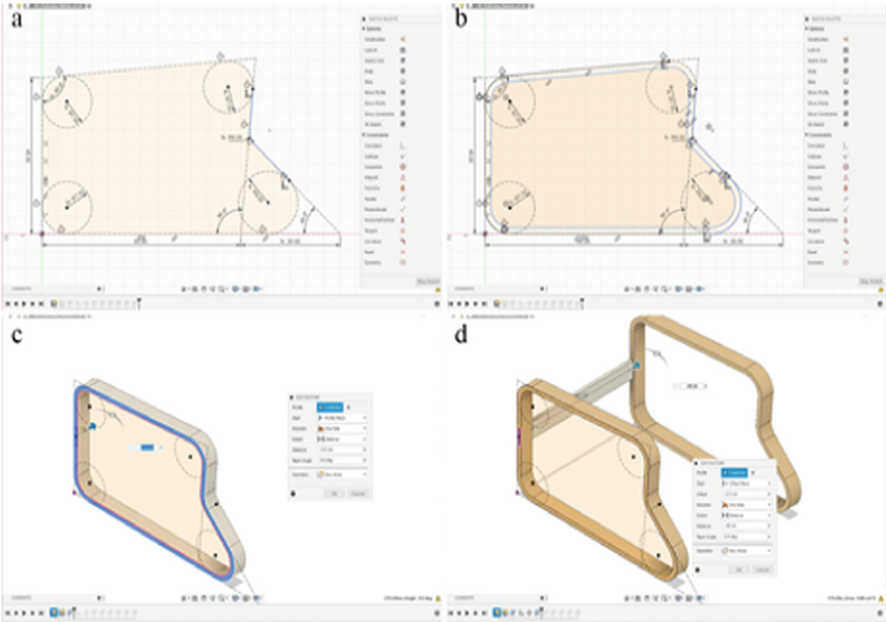

Fig. 8. Main steps of the construction of the Paimio Chair structure.

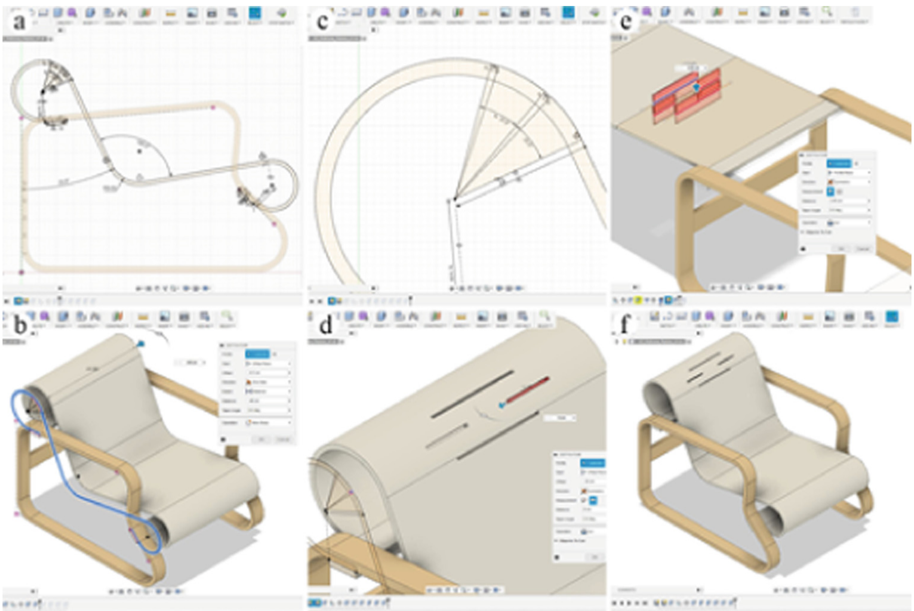

Fig. 9. Main steps of the construction of the Paimio Chair seat.

whose profiles - suitably proportioned and sized - are determined on the plane of the profile constituting the seat itself (Fig. 9c, 9d). The second consists instead in a subtraction of volumes made on the developed model of the seat, after having defined the profiles of the volumes to be subtracted - appropriately proportioned and sized - on the developed surface (Fig. 9e, 9f).

Also in this case, as for the X600 Stool, the use of parameters allows considerable design flexibility, as it lets constantly to modify proportions and dimensions of the object and its individual parts, in search of the most convincing solution.

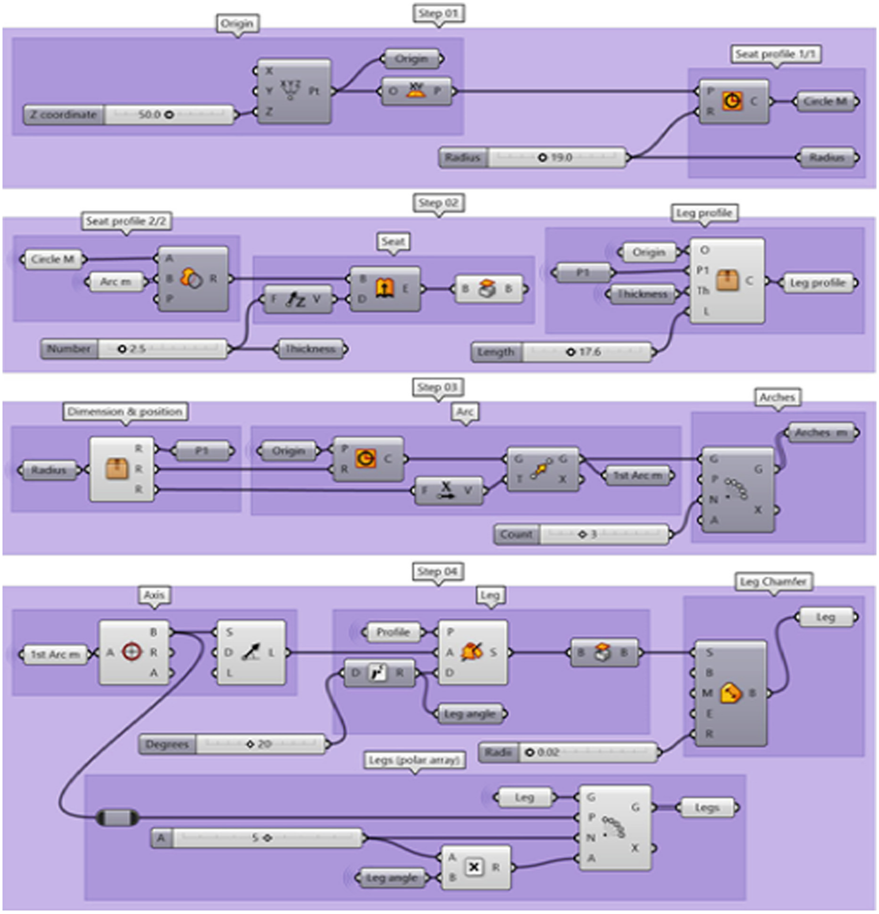

Fig. 10. Graph of the generative model of the X600 stool by Alvar Aalto: its structure tells the model construction logic.

3 Conclusions

As can be seen from these two simple but significant case studies, the generative approach allows to create a model of geometric and metric information ordered in a logical way, able to evoke not only the appearance of an object, but above all to describe in detail the process that generated it, a characteristic destined to greatly enhance our ability to design and communicate (Fig. 10).

As for the design aspect, this information is necessary to build the model and must respect a logical-operational consequence without which it is not possible to proceed correctly. Therefore, it becomes fundamental, for the formal optimization of the model, to make a logical synthesis that foresees a necessary and sufficient number of operations to describe in a comprehensive and "clean" way the genesis and the composition of the object. The level of logical synthesis achieved, formally expressed by the graph, also allows us to judge the quality of the model. Moreover, thanks to the steps recorded in the history of the model, it is possible to intervene in each phase of its genesis to modify form, dimensions and proportions of the parts that constitute it: in this way, the editability of the model becomes an interesting prerogative of the model itself.

From the point of view of communication, the generative approach allows to create a model whose consultation produces the most in-depth knowledge of the represented object. This knowledge is not only limited to its geometric composition and dimensional characteristics, but it can also be extended - structuring the model in an appropriate way - to the type of materials used or to the sequence of operations necessary to physically construct the object. Among the most important characteristics of the generative model we can recognize the ability to guide the user to read the object, reading that proposes a representation or at least a detailed interpretation of its geometric genesis. When the recipient of this model becomes the student, here we perceive the profound didactic value inherent to the generative approach. Whether it is the decomposition of the architectural order [9], or the geometric analysis of an architecture [3] or of a design object [2] of which the relational ties between the parts are illustrated, the student will be educated to a conscious and structured reading of the form of object in its becoming and will therefore acquire, in turn, a greater critical and logical capacity in the ordered composition of the form and in its punctual and global control, fundamental characteristics in the design practice.

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