COMPUTATIONAL FURNITURE DESIGN CASE STUDIES

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Furniture design has been considered as an art for several years. Today, following the development achieved in other industries such as automotive, electrical appliances etc., and the highly competitive use of advanced Computer Aided Design tools, an effort towards integrating and automating the furniture design and fabrication has been under way. The present paper offers access to a few case studies developed with the help of a Grasshopper^{TM} based application that is able to process very complex geometries in furniture design and supply the final product with all the appropriate fabrication details.

Keywords: furniture design, CAD-based application, Grasshopper^{TM}, digital tools.

1. Introduction

Furniture design combines both crafting and technological advancements. It offers a substantial amount of added value, and it is perceived from the end-user point of view as extremely important and worthy of the price to pay. The wooden products are related to a series of research areas dealing with the circular economy (CE) and the CO2 reduction i.e. recycling and repurpose that other materials may not offer [1].

Over the years, new computer-aided design (CAD) pieces of software have been introduced in furniture design and manufacturing. Unfortunately, the achievement of digitalization is relatively low and does not incorporate the total lifecycle of the furniture as a product. Companies usually have islands of computer-based applications that are not integrated. At the same time, the designer culture towards computer aided integration is far from being implemented. Computational furniture design as a design technology, effectively pushes towards automation in the design procedure and the fabrication processes. Novel computational design

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tools available can be programmed both with visual and text programming languages. The outcome contains component design, part assembling, manufacturing files, prototyping exported formatted files [2, 3].

2. State of the art

Incorporating digital technologies within the furniture industry can offer a series of positive effects. Use of 3D scanning technologies is advantageous with an aim to create CAD models that can be used in a variety of downstream applications i.e. prototyping, dimensional validation between digital 3D solid models and actual manufacturing parts, digital and physical reconstruction of renovated furniture, robot guidance for fabrication, application of high accuracy tool die manufacturing technologies, 3D printing models used as the base for sand casting tool fabrication [4].

Use of integrated computer aided design and analyses tools in the development of mass customization of furniture, strongly promotes the synthesis procedure, when an annealing algorithm is used. In this way, the solution exploration is wider and results in generating a great deal of custom furniture 3D parametric models with increased aesthetics [5].

Parametric design can integrate a series of steps with an aim to design furniture and interior design related products. Following this methodology, input parameters together with geometrical rules, mathematical models and conditional relationships offer a great deal of alternative designs, thus promoting designing families of products optimized by a number of criteria [6].

Although for a great deal of industries, i.e. automotive, electronics, aerospace, Computer Aided Design (CAD) systems have been used and high-end technologies push towards lower cost and development times, this is not the case in more traditional industries i.e. furniture design and manufacturing. Nowadays, although more integrated computer aided design and manufacturing systems (CAD/CAM) together with data management systems (product lifecycle management-PLM- systems) are in place for the furniture related enterprises, a cultural transformation should take over the sector [7]. Use of modern CAD systems can provide the basis for well perceived products and especially furniture. Designers use a variety of methodological tools in order to establish creative ideas and develop them further with an aim to present innovative solutions to the end user. Architectural structures created by Rhino3D™ and then prototyped in smaller scale resulted in the implementation of highly complex geometries. These geometries were the results of a protocol followed, where initial prototyping of the geometry with non-conventional machining (laser cutting engraving and cutting) was used [8].

A few dedicated design and manufacturing tools can be developed by using the application programming interface (API) of general purposes CAD systems. This is to say that instead of letting the designer key and select several commands sequentially; in order to build the product on a CAD system, applications can be programmed and automate all these procedures, thus increasing dramatically the complete productivity. There are basically two directions to be followed: a) textual programming languages i.e. Visual Basic for Applications (VBA) and b) visual programming languages i.e. Grasshopper^{TM}. Of course, combining both approaches can result in having more functionality created, especially when special products and applications are involved (i.e. furniture industry) [9]. Computational furniture design, which is the result of advanced CAD programming from the designer point of view, results in building a computer code that incorporates a series of design and manufacturing parameters. By doing that, a series of furniture is designed and fits the end users demands and needs. The complete process offers a great deal of manufacturing and prototyping tools together with design alternatives. The end-user is able to participate in the customization procedure and feel increasingly satisfied [10].

One of the most important advantages of computational design is the reduction of the design time needed. The algorithm automates a series of repeated steps, allowing the designer to further develop the product and thus offering the opportunity for increased productivity [11]. Traditionally, when designing a product, many procedures must be manually repeated. With computational design these procedures can be highly automated via programming and function creation. It has been documented that using programming in the design process dramatically reduces the time needed during the execution of the application, from the time point of view [12]. In the case of designing a family of products, mainly to offer customized products and increased customer satisfaction, computational design offers a great deal of alternatives and highlights different geometrical characteristics [13].

The present paper aims to automate the design and manufacturing procedure of furniture that incorporates simple or even complex geometries. The application built, creates all the CAD based part models required for the final product, the appropriate assemblies and applies the selected materials in order to provide high-quality rendering facility within. The code was created to work with a variety of input formats and export all the necessary files for production. Three case studies are presented with the aim of proving the code consistency.

3. Methodology

The implementation of the current project took place by using both a series of methodological tools and the visual programming language Grasshopper^{TM}, which is integrated within the Rhino3D^{TM} CAD system. Figure 1 depicts the workflow followed. The key idea was to focus on the automation of the design and fabrication procedure, when designing modern wooden furniture. The shape was considered to be generic. In other words, even very complex geometries should be able to be processed and the final furniture to be ready for fabrication. Use of plywood was considered an acceptable option for establishing a relative low cost and modern appearance. The code produced deals with all the technical difficulties related with both the design and fabricating the final geometry and incorporates features such as: 3D modeling of all the components/parts required, 3D assembling them, nesting facility for securing the highest material usage and environmental friendliness of the furniture, directly calculating the appropriate G-code for CNC machining and 3D printing prototyping.

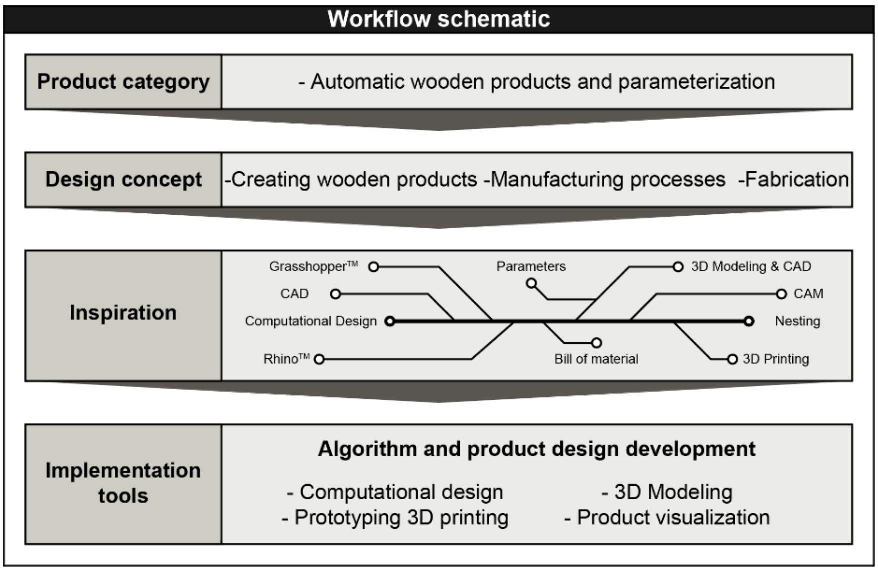

Fig. 1. The research workflow

3.1. Design automation

Figure 2 depicts the CAD based application created and the appropriate code in the visual programming language Grasshopper^{TM}. The application accepts a number of input geometries and automatically designs the furniture based on the additional input required i.e. number of slices, number-size-positions of the setscrews, wooden material and its thickness, texture. Even for high complexity geometrical forms, the application manages to automatically export all the pieces of information that relate to the integrated furniture design.

Three alternative design geometries were imported with the aim of providing:

- an armchair, with an unusual geometry that handles customization and special geometrical features for improved ergonomics due to extensive use of advanced surface design incorporated (3D scanning technologies are used for increasing customer satisfaction and comfort),
- a supporting furniture with highly unusual geometry that can accompany the designed armchair or be presented separately,
- a table with a geometry that can inspire the end users and purchasers.

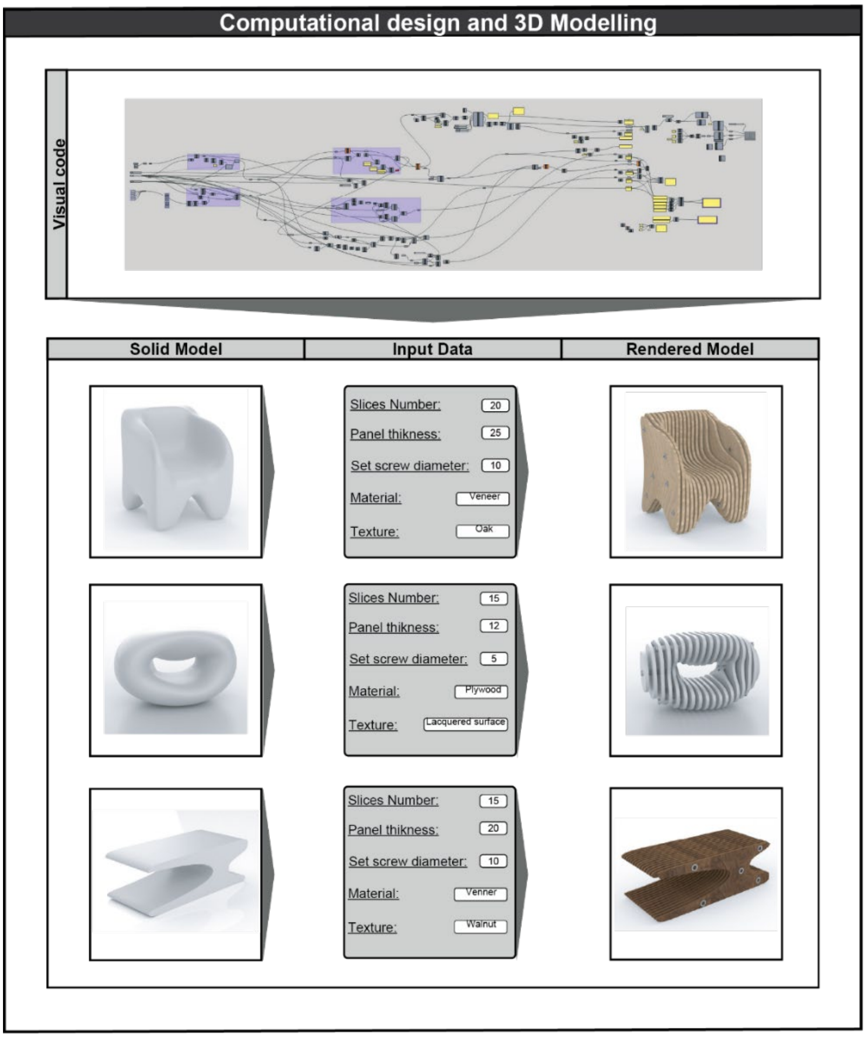

Fig. 2. Applying the code generated in a number of case studies

All the initially imported unusual geometries were implemented without interruption of the code run or code errors and all the supportive outputs for the fabrication of each furniture were provided. This was accomplished with all the related initial geometrical forms introduced, thus proving the flexibility and reliability of the application made, to handle a variety of other complex geometries as well. Especially with those that are the result of 3D scanning procedures which are usually with increased complexity in 3D space.

Further to the industrial design of the case studies based on the code produced, a set of downstream application data was received. First, the nesting of the generated geometry based on all the fabrication pieces of information (i.e. plywood dimensioning) was used in order to calculate the plywood material needed for the actual manufacturing of each product. Nesting is implemented through the OpenNest™ plugin, using a heuristic nesting algorithm based on binning logic [14], [15], [16]. At the same time, optimization of the material waste was performed, thus the environmental sensitive product design principles and cost reduction criteria were supported as well. Second, the bill-of-materials (BOM) served as a guide in handling and purchasing all appropriate components for the final assembly. A complete list of all the parts used together with their quantities was available to the designer and assisted in performing all the final checks prior to assembling the furniture. Third, the necessary g-code needed for the fabrication of all the plywood components that have unusual 2D geometry, led to the final definition of the data required for each furniture. Each individual slice contains a complex geometry together with automatically created holes for the setscrews. The application reads the geometrical pieces of information and the default manufacturing parameters and exports the g-code based on the machinery used (Figure 3).

Extra functionality added include exporting vector files for all the 2D geometrical components and neutral CAD files for prototyping (.STL) and data transfer among design systems for the 3D models (.STEP).

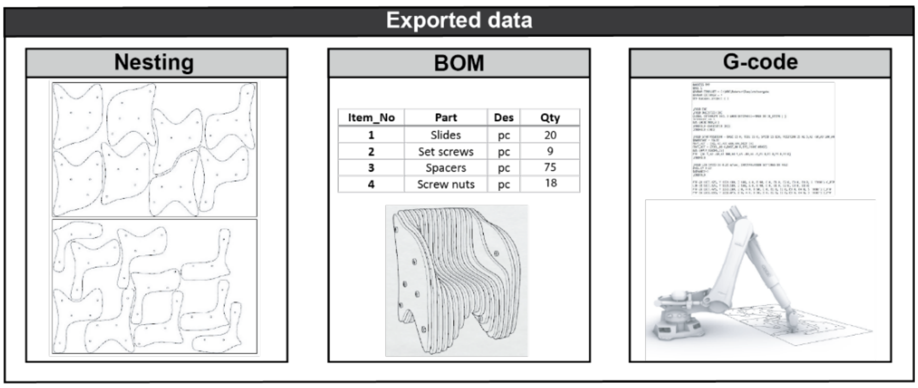

Fig. 3. Downstream application data exported to support nesting, bill-of-materials, manufacturing machining code

The design time for a product via the algorithm was approximately 2 minutes depending on the initial setup request and the geometric complexity of the furniture introduced to the algorithm. The time needed to develop and test the algorithm was approximately 12 hours. On the other hand, following the traditional design approach (manual) of such a product would require approximately 7 hours for each of the furniture modelled.

Table 1 includes the design time demands in each case. The computational design approach offers increased productivity and reduced design time when it can be used for a variety of products and a series of alternatives. All these alternatives provide a solid basis not only for reduced costs but for increased customer satisfaction as well.

Table 1.

Time needed when following traditional and algorithmic design methods

	Design only 1 product		**Design 20 products**	
Design method	Traditional	Algorithmic	Traditional	Algorithmic
Algorithm design	-	12 h		12 h
Computing time	-	2min	-	40min
Traditionally Designed time needed	7 h	-	140 h	-
Total time	7 h	12h 2min	140 h	12h 40min

The algorithm guides the application user to select a number of input parameters, i.e

- the thickness of the wooden material (for plywood 6/9/12/15/18/21/24mm were included),
- the spacers' distance (can be automatically defined by the length of the furniture and the wooden slices thickness),
- the diameter of the setscrews (can follow the standardized values of 8/10/12/14mm radius). The same applies for the number of setscrews needed (the user can select the number of setscrews and their position).

The default values set were: 16mm thickness of plywood, 8mm for the radius of the setscrews and 6 setscrews needed for assembling the furniture.

Fig. 4, depicts the final proposals for the three furniture designs. The 3D CAD-based models have incorporated the material visual properties and the texture selected by the end-user. All furniture were presented in a virtual environment with high quality rendering facility implemented. In this way, both the designer and the end-user were able to accurately see the final product and decide possible design changes or approve the design and send it for fabrication. In addition, the application supports a series of wooden materials together with their texture appearances with an aim to provide accurate photorealistic images of how the furniture will look when fabricated.

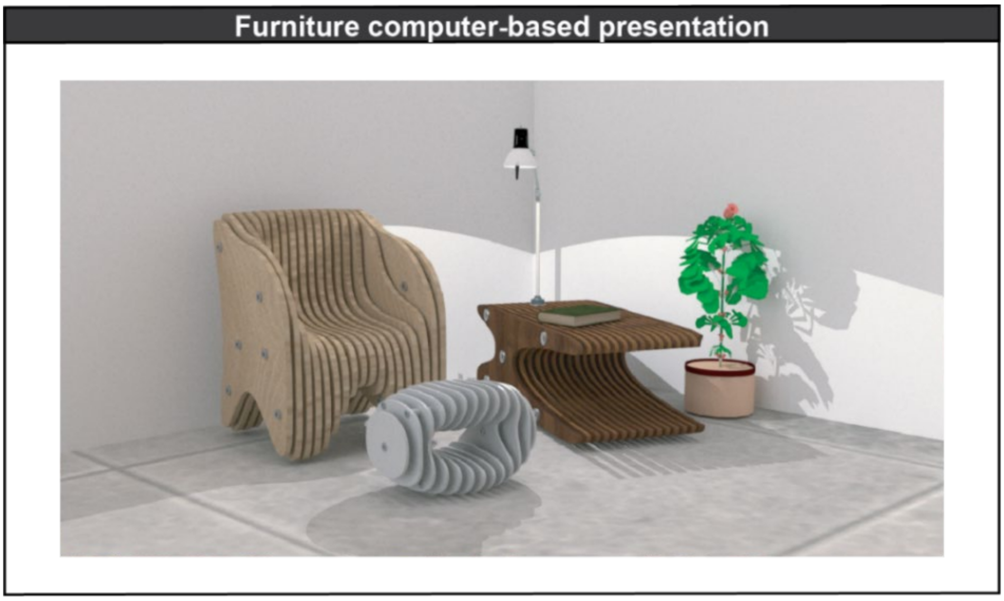

Fig. 4. Final computer-based presentation of the furniture using the appropriately visually assigned texture

6. Conclusions

The use of an advanced CAD system via their visual programming language was depicted in the current research. The Grasshopper^{TM} language was used with an aim to build an application that can automate the furniture design process. Even complex geometries could be introduced as an input data, together with a series of pieces of information related to furniture fabrication. Default values are offered, and the application supports additional adjustments and additions i.e. materials, textures, dimensions, equipment for machining.

The outcomes received support that automated fabrication process by supplying nesting facility, bill-of-materials capacity, g-code for guiding a robotic arm or a CNC machining center. These downstream application data are directly connected to the 3D solid models and 3D assemblies/subassemblies built at the first stages of the design process.

Computational furniture design leads to changing the traditional role of the designer that should acquire CAD-based programming skills. In this way, investing some time at the beginning for building the application offers substantial reduction in time and cost when changes are needed.

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