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Furniture design using MDF boards applying concepts of sustainability

Tomás Queiroz Ferreira Barata, Osmar Vicente Rodrigues, Beatriz Martino Matos, Renato Santos Pinto
Universidade Estadual Paulista "Júlio de Mesquita Filho"
e-mails: barata@faac.unesp.br; osmar@faac.unesp.br; beatriz_martino@yahoo.com; renato_di@hotmail.com

Abstract: This research presents the design and production process of furniture prototypes with the use of reconstituted wood sheets and emphasis on application of sustainability concepts in product development. The materials used for the production of furniture were MDF (Medium Density Fiberboard) boards 18mm of thickness with melamine covering. In the machining process of the boards was used a CNC router. The results presented are of similar projects researched, guidelines for sustainable product development, design development process, production steps for prototypes production in the laboratory and analyzes performed afterwards the entire process.

Keywords: furniture, MDF, CNC router, product design, sustainability.

1. Introduction

The expression "environmental sustainability" regards to systemic conditions from human activities, either in global or local scale, which do not disturb the natural cycles beyond the ecosystem limits and do not turn this kind of asset weaker for the next generations (MANZINI, 2008). Having the purpose to be sustainable it is necessary to accomplish requirements such as: use of renewable resources as priority, optimized use of non-renewable resources, reduced generation of waste and energy in the production process.

When analysing the objects production chain from the extraction of raw materials to consumption and post consumption, different environmental impacts can be seen, since the production to products use and their discard. The use of materials from renewable sources and low environmental impact, as well as the adoption of a clean production, are two important tools in the production of sustainable products.

The MDF (*Medium Density Fiberboard*) sheets are produced by cellulosic fibers mixed with synthetic resins and pressed helped by heat. This material presents specific characteristics, such as: it is a recyclable and renewable raw material, immobilize carbon in its composition and demands less energy to be produced in comparison with other materials (steel, plastic, aluminum, etc.). Other advantages are the Strong relationship among mechanical strength, good workability, absence of defects, besides adding value to materials that depend on waste or remaining parts of production processes (VALENÇA; ROQUE; SOUZA, 2013). The selected milling process for the prototype development was the CNC milling, which allows high precision and cut planning, resulting in a much better use of each sheet and consequently in a significant reduction of waste material from the process.

The main objective of this study is to present furniture solutions for internal environments emphasizing the methodology adopted not only in the design steps, but also in the entire prototypes production processes. This research aims to minimize the impacts present in similar products already available in the Market and also to increase the importance of a design product process and its steps towards the users´ satisfaction, their quality of life improvement and industrial advances.

Lastly, the present research is connected to the university extension Project entitled "MUDADesign" which has its focus in the production of sustainable products as well as their life cycle analysis, using materials from renewable sources.

2. Bibliographic review

2.1. Sustainability concepts applied to product design

Sustainable development is a term that has been popularized and incorporated in daily life. This way more concrete guidelines are emerging in order to have an effective action of designers on the development of products with a correct environmental approach, considering the whole product's life cycle. These proceedings have priority aspects such as fulfillment of the population's basic needs, solidarity with the next generations, preservation of natural resources and elaboration of a social system respecting the environment (SACHS, 2004).

With the increasing worry about environmental issues related to the development of sustainable products, the state

and institutions' role is to create public politics that encourage researches aimed at the conception and the development of innovative products which incorporate sustainable design's concepts and theories. For designers, companies and also common citizens in their communities and organizations, a possibility of action lies in their capability of giving a strategic orientation to their own activities, reinventing reality. Therefore, one should get conscious about the product's life cycle since the project stage, prioritizing the usage of local materials from renewable resources and proposition of effective solutions considering possible environmental impacts at the production of new objects. Broadly, it may be considered that the designer's action lies in his ability to determine objectives and goals which attends the user's needs and requirements with sustainable criteria that are gradually arising in contemporary society (MANZINI, 2008; MARGOLIN, 1998).

From this paradigm on, the creation process in design must prioritize, among other aspects, performance optimization, innovation, quality, durability, appearance and the costs of each product. Manzini and Vezzoli (2002) use the *Life Cycle Design* methodology that sets project procedures in which all the productive chain has to be considered. Therefore, the sustainable design should be related to the act of designing. However, his focus is not only in the product, but in a systemic form it must consider the whole product life cycle. This way is important to analyse from origin to extraction of resources necessary for production, as well as the productive process inspection, logistics and the way of use and discard.

Considering this methodology, an object's life cycle can be organized in five parts: pre-production, production, distribution, use and discard. In each of them there are mentioned sustainable guidelines with the purpose of improving product development.

Pre-production consists in a stage used by the designer to do the executive design, definition of the materials and planning production. The product may arise according to a necessity, can be a company order or also a marketing innovation. Independently of the product finality, the designer must take into account several criteria in pre-production stages to design something that attends sustainable concepts and also in accord with environmental necessities.

As first example, it can be mentioned atemporality. Atemporal design is one of the most important features that make the consumer accept the product for a longer period of time, without wanting to substitute it for being old-fashioned. Designing something that is atemporal, means designing a product that lasts while his materials satisfies his own functions. Along atemporality, is durability, according with Kazazian (2009), in every consumer good projective activity is regarded durability problematic, determined as the object capacity of lasting for longer than the majority.

Production is the stage in which machineries are used for material transformation (machining, assembling and finishing), and it is in this stage that low environmental impact methods must be prioritized. To make this happen, it is essential to relate design activity to a process of environmental impact analyses and execute approaches linked with eco-efficiency term (KAZAZIAN, 2009). Clean production seek to optimize the usage of materials without reducing product's resistance and final durability, to utilize tools with low acquisition and energetic cost and, mostly, to reduce the production of leavings, generating whenever possible, alternatives to use the waste within the own company, through secondary products, which reduces the amount of leavings, without displacing the material, in addiction to increase the company's income (FUAD-LUKE, 2002).

Product distribution occurs when it is ready to be delivered to stores or distributed to the clients. Three fundamental aspects are prioritized: the design of assembly and disassembly, products with flat or planning packages and the usage of reusable packages.

The usage stage is the stage in which all pre-production and production are dedicated. It is often the stage that companies consider the last, ending the whole product life cycle, excluding the discard stage, which mostly ends up creating many huge environmental problems. A modular design emphasizes the usage because it is needed to think of products which can be set in several manners according to the user's desires and necessities, equal or similar individual pieces that in a context can connect itself in different forms. Modular performance is important in a use adaptation practice, as number, size, geometry and inter-relation, service and equipment and flexibility prevision (FREIRE; SUARÉZ, 2010). As consequence of modular objects, comes the enlargeable, which are objects with certain dimensions, that when needed, can expand occupying new spaces beyond the original area and perimeter. This consequently increases the quantity of possible users and also its volume. Along with modular and enlargeable objects are the "Do It Yourself" (DIY) objects. They are those objects who stimulate the independence of final user with the industry. DIY is a concept wherein the consumer can take home the disassembled products and easily assemble them by itself. The object has a transformation potential that allows the user to use his own creativity arrange and order as he wishes.

Discard is the last product's life cycle stage, but can also be the beginning of a new product. However, many times it is ignored by manufactures, as well as users. The discard stage does not consist only in throwing away that product which is not useful anymore for his user. The correct environmentally discard is about where this garbage goes,

if it is possible to reuse it and what are the environmental damages. Nowadays, as a way to reuse the material, there are refill products that the person returns the container in which the product came with obtaining the same product for a cheaper price. There are also bonuses for those who develop products, whether by discount or toast. Whereas it cannot be reused, it must be recycled, in other words, these materials have to be reintroduced into the industrial cycle. However, for this, must be analyzed the environmental opportunity, which cannot be always guaranteed, because sometimes recycling demands more energy and has more environmental impact than using a new raw material (KAZAZIAN, 2009).

2.2. Use of MDF in the furniture sector

The application of reforested wood and materials derivatives of wood is gradually growing in the last years in substitution of native solid wood in furniture's production, due to environmental questions, production costs and social responsibility. This way, MDF sheet has shown up as an alternative material for furniture fabrication, since features such as resistance, durability, dimensional stability and low production costs allows furniture industry to fit in needs and requisitions made by society that is more and pickier in relation of an ecologically correct production. Lately there is a great demand for modular furniture, which are mass produced, but at the same time enable a composition by modules according to the designs and needs of each client, thus although the furniture can be mass produced, they can also be customized and personalized to attend unique needs. In accord with Zenid (1997), wood, by its own physical, mechanical and market characteristics, can be considered competitive with other materials, like metals and plastics, both in civil engineering and furniture production.

Still according to Zenid (1997), furniture sector is concentrated in the South and Southeast Regions and 60% of the production is designated to home sector, 25% to offices and the rest to the institutional sector (schools, hospitals, restaurants etc.). Wood is the furniture productive chain basis, representing around 60 to 70% of the raw material consumed by furniture industry. However, the usage of native solid wood offers diverse restrictions, from difficulties with processing, lack of qualified professionals, management marked by high environmental impact to high marked cost. Being like this, MDF emerges as a more popular alternative and with low-cost to furniture manufacturing.

The MDF is a sheet manufactured from agglutination of wood fibers with synthetic resin, in a joint action with temperature and pressure. To obtain fibers, the wood is cut in small chips, and after that, they are mashed by equipment named shredders. Besides that, MDF is a relatively new product, made for the first time in the early 60s at United States of America. In Brazil, its production is still fresh, having the first industry started in 1997. The MDF has consistency and some of its mechanical characteristics close to solid wood. Most of its physical strength parameters are higher than the particle board, characterized also for having good dimensional stability and great capacity of machining, in which unity proportioned by the uniform distribution of fibers allows MDF finishing such as varnishes, paintings or decorative paper coverings, wood layers or PVC. Joints can also be implemented with benefits related to solid wood, since it does not have reverse veins, knots and common imperfections of the natural product Valença, Roque and Souza (2013).

According to Valença, Roque and Souza (2013), MDF is mainly destined to furniture industry. Frequently used as a furniture element for pieces that require specific machining MDF has the followings advantages:

- Speed in the execution of activities;
- Insignificant losses;
- Optimization and rationalization of processes;
- Easy raw material handling;
- Does not need large rooms to stock;
- Easy to transport;
- Excellent durability and;
- High resistance.

However, MDF must not be used in production of furniture which:

- Are constantly exposed to outdoors;
- Requires many times of an assembly and disassembly;
- Are exposed to overweight and;
- Claims high impact resistance.

2.3. Machining from CNC system

The process of machining consists in the extraction of the material providing shape, dimension and finishing to the design, by the usage of cutting tools, mostly a mill, where the cutting material is harder than the material to be machined. Currently exist a variety of machining operations and a wide technology range for this procedure.

Burdek (2010) says that the use of computational resources has become an important tool in a design process. Along with other technologies, as a CNC (*Computer Numeric Control*) router, it is possible to conceive complex designs in a short time, sometimes impossible to be made by conventional cutting methods, while also minimizing costs, production time and material. Azevedo and Conci

(2003) assert that nowadays computational resources can reproduce and develop everything we imagine. Since it is a more accessible technology and also financially cheaper. If compared to others CNC machining systems, CNC routers have been often used in design, both for model making and for Rapid Prototyping. We can notice this move in "Fab Labs" and machining centres available to community.

3. Materials and methods

As to the nature, this research is applied, because it seeks to create knowledge and techniques directly related to the development of products that uses MDF as raw material. Specifically this research addresses the design and production of the following furniture prototypes: (a) two places workstation (1.900 x 600 mm); (b) six places meeting table (2.100 x 1000 mm) and; (c) shelf (1.350 x 300 mm).

Considering the theoretical foundation, the practical process of designing activity development, productive development of prototypes and analysis of data and results, the methodological structure of this research is divided in ten stages, according as follows:

Stage 1: Bibliographic references and similar research;

Stage 2: Setting sustainable guidelines for product development;

Stage 3: Establishment of design requirements;

Stage 4: Development of sketches and design of board planning;

Stage 5: Development of virtual modeling and renderings;

Stage 6: Development of scaled models;

Stage 7: Production of prototypes;

Stage 8: Analysis of the manufactured prototypes in accordance with sustainable guidelines;

Stage 9: Re-elaboration of the original design and/or its adjustments;

Stage 10: Analysis of the data and results achieved, and disclosure of research.

3.1. Materials

The chosen material for this research is MDF with 18 mm of thickness and sheet size of 2.750 x 1.830 mm covered in gray layer of melamine in both faces. Because it is a processed material, it is presented without surface irregularities, which grants high accuracy to the design and consequently gives more stability to the produced furniture. For the finishing, it was used a black PVC plastic edge trim.

Besides that, MDF was chosen because the biggest producer of this material for all Southern Hemisphere is located in Bauru, which is the same place where this research was developed. This company works with a conscious forest management, and the master and application of top techniques at handling the cultivation areas reflects the company's concern about gain forest efficiency and increase productivity, always with social responsibility, reducing as a result, and potential impacts of its activities in the environment.

3.2. Methods

The machining was done by a CNC Router 3D Transform 2000/2 from CADEP – Centro Avançado de Desenvolvimento de Produtos (Center for Advanced Product Development) located at FAAC - UNESP/Bauru, with cutting area of 2.550 x 1.850 mm, whose function is two-dimensional and tridimensional machining all kinds of materials except steel. It is a computerized machine with three axes configuration (x, y and z) that makes the machining through a CNC (Computer Numeric Control) system. The machining process consists in a series of procedures. After the design's definition, the same is done in a program that is able to create a file based on vectors, also generating a tool path, in which the machining parameters as rotation, cut speed and advance speed between others are defined. Once the parameters are defined, the software generates a G-Code file to conduct the machining. The software Aspire was used for this part of the process. After this procedure, this G-Code is transferred to software called Mach 3, which reads the G-Code transferring it to the CNC. After been defined the origin through Mach 3, the CNC Router starts the process of machining the material fixed in its table. Its high accuracy and cutting planning refers to a better use of the sheet and consequently to a considerable reducing of waste.

4. Results and discussion

This part is organized as follows: similars research and definition of sustainable guidelines for product development process.

4.1. Research of similars

The research of similar focused on products which design was based on crossed plans. The images below present some of them. The majority has wood joints such as edge cross lap, Mortise & Tenon. Thought for reducing costs, from the production to distribution, the stool Lapa (Figure 1) put together design and environmental responsibility. Being disassemblable, it offers a better space use in transport, without any aesthetics compromise. The result is a furniture of five parts that can be assembled by wood joints only, and

the upper part of it is made from the remaining from its legs. It also can be used as a little table or a laptop support.

The chair Chairfix (Figure 2) was developed for the British designer Ben Wilson. The chair is delivered in a plan package and the consumer can assembly it from a basic drawing that simplifies the process. The differential is its personalized prints of each part of it.

Prefab design (Figure 3) is a collection of furniture developed by Dutch designer Dave Keune, which is sold as a DIY (*Do It Yourself*) package. The designs are simple and based on low cost production processes. Prefabdesign turns design accessible to all due to its vast portfolio of products that everyone can assembly as well as personalize.

As a result of digital fabrication process, the tables from the Dutch brand Fraaiheid (Figure 4) are based on wood joints only and can be produced by any "fablab" from one single plywood sheet.

From this research of similar it was possible to analyze not only the design of each one, but also their production processes and the types of joints applied. The edge cross lap type of joint gives a lot of stability to the pieces, especially those milled from 2D milling softwares and milling preparation from softwares base on vectors. Such combination results in more precise cuts and consequently more accurate joints.

4.2. Definition of sustainable directions to product development

Considering the bibliographic research, which took into account important concepts of sustainability, the different possibilities of the MDF uses by the furniture industry, as well as the milling potential from a CNC System, sustainable directions considered relevant for product development for a design of a new furniture, were then defined.

- The MDF is a material provided by a renewable and natural source;
- The MDF can be considered a material of local

Figure 1. Stool Lapa.

Figure 2. Chair Chairfix.

Figure 3. Prefab design furniture.

Figure 4. Fraaiheid tables.

supply, because the largest producer of this kind of material in South America is located in Bauru area, in which there is a huge exploration of eucaliptus and pinus used as row material in the production of MDF sheets. Bauru is a city in which not only this research took place, but also where the products were designed and their prototypes produced. This means that the entire production was thought to optimize the logistic and the consequent reduction of energy for the row material transportation from the plantation to the production location and usage. In addition, as a processed monomaterial, the proposed furniture were based on MDF;

- The production of these furniture is based on wood joints only, without any fixing accessories, nails, bolts or even glue for their assembly;
- The MDF is a material with adequate level of strength, in association with the protection of a layers of melamine covering their faces, increase the parts resistance and protection, even water proof, turning the furniture very durable for internal usage, which is the case of this work;
- The adoption of atemporal forms was chosen in order to guarantee a product out of any fashion, which can result in a better reception from the majority of the consumers;

- The CNC milling was also chosen because it is a suitable for this design, besides being not only a technology with high level of accuracy, but also with a low level of waste and energy consumption, which means a more sustainable technology;
- Considering that it does not use any fixing accessories, its assembly and disassembly is easy and straightforward. This means that the furniture is ease to transport disassembled (in flat parts) taking much less space whenever necessary;
- Ease maintenance due to its ease parts replacement and repair capabilities;
- The design was thought for a specific demand having in mind the number of users, the dimensional analysis of the ambiance and the purpose of fulfilling the research and extension needs, considering the refurbishing of the Laboratório Didático de Materiais e Protótipos (LDMP).

4.3. Product development process

In the product development process the design that would be developed were selected. Taking into account the office needs for the "MUDA Design" research and extension project, the following aspects were then considered: a) a workstation for two people, which besides accommodating a computer, it also should offers enough space for writing and specially drawing; b) a meeting table for six people; c) a book shelf for the project's book collection. Having these three pieces of furniture, the workstation was chosen as the first to be developed, which was then used not only as a starting point, but also as a reference for the others. The dimensions stablished for the workstation were 1.900 mm x 600 mm due to the distance between shelf's doors and the wall, and also an adequate height according to the design specifications. From these data an important aspect must be considered in this case (the adoption of wood joints only), sketches were then prepared, as it can be seen in Figure 5.

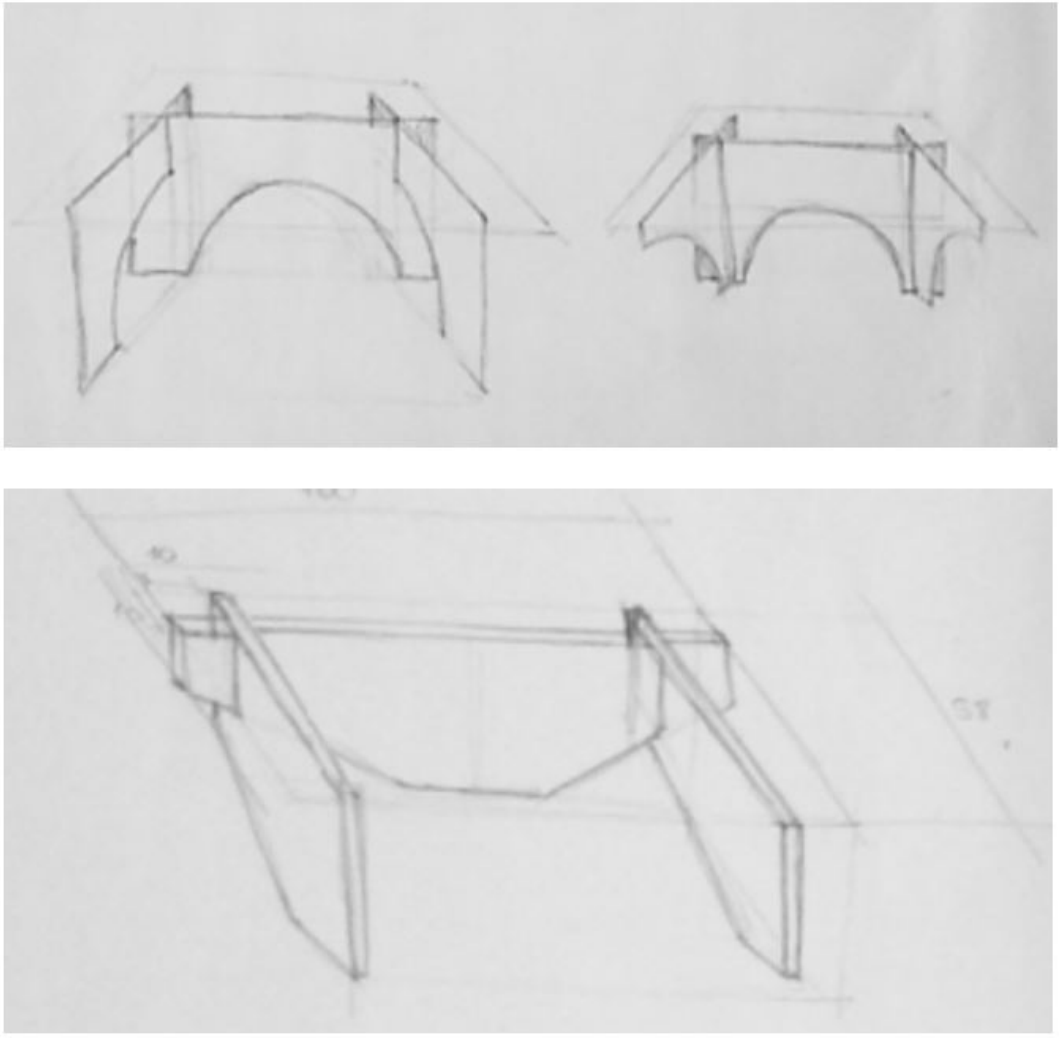

Figure 5. First sketch.

After the concept generation step, a new step of sketches were developed in order to verify aspects such as design's dimensions as well as the CNC cut optimization and the best use of MDF sheet measuring 2.750 mm x 1.830 mm, planning the better positioning for all the parts to be cut, as it can be seen in Figure 6.

After selecting the most adequate sketch, in accordance with the briefing, it was then planned. In Figures 7, 8 and 9 it can be seen examples of studies of the best use for the MDF sheet as well as the best angle for the workstation legs. It was prioritized the planning in which all the parts could be jointed like a puzzle.

At this point, it was realized that the best use for the sheet combined with the best legs angle, demanding less material as well as generating fewer number of separated cut, was that from Figure 7. Despite the fact that the crossing area being the smallest among the three studies, the parts size shown to be more than enough to ensure the necessary stability for the workstation. It was then time to start the virtual modeling work (Figure 10 and 11) by means of a 3D modeling software based on CAD – *(Computer-Aided Design)*.

An scaled model (1:6) was developed at Laboratório Didático de Materiais e Protótipos (LDMP) in order to test not only the wood joints, but also the workstation's stability (Figure 12).

From the parameters of the Figure 13 drawing, the workstation was CNC milled (Figures 14 and 15). The milling time was 33 minutes and 47 seconds.

After milling, the assembly took place and the wood joints and stability were tested as it can be seen in Figure 16. Once having the tests done it was confirmed a high level of stability for the workstation as well as a high level of precision for the wood joints. However, its long central

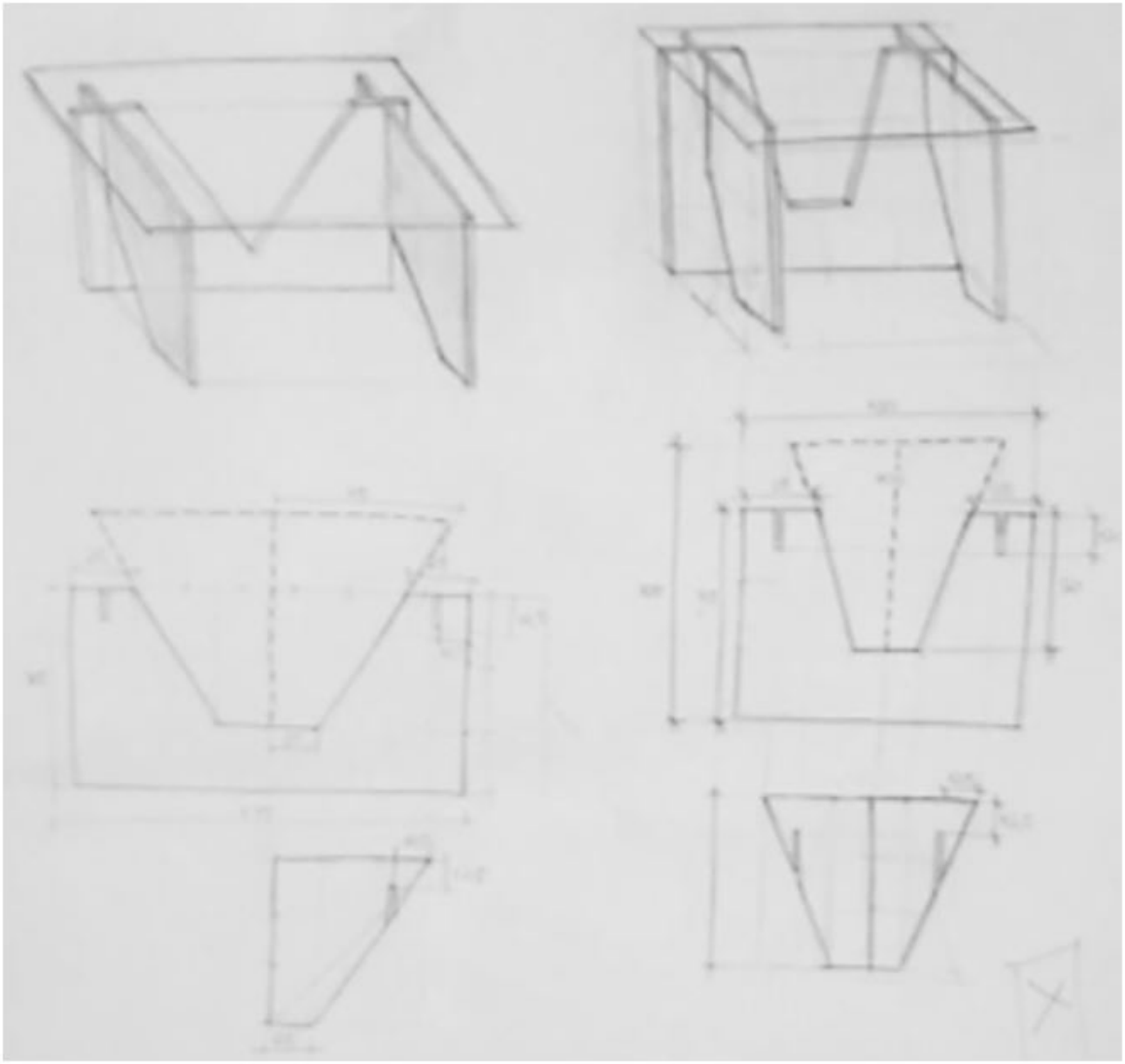

Figure 6. drafts and parts planning.

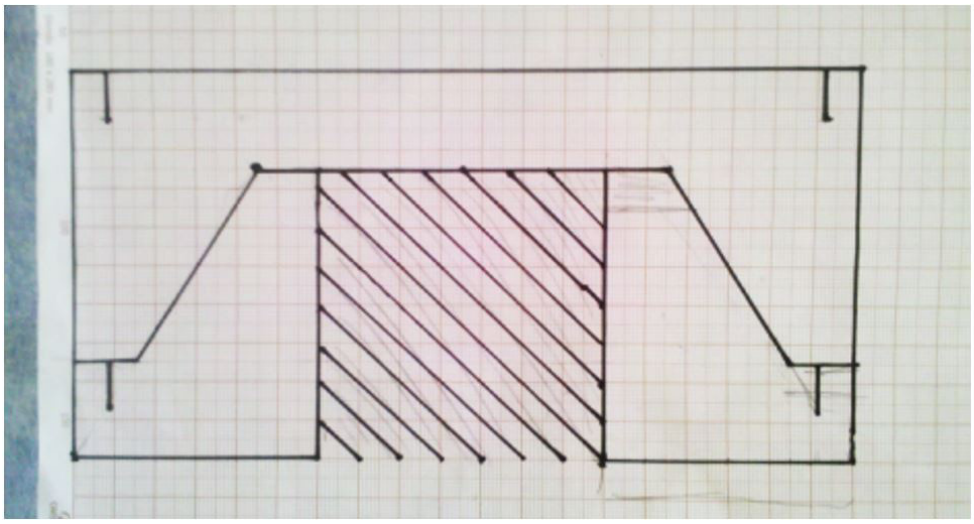

Figure 7. Planning with the biggest angle as possible.

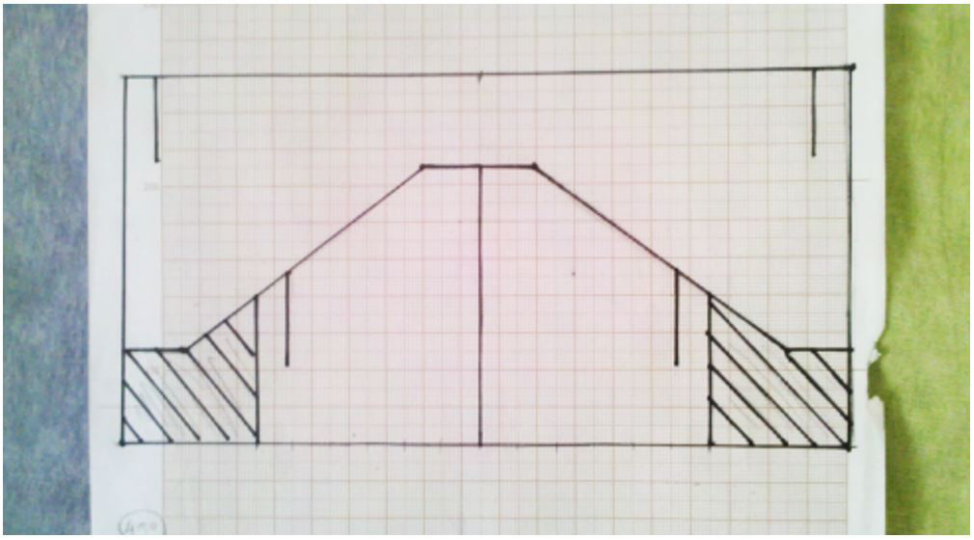

Figure 8. Planning with the smallest angle as possible.

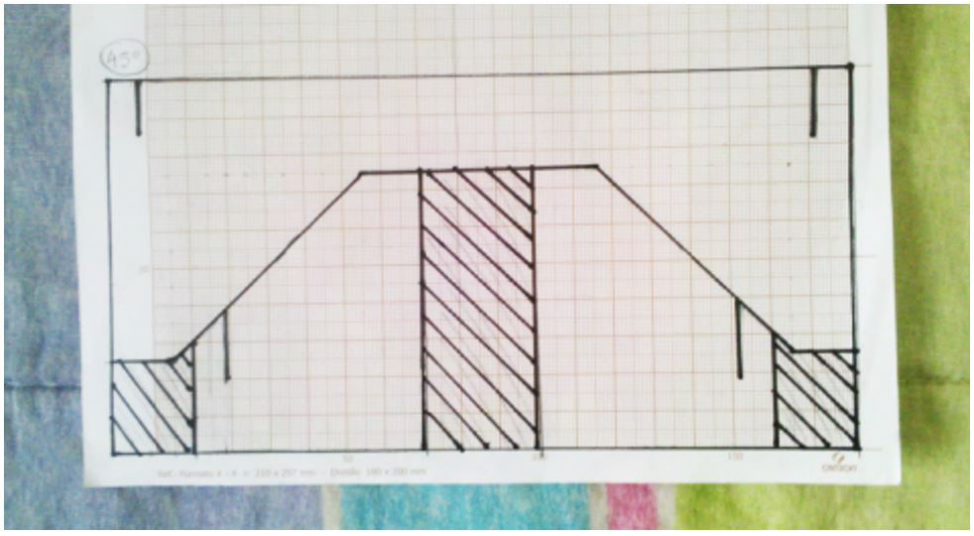

Figure 9. Planning with 45° angle.

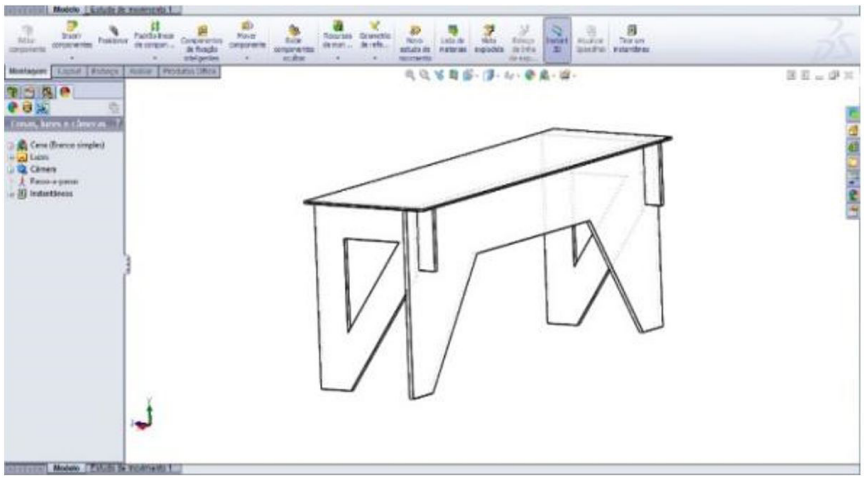

Figure 10. Virtual modeling.

Figure 11. *Rendering.*

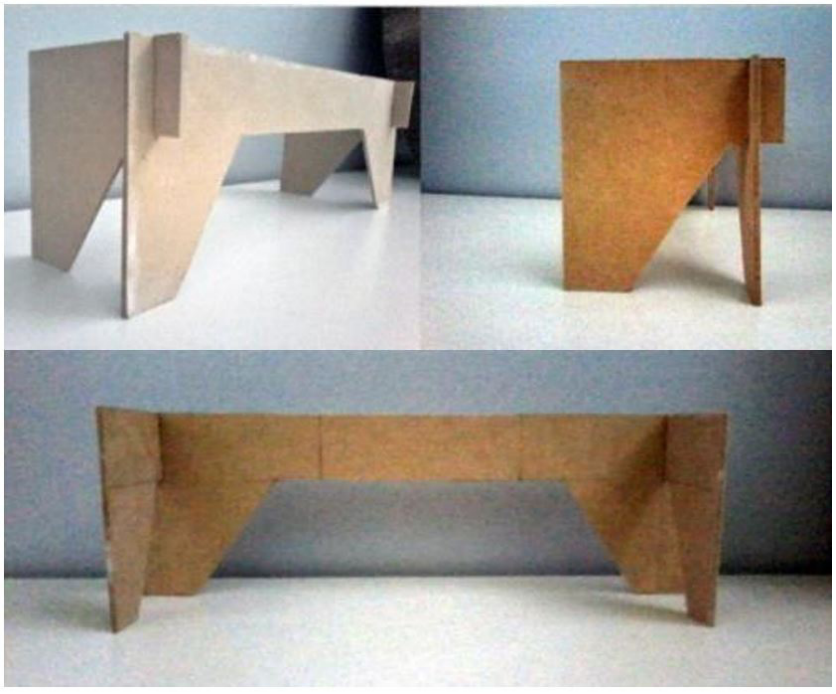

Figure 12. MDF scaled model

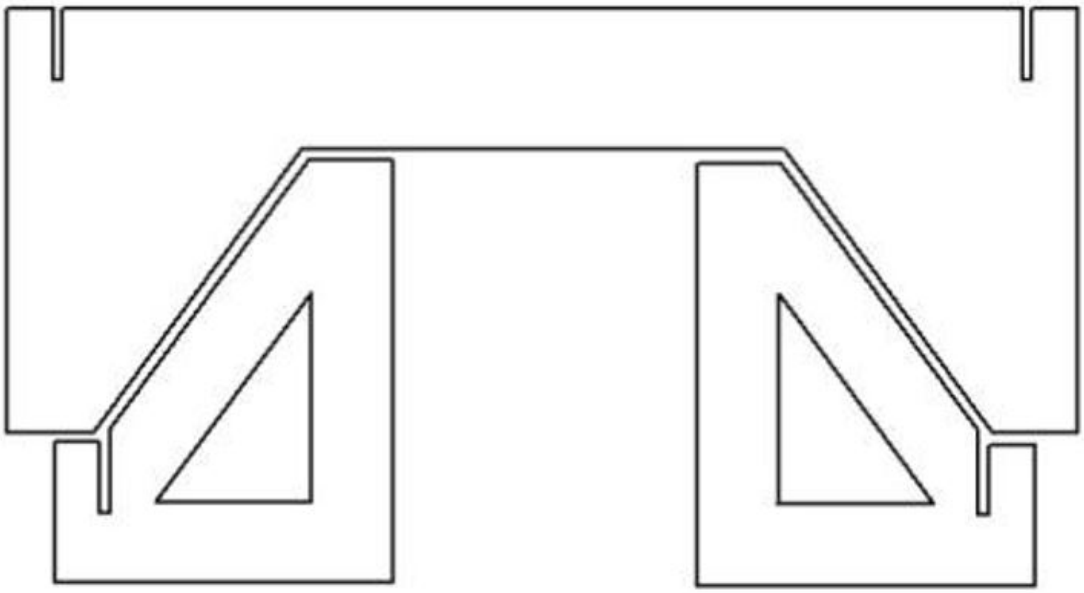

Figure 13. Workstation vetoring.

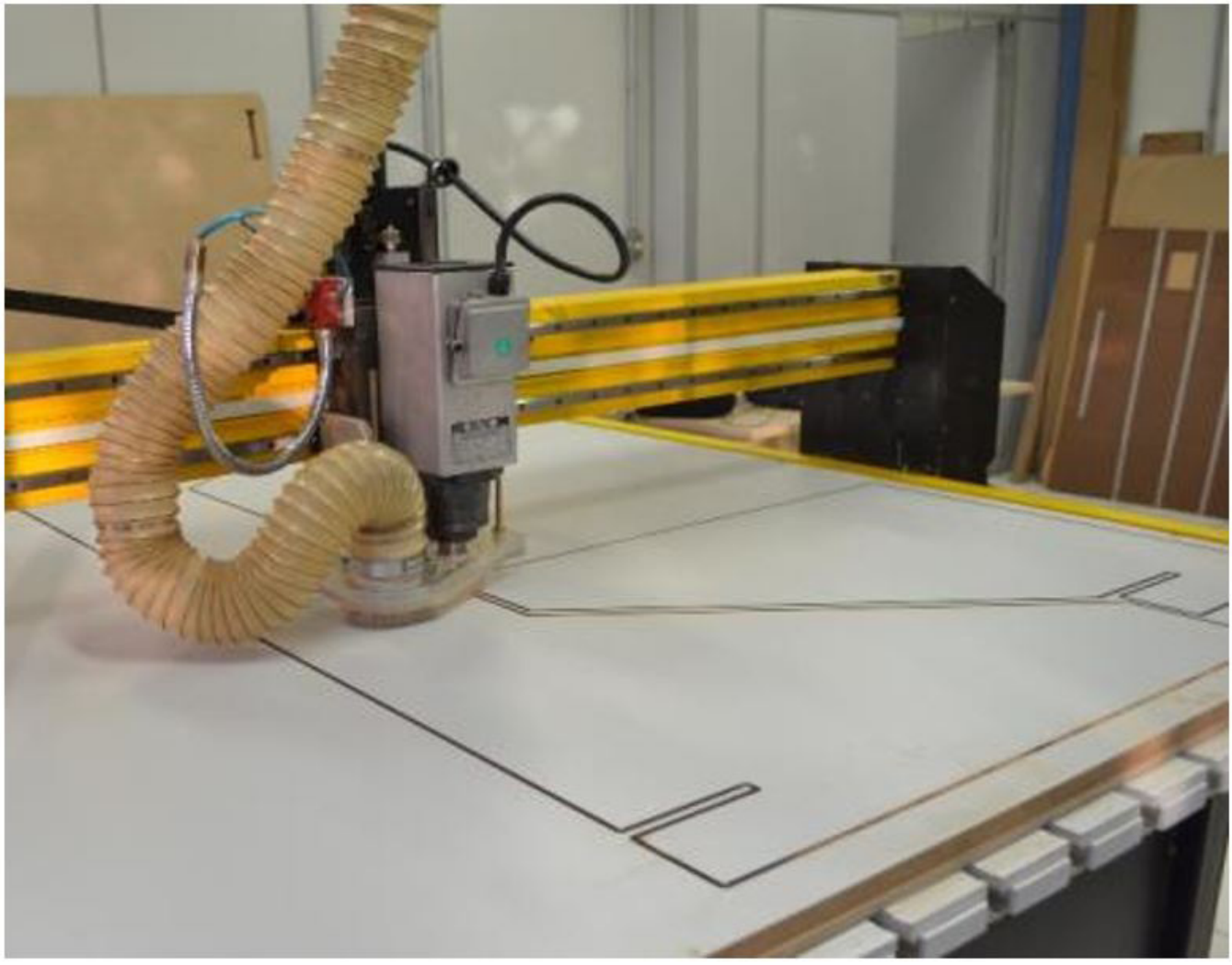

Figure 14. CNC router milling the parts.

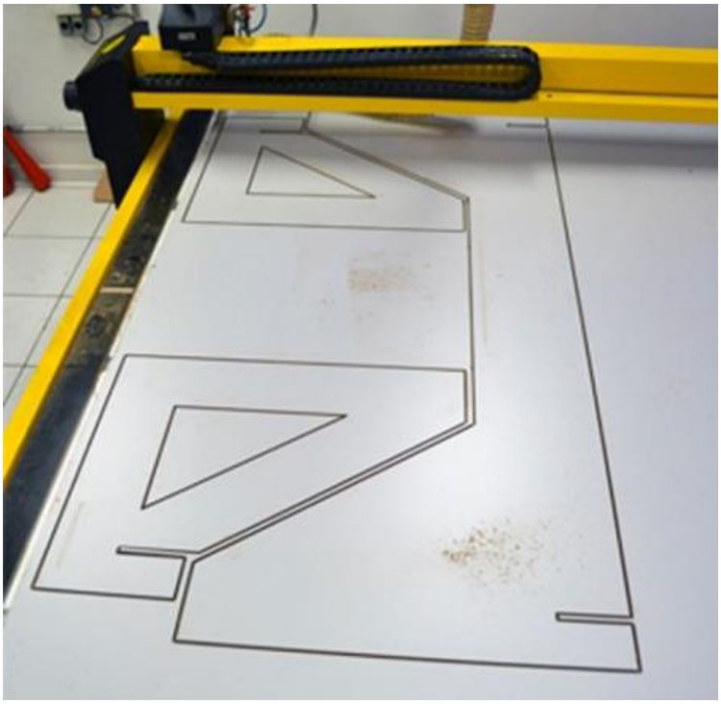

Figure 15. CNC router milling the parts.

Figure 16. Tests of assembly and usage.

gap turn the glass sheet flexible, and therefore, the design was reviewed and a lock positioned in the front of it was installed to solve this problem, as it can be seen in Figure 17.

Having all the milling work done, it was then produced a book shelf to share the same room with the workstation and the meeting table, following the same methodology: and sketches of design concepts (a), virtual modelling and rendering (b), and a prototype (c), as it can be seen in Figures 18 and 19.

The meeting table finishing includes adjustable feet and silicone drops to support the glass with 8 mm of thickness. The shelf uses a invisible support to fix it on the wall. In the end three prototypes were produced as it can be seen in Figures 20, 21 and 22.

Figure 17. Workstation Rendering.

Figure 18. Meeting table development - hand sketches of design concepts (a), virtual modelling rendering (b) and a prototype (c).

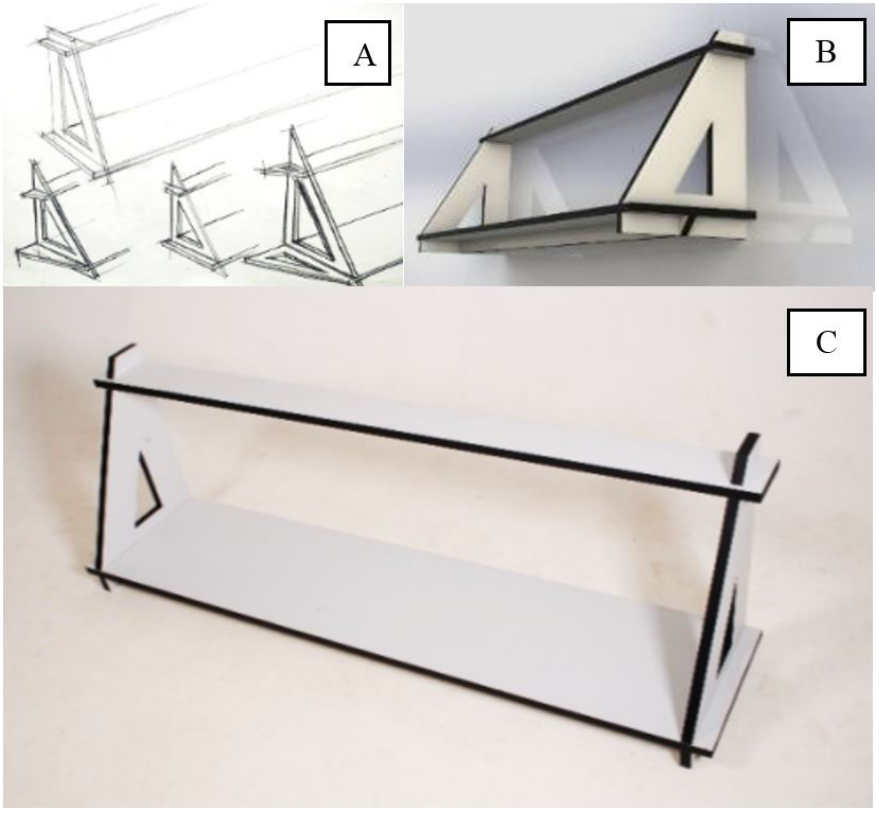

Figure 19. Shelf development" - hand sketches of design concepts (a), virtual modelling rendering (b) and a prototype (c).

Figure 20. Workstation prototype.

Figure 21. Shelf prototype.

Figure 22. Meeting table Prototype.

5. Conclusions

The methodology adopted in this work results in the production of furniture aligned with the objectives initially proposed, reinforced for three main aspects: a) the inclusion of sustainability concepts in product design; b) the design development based on hand sketches, physical scaled models and virtual modelling resources; c) in house production of prototypes.

It was confirmed that a methodological structure focused in the integration among the materials and research of similar steps, virtual and physical modeling were crucial to the concept generation process, supporting the prototypes production in the Lab.

It was also possible to understand the different possibilities presented by the material, as well as its limitations through the similar research. The research regards the wood joints shows different options of what could be created, expanding the range of ideas that were then sketched in the next phase.

The virtual modeling process helped to determine the right dimensions as well as to generate a file based on vectors, which in this case, is readable by the CNC router used for this job. The compatibility between both softwares is a facilitator, due to the fact that there is a product in 3D, and also a product in 2D, for milling. The rendering development also contributed to the visual aspect of the design, being possible to apply different finishing, not only in terms of color, but also bringing a realistic aspect to the virtual model.

In relation to the scaled models production, it was shown the importance of this process not only to visualize the object real shapes, but also to verify how those shapes could be milled and assembled.

The prototype assembly was necessary in order to validate the entire design. When one of its requirements failed, it is necessary to present other viable alternatives, taking into account their adaptation to the original briefing or something new shall be considered. Using a methodology based on verification the workstation was adapted having a lock incorporated to it offering more stability and a better usage of it. This lock demanded to be adjusted by a band saw in order to better fit the wood joints.

Regarding the adoption of the MDF in the prototypes production, some points have to be considered:

- The material presented adequate performance during its milling, without any damage to the layer of melamine covering the sheets;
- The decision for the material with melamine covering was based on the fact that all the parts once milled could be leave the CNC machine ready for assembly, demanding just final finishing;
- This melamine covering also offered in different options of color.

The adoption of wood joints in conjunction with the adoption of a CNC milling machine were decisive to ensure precision and stability to the furniture. Moreover, the presence of the wood joints also facilitates the transportation as well as the maintenance of the parts.

Regarding the fabrication analysis of the products, some aspects can be point out, as follows:

- The workstation presented adequate height for its purpose. However, as said before, it was necessary to add a special device (lock) to support the glass;
- It was verified that after the assembly the design confirms an adequate level of structural resistance of it. However, it generates a small limitation in terms of mobility for the users' legs, in particular from the small face of it.

To conclude, the furniture fulfils the proposal objectives, presenting an alternative that is able to accomplish different sustainable aspects, using MDF sheets.

6. Acknowledgements

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