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Cleaner Production Applied in a Small Furniture Industry in Brazil: Addressing Focused Changes in Design to Reduce Waste

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Abstract: The wood industry is known for being among the biggest resource consumers, having a relatively low yield. The wood furniture industry as part of the wood industry also remains a big generator of residues and a big consumer of resources. Diverse solutions and technologies have been developed to deal with the residues generated, but those technologies are mostly applied at the end of the production chain with limited results. Cleaner production represents a program based on continuous strategies applied to a more sustainable use of materials and energy, minimizing waste and pollution. This paper presents a case study of a cleaner production program developed in a small furniture industry in Salvador de Bahia, Brazil, applying the concepts of cleaner production with parameters of ecodesign developed for the furniture industry. The object of study was the production of a wooden chair made from eucalyptus wood. The application of the cleaner production program and ecodesign parameters allowed a detailed characterization of the waste, resulting in opportunities for a reduction of the use of raw material by 30%, a reduction in waste by 49% and allowing a reduction in energy by 36% due to simplification of the productive process. Among the strategies applied were reshaping pieces, redesigning, and the substitution of materials. The results suggest that despite the existence of more complex environmental methods and approaches, the application of cleaner production plus ecodesign parameters could be more achievable for micro and small furniture industries.

Keywords: cleaner production; wood; waste; ecodesign; furniture

1. Introduction

The production and mass consumption of industrial products have caused natural resources to be used in an unbalanced way, generating large amounts of waste. The wood industry is one of the highest consumers of these resources. The yield reported in the wood industry in Brazil varies from values as low as 30% [1] up to 75% [2], mainly due the different production process, type of wood and technology. Despite the differences in the yield, the common ground is the acknowledgement of the wood industry as a major waste generator.

Due to this reality, the wood industry has sought to improve processes, making the most of the waste generated to be used in the production of other sub-products, consequently adding value to the production chain. Companies have their own interest in developing processes that are more environmentally friendly and customers are increasingly interested in environmental performance and product impacts [3].

In Brazil, the wooden furniture sector is an important division of the wood industry, reaching nearly 430 million goods sold by 2015 with a value of US $16.54 billon [4]. Despite such values, the wooden furniture sector in Brazil has characteristics that make it the object of continuous studies: as per the National Bank of Economic and Social Development [5], the sector of wooden furniture in Brazil is considered one of the most traditional activities in industry, with high use of natural resources, labor-intensive processes, low technological dynamism and a high level of informality [5]. Most of the wooden furniture producers in Brazil are classified as microenterprises or small enterprises [5], and generally they don't have consolidated environmental control systems. For this reason, the diagnostic studies for this sector help companies with proposals to reduce impacts and improve productivity through techniques for the rational use of raw materials and the reuse and recycling of waste [6]. Among the proposals is the implementation of Cleaner Production (CP) programs.

Cleaner production is a continuous program for increase the efficiency in the use of raw materials, water and energy through the mitigation of waste and energy misuses in the industry and service sectors [7], focusing on the application of continued integrated environmental strategies that have now evolved towards sustainability.

One relevant capacity of CP is that during its implementation it is possible to combine it with other environmental principles, methods or tools in order to increase even further the efficiency in the use of resources and to reduce the waste.

This paper presents the application of a CP program in a small size wood enterprise in Brazil, following the specific implementation methodology developed by the National Center for Clean Technologies (CNTL) in combination with several ecodesign principles applied in the production process of a eucalyptus wooden chair. The results, discussion and conclusion of this work are expected to help to promote the use of CP and ecodesign principles as suitable programs and principles to be implemented in micro and small size companies in Brazil, addressing at the same time the widespread paradigm that claims that implementing environmental programs is reserved only for the medium to large companies.

Literature Review

The United Nations Environment Program (UNEP) defined cleaner production as "the continuous application of an integrated environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment" [7]. As shown in Figure 1, this has been developing toward a more holistic definition. Indicated in the same timeline are the contribution of the United Nations Industrial Development Organization (UNIDO), the Environmental Agency for the State of Sao Paulo, Brazil (CETESB), the National Center for Clean Technologies (CNTL) and the National Service of Industrial Learning (SENAI).

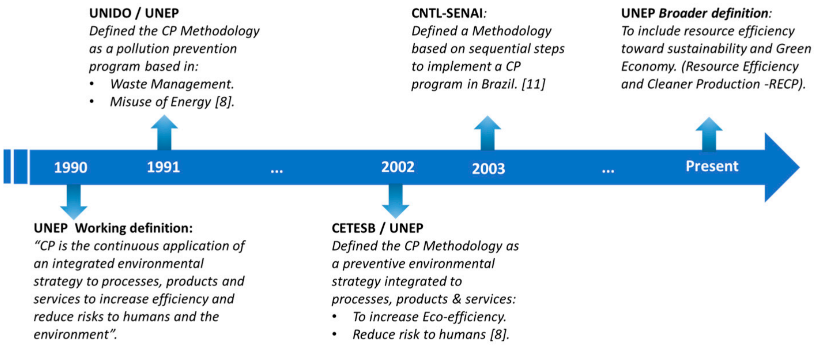


Figure 1. Selected stages in the definition of CP programs.

The evolution of the definition was in line with the development of environmental practices, whose origins were focused on the destruction of the residues once generated, either by disposal, treatment or recycling [8], but nowadays such focus has also evolved to the pursuit of sustainable consumption [8], resource efficiency and green economy [7].

According to the Brazilian Business Council for Sustainable Development (CEBDS), the waste generated has a high cost for the company, not only because it was purchased at raw material prices or because it consumed other resources during the production process (such as water or energy), but also because it might include final disposal cost, environmental fines or cause damage to the company's reputation [9]. CP proposes changes, encouraging the whole company to think of different proposals and more economical or intelligent ways to produce. It also aims, through the reduction of waste and emissions, to link production processes to environmental objectives.

The implementation of CP programs presents multiple advantages:

- It requires commitment from management, staff and operational levels, focused on a continuous improvement approach [10].
- It includes a defined methodology for the implementation [10].
- It can produce economic benefits such as reducing operating costs of materials and processes [11].
- It can improve the image of the company [9].
- It can be implemented from low-cost levels (self-sourced) to high-cost levels (financial assessment), depending on the cases and the scope of the program.

The methodology for implementation included in CP programs is composed of a sequence of steps that include a feasibility analysis. This step aims to find opportunities for waste reduction and efficiency in resource consumption, that can be addressed in a combination of different tools, methods or approaches. One of the most used approaches is ecodesign.

Ecodesign consists of developing and re-thinking products, processes or services to be respectful of the environment [12] by choosing materials and manufacturing processes, and designing the use and final disposal while developing a new product, i.e., determining the environmental impact of the product during the life cycle [12,13].

One of the earliest attempts to address design considerations toward the environment was developed in 1974 by Victor Papanek, who classified the developing of new products in a 6-stage framework, indicating that the potential environmental impacts should be considered in all of the stages: selecting materials, production, packaging, finishing, transport and waste generation [14].

The wooden furniture industry in Brazil has also developed their own framework toward ecodesign. One example is the guide for introducing environmental parameters in wooden furniture designs, developed at the University of Minas Gerais in 2010. The parameters presented in Table 1, were developed specifically for the wood furniture industry in Brazil.

Table 1. Environmental design parameters. Source: [15].

Category	Refers to:
Reduce	The reduction of raw materials, simplification of the furniture structure, rethinking of cutting processes, and reuse and recycling of residues among others.
Facilitate	Design of new systems to facilitate the assembly of the furniture with fewer pieces and fewer tools.
Extend lifespan	Offers maintenance packages for the furniture to expand the lifespan.
Select	Use of alternative wood types (including composed) and the use of certified wood sources.
Valorize the difference	Let the customers know the new aspect of the furniture to highlight the efforts to turn "green".

The concepts of CP and ecodesign are particularly applicable for the furniture industry in Brazil, due to their characterization: general agglomeration of production processes, the use of organic raw materials and the intensive use of labor resulting in a very large range of final products [16] with a strong fragmentation, technological diversity and vertical integration [17] combined with a predominance of micro and small companies with limited resources both administratively and financially [18].

The Brazilian Institute of Geography and Statistics (IBGE) classifies the size of the industries according to the number of permanent employees: microenterprise (less than 19 employees), small enterprises (between 20 and 99 employees), medium enterprise (between 100 and 499 employees) and big enterprise (more than 500 employees). Such distribution gives perspective regarding the wooden furniture sector in Brazil. For example, a survey developed in the state of Rio de Janeiro in 2015 characterized the distribution of the furniture wood industries as being 70.8% microenterprises, 25.8% small enterprises and 3.4% medium enterprises [19], and was considered a good representative of enterprise distribution in Brazil. When analyzing that distribution along with different approaches suitable to be combined with CP programs (as shown in Figure 2) the convenience of using CP plus ecodesign for the micro and small wooden furniture enterprises is highlighted.

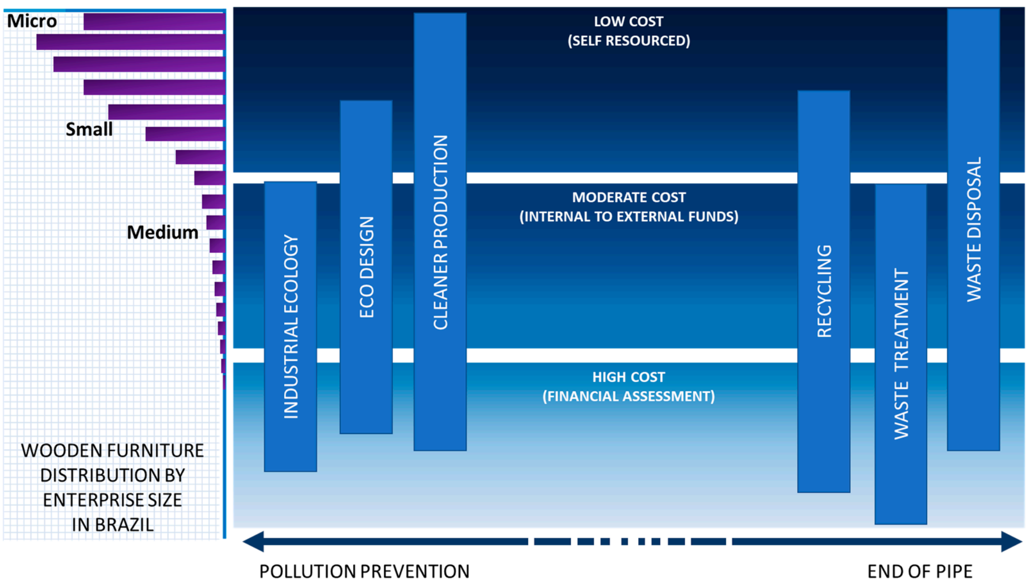


Figure 2. Wooden furniture enterprises size distribution analyzed along with some environmental approaches and methods.

As a result, the focus of this paper pursues the application of a combination of CP plus ecodesign as a suitable combination accessible for micro and small companies who are interested in improvement focused on prevention instead of end-of-pipe solutions.

2. Materials and Method

2.1. Characterization of the Object of Study

The study took place in a wooden furniture industry located in Salvador Bahia, Brazil. Due to the number of employees, it is classified as a small enterprise as per the IBGE classification. The enterprise produces home and office furniture such as tables, desks, cabins and chairs but can produce a diverse range of products, since it has invested in specialized wood machinery, therefore it has the capacity to produce a wide variety of goods.

By the time the study took place, the key product was a eucalyptus wooden chair (L1 model) designed to be used in the food court of shopping centers. The volume of production contracted represents more than the 60% of the daily goods produced by the company, becoming the object of analysis. Figure 3 presents a sketch of the wooden chair with its different components.

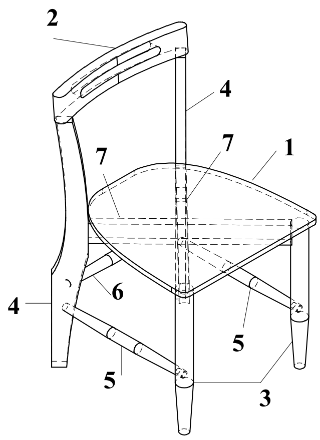


Figure 3. Parts of the wooden chair: 1-Seat; 2-Backrest; 3-Front leg (two); 4-Rear leg (two); 5-Side rail (two); 6-Back rail; 7-X Rail (two).

The general process to produce the wooden chair is based on taking the raw material (Eucalyptus *urophylla* boards, dimension 20 × 30 × 2000 mm delivered by the supplier with specific conditions of humidity and quality) and cutting it into smaller rectangular pieces close to the final size of the pieces to be transformed. In the case of the seat and backrest, such pieces are made of smaller slats that are cut, glued and pressed to constitute boards or blocks to be cut and sculpted before being transformed into its final shape. The different pieces require a series of machinery to be used to perform specific tasks on the pieces being transformed. Table 2 presents the list of the utilities used in the production process of the L1 chair.

Table 2. List of utilities used in the production of the L1 wooden chair.

Utilities	Work Areas
(1) Circular saw	(A) Assembly area
(2) Jointer	(B) Finishing area
(3) Straight line ripsaw	
(4) Four-sided-planer	
(5) Thicknesser planer	
(6) Band saw	
(7) Sander	
(8) Sliding table	
(9) Drilling machine	
(10) Wood lathe	
(11) Milling duplicator	
(12) Horizontal milling	
(13) Wood press	
(14) Air compressor	

At the end of the process, two stations A and B are used to perform the assembly and the finishing of the chair. Figure 4 presents a general description of the process. The size of the arrows suggests the relative contribution to the process.

The inputs of the system are defined as materials, consumables and expendables. The outputs are composed of the products, the wood residues and other expendables residues.

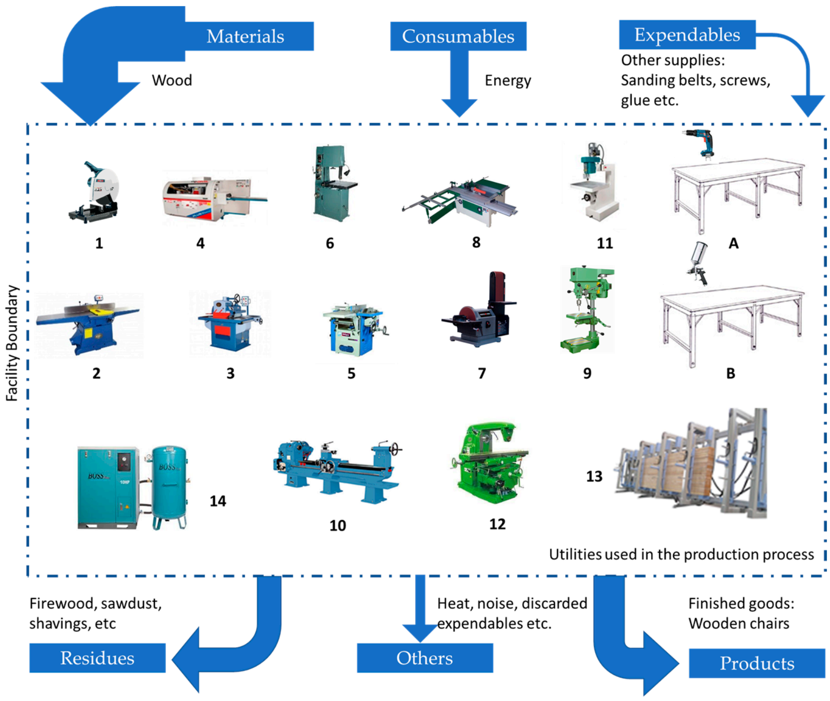


Figure 4. General production process and utilities involved in the production of the L1 wooden chair.

Measurements and data were collected in April 2016. The equipment used to measure the components of the chair and the sorted waste was a precision balance model Mark L2102i with 2100 g capacity and 0.01 g resolution, with automatic internal calibration. The individual process time register of each workstation was measured using a chronometer.

2.2. Method

The methodology applied was the one defined by the Cleaner Production Program, developed by the National Center for Clean Technologies (CNTL) in Brazil. The results and findings of CP then became the inputs for the application of ecodesign parameters as proposed by [15], to identify and achieve the environmental gains for the case study analyzed.

The selection of the eucalyptus wooden chair as the object of study was made from an analytical approach, i.e., one single chair was selected and analyzed in detail throughout the entire production process, component by component. This approach was preferred instead of selecting a statistical sample since the objective was not to enumerate frequencies [20] or tolerances in the production process, but to identify opportunities for environmental improvements by the combination of the methods of CP and ecodesign.

The production process was analyzed by direct observation and recorded for validation of procedures. The values of the weight of the pieces and the waste generated were conciliated using Stan® software version 2.5.1302 (Institute for Water Quality, Resources and Waste Management Vienna University of Technology Karlsplatz 13, A-1040, Vienna, Austria). The power requirement of all the wood equipment was taken directly from the placard of the manufacturer of each piece of equipment involved in the production, and the consumption was estimated by multiplying the process time by the power requirement and considering the efficiency declared for each machine. The process of data collection includes: cleaning and preparation of the work area (equipment and material), measuring of initial conditions (weight of the pieces before procedure and power requirements of equipment), direct observation and record of the procedure of transformation carried out by a qualified operator, sorting and classification of the waste generated, weighing of the final component and sorted waste, and the conciliation of values.

The specific methodology developed by the CNTL when implementing CP programs, despite not being mandatory, constitutes an organized and sequential guide easily understood and suitable for micro and small wooden furniture companies. The methodology consists of the following steps:

- Planning and organization, where the company was selected, defining the organizational context considering the size of the company, the type of management and the number of employees, differentiating the administrative level from the operative workforce.
- Pre-evaluation. In this stage, the product was selected considering its relevance in the productive process and in the key aspects of the study, generally represented in a detailed list of a flow diagram of the production process.
- Evaluation. Here the mass balance was calculated for every step of the production process, by quantifying the inputs and outputs generated in each process, identifying the sources and causes of waste in materials, energy and water. Analysis of the flowchart, brainstorming and mass balances were made to identify CP opportunities.
- Feasibility study and implementation. In these final steps, product modification is implemented with the purpose of reducing material consumption and energy consumption, along with the related reduction in waste. At this stage a new design is proposed considering ecodesign parameters. The proposed product changes directly affect the production, and therefore, the residues and energy consumption.

3. Results

3.1. Planning and Organization

The case study was developed in a small enterprise classified as per Brazilian Law 123/06 regarding their annual income [21], and by the number of employees since it has 22 permanent employees (IBGE criteria). The geographical location of the company does not correspond to a specific furniture cluster, despite being in an industrial zone. For the project, a cleaner production team was assembled consisting of the general manager, the chief of the workshop, the senior carpenter and two consultants in CP. All the members of the team received a basic training on the CP principles. The objectives, scope and work schedule was defined during this stage.

3.2. Pre-Evaluation

The selection of the wooden chair was based on its sales importance, as it predominated nearly 40% of the total sales of the company. Due to the chair design, production involves most of the equipment of the company, therefore it is also considered the main consumer of resources and generator of solid waste. Table 3 presents the stages to production, indicating the inputs and outputs factors. The descriptive framework is intended to facilitate recognition of all the procedures involved in order to avoid overseeing any relevant step.

Table 3. Operations required for producing L1 chair.

	Inputs	Operations	Outputs
1	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
2	Electric energy	Cutting, flattened surfice of the plank	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
3	Electric energy, compressed air, glue multibond, roll	Pressing the ribbons	Glue, heat, noise, energy losses
4	Electric energy	Duplicating the seat	Woodchips, sawdust, air output, heat, noise, energy losses

Table 3. *Cont.*

	Inputs	Operations	Outputs
5	Electric energy	Drilling the seat	Woodchips, sawdust, air output, heat, noise, energy losses
6	Electric energy, sandpaper	Sanding the seat	Sawdust, air output, heat, noise, energy losses
7		Assembling the seat	
8	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
9	Electric energy	Cutting, flattened surfice of the ribbons	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
10	Electric energy, compressed air, glue multibond, roll	Pressing the ribbons	Glue, heat, noise, energy losses
11	Electric energy	Sanding the backrest	Firewood, sawdust, air output, heat, noise, energy losses
12	Electric energy	Drilling the backrest	Woodchips, sawdust, air output, heat, noise, energy losses
13	Electric energy, sandpaper	Sanding the backrest	Sawdust, air output, heat, noise, energy losses
14		Assembling the backrest	
15	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
16	Electric energy	Cutting, flattened surfice of the ribbons	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
17	Electric energy, compressed air, glue multibond, roll	Pressing the ribbons	Glue, heat, noise, energy losses
18	Wood, electric energy	Multiple cuts, angular rectification of the front leg	Sawdust, air output, heat, noise, energy losses
19	Electric energy	Cutting, flattened surfice of the front leg	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
20	Electric energy	Drilling the front leg	Woodchips, sawdust, air output, heat, noise, energy losses
21	Electric energy	Woodturning the front leg	Woodchips, sawdust, air output, heat, noise, energy losses
22		Assembling the front leg	
23	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
24	Electric energy	Cutting, flattened surfice of the plank	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
25	Electric energy	Sanding the plank	Firewood, sawdust, air output, heat, noise, energy losses
26	Electric energy	Duplicating the rear leg	Woodchips, sawdust, air output, heat, noise, energy losses
27	Electric energy	Horizontal milling of the rear leg	Woodchips, sawdust, air output, heat, noise, energy losses
28	Electric energy	Drilling the rear leg	Woodchips, sawdust, air output, heat, noise, energy losses
29		Assembling the rear leg	
30	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
31	Electric energy	Cutting, square cutting the side spindle	Woodchips, firewood, sawdust, air output, heat, noise, energy losses

Table 3. *Cont.*

	Inputs	Operations	Outputs
32	Electric energy	Woodturning the side spindle	Woodchips, sawdust, air output, heat, noise, energy losses
33		Assembling the side spindle	
34	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
35	Electric energy	Cutting, flattened surfice of the rear spindle	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
36	Electric energy	Woodturning the rear spindle	Woodchips, sawdust, air output, heat, noise, energy losses
37		Assembling the rear spindle	
38	Wood, electric energy	Multiple cuts, angular rectification of the plank	Sawdust, air output, heat, noise, energy losses
39	Electric energy	Cutting, square cutting the plank	Woodchips, firewood, sawdust, air output, heat, noise, energy losses
40	Electric energy	Drilling the X rail	Woodchips, sawdust, air output, heat, noise, energy losses
41	Wood, electric energy	Multiple cuts, angular rectification of the X rail	Sawdust, air output, heat, noise, energy losses
42		Assembling the X rail	
43	Electric energy, sandpaper	Sanding the chair	Sawdust, air output, heat, noise, energy losses
44	Ink, electric energy, compressed air, solvents	Finishing the chair	Cano of ink, ink in the air, solvents in the air
45	Plastic, paperboard, metal tape, plastic tape	Packaging the chair	Plastic leftovers, paperboard, metal tape, plastic tape

3.3. Evaluation

The data from the framework was used to identify the relevant process where waste was generated. It was identified that the main material involved was the eucalyptus wood being transformed. The quantities of water and other spendable materials such as glue, paint, solvent and drills represented less than 2% of the final product weight. Therefore, the focus was placed on the wood used and the energy required for the production. As a result, the input/output quantification shown in Table 4 summarizes the values measured in the evaluation.

Table 4. Inputs and outputs for energy and mass for the wooden chair.

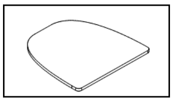
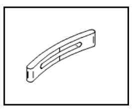
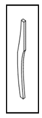
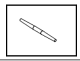
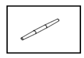
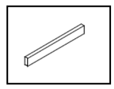
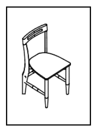
	Inputs		Process	Outputs		
No	Raw Material Eucalyptus Wood g	Energy kWh (Input Power)	Stages	Outputs, g of Wood Residues	Losses of Energy kWh	Pieces
1	3283.62	2.79×10^{-1}	1	131.34	5.82×10^{-2}	
		1.15×10^{-2}	2	163.92	3.22×10^{-3}	
		6.90×10^{-2}	3	0.00	1.93×10^{-2}	
		9.65×10^{-3}	4	597.67	2.70×10^{-3}	
		1.73×10^{-3}	5	167.35	4.83×10^{-4}	
		8.63×10^{-3}	6	155.63	2.42×10^{-3}	
2	1150.32	2.64×10^{-1}	8	46.01	5.42×10^{-2}	
		1.15×10^{-2}	9	57.42	3.22×10^{-3}	
		6.90×10^{-2}	10	0.00	1.93×10^{-2}	
		8.63×10^{-2}	11	261.72	2.42×10^{-3}	
		1.73×10^{-2}	12	78.52	4.83×10^{-4}	
		8.63×10^{-3}	13	116.60	2.42×10^{-4}	
			14			

Table 4. *Cont.*

	Inputs		Process	Outputs		
No	**Raw Material Eucalyptus Wood g**	**Energy kWh (Input Power)**	**Stages**	**Outputs, g of Wood Residues**	**Losses of Energy kWh**	**Pieces**
3	1324.03	5.58×10^{-1}	15	79.44	1.16×10^{-1}	
		2.30×10^{-2}	16	74.68	6.44×10^{-3}	
		1.38×10^{-1}	17	0.00	3.87×10^{-2}	
		5.58×10^{-1}	18	46.80	1.16×10^{-1}	
		2.30×10^{-2}	19	44.92	6.44×10^{-3}	
		3.45×10^{-3}	20	43.13	9.67×10^{-4}	
		6.17×10^{-2}	21	251.52	1.73×10^{-2}	
4	2179.74	5.58×10^{-1}	23	152.58	1.16×10^{-1}	
		2.30×10^{-2}	24	121.63	6.44×10^{-3}	
		1.73×10^{-2}	25	756.49	4.83×10^{-3}	
		6.17×10^{-2}	26	91.92	1.73×10^{-2}	
		5.18×10^{-2}	27	52.86	1.45×10^{-2}	
		3.45×10^{-3}	28	20.09	9.67×10^{-4}	
5	672.24	5.58×10^{-1}	30	26.89	1.16×10^{-1}	
		2.30×10^{-2}	31	38.72	6.44×10^{-3}	
		6.17×10^{-2}	32	254.78	1.73×10^{-2}	
6	283.12	2.79×10^{-1}	34	11.32	5.82×10^{-2}	
		1.15×10^{-2}	35	16.31	3.22×10^{-3}	
		3.09×10^{-2}	36	107.30	8.64×10^{-3}	
7	1399.26	5.58×10^{-1}	38	69.96	1.16×10^{-1}	
		2.30×10^{-2}	39	39.88	6.44×10^{-3}	
		3.45×10^{-3}	40	95.42	9.67×10^{-4}	
		5.58×10^{-1}	41	78.07	1.16×10^{-1}	
		3.45×10^{-2}	43	258.11	9.67×10^{-3}	
		3.45×10^{-2}	44		9.67×10^{-3}	
			45			
	10,292.33	**5.00**		**4509.01**	**1.10**	
	grams of eucalyptus wood to produce a chair	kWh demand of the network	**Total**	grams of wood in the form of sawdust, splinters, tips, woodchips and others	energy losses in motors and systems due inefficiency: heat, noise, vibrations and others	
				43.81%	**22.05%**	

The results of the evaluation indicate a yield of 43.81% in the use of wood. The result is found within the typical range of yied values in wood furniture industries. The energy consumption was related to the manufacturing process of every piece and the efficiencies of the electrical engines of every machine involved. The characterization of the waste generated in every step is shown in Table 5.

Table 5. Wood yields per component of the wooden chair (g).

	Piece	**Inputs**	**Outputs**				**Total Losses**	
		Wood	**Wood Shavings**	**Firewood**	**Sawdust**	**Others**	**Losses**	**%**
1	Seat	3283.62	674.77	361.88	167.45	11.81	1215.92	37.03%
2	Backrest	1150.32	153.79	281.71	85.35	39.42	560.27	48.71%
3	Front Leg (2)	1324.03	378.49	135.64	19.37	6.97	540.49	40.82%
4	Rear Leg (2)	2179.74	293.21	768.29	124.74	9.32	1195.57	54.85%
5	Side Spindle (2)	672.24	279.65	32.27	6.55	1.92	320.39	47.66%
6	Rear Spindle	283.12	117.78	13.59	2.76	0.81	134.94	47.66%
7	X Rail (2)	1399.26	144.25	110.31	23.53	5.24	283.33	20.25%
	Assemble				193.58	64.53	258.11	
	Total	10,292.33	2041.95	1703.70	623.33	140.03	4509.01	
	% losses	100%	19.84%	16.55%	6.06%	1.36%		43.81%

The characterization of the total waste of 43.81% can also be expressed in relative values as follows: 13.82% sawdust, 45.29% brush and 37.78% firewood, with a balance of 3.11% air releases. Typical values of such losses in the timber industry are 14% for sawdust, 18% for wood shavings and 68% for firewood [22]. Such values can also be seen in Figure 5, expressed in mass.

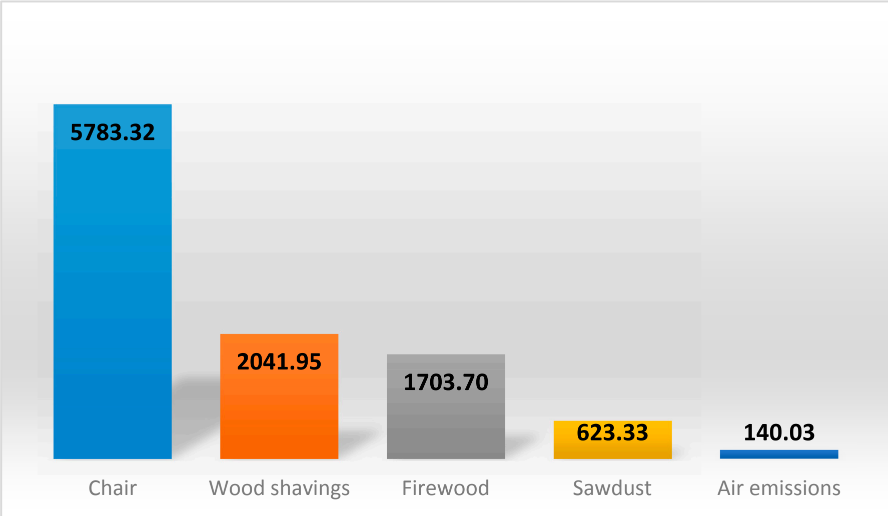


Figure 5. Wood utilization in the production of the chair (g).

When analyzing the assembly of the wooden chair, it is noted that the main loss of material was during the production of the seat (1216 g equivalent to 31.90% of the wood used), in second place was the rear leg (1196 g equivalent to 21.18% of the wood used) and in third place the backrest (560 g equivalent to 11.18% of the wood used). Those three items represented more than 64% of the total material losses (see Figure 6).

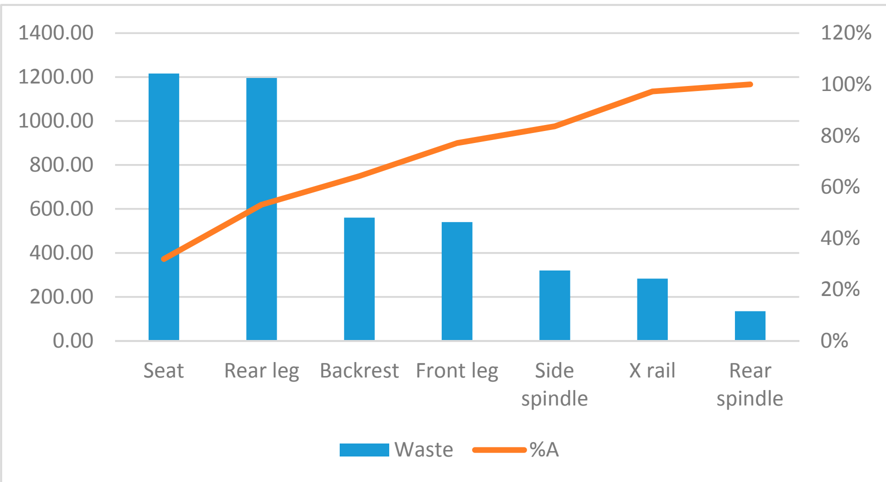


Figure 6. Pareto Chart of the chair components and their usage of material.

The type of production process is also important to analyze since the type of waste can indicate a process subject to be improved or replaced. Applying this approach, it is noted that for the rear leg, the most representative residue was firewood (768 g), mostly due to the production process used. For the backrest it was also firewood (282 g) whereas for the seat the main type of loss was wood shavings (675 g) (see Figure 7).

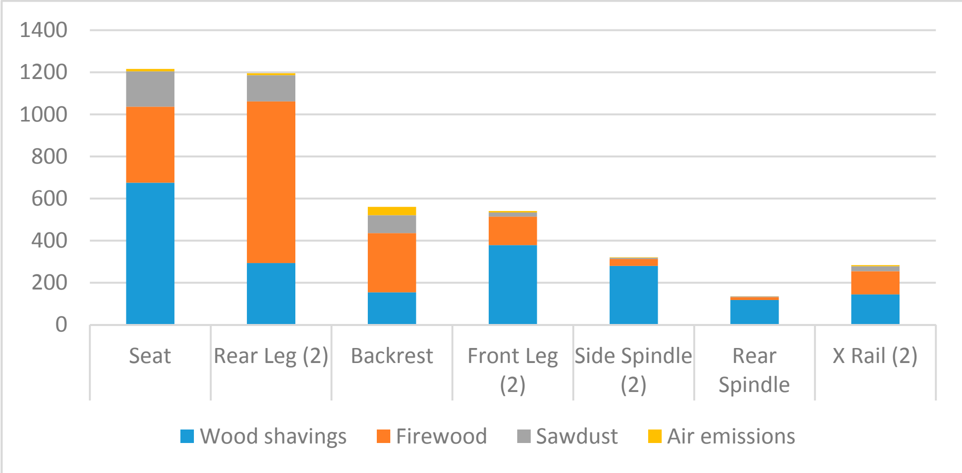


Figure 7. Losses per assembly component.

3.4. Feasibility Study and Implementation

In this stage, the study focuses on reducing the losses of raw material, taking into account the productive process and the characteristics of the product, therefore, affecting the total amount of raw material, waste generated and energy requirements.

Three proposals were made:

- Product design considering component modulation within the dimensions of the raw material.
- Product design substituting materials in components.
- Product design reshaping in order to reduce material.

The eco-design process began by analyzing the pieces of the chair that generated the most waste, seeking what could be eliminated, reshaped or substituted. As shown in Figure 4 these components where the seat, the backrest, the rear leg and the rails.

Design modification of the seat was suitable for different strategies, all aimed to reduce material consumption. The first of them was a substitution strategy: it was proposed to change the material of the seat for plywood, taking advantage of the possibility of modulation the shape of the seat. This could reduce waste while decreasing the thickness and weight of the chair. By doing so, the residues would drop to 19.52%, i.e., that means a reduction of 3284 g of solid eucalyptus wood while requiring a consumption of 2198 g of plywood, to obtain the same number of seats.

For the backrest, a reshape strategy was proposed by redesigning the backrest size and modeling the shape of it in a wood board composed of small glued pieces reused from another process. By doing so, the waste could be reduced from 48.71% to 15.38%, saving up to 590 g of eucalyptus wood.

The rear leg can also be redesigned. By producing a large board of glued joints of reused wood pieces, it is possible to obtain several rear legs pieces, optimizing wood consumption. For instance, from a board made of glued pieces of 65 cm glued pieces could fit 10 legs, thus reducing the waste from 54.85% to 39.74%, equivalent to 984 g of eucalyptus wood. Figure 8 presents a sketch of such modulations either for the seat and the rear leg. Figure 9 presents the estimated amount of wood saved.

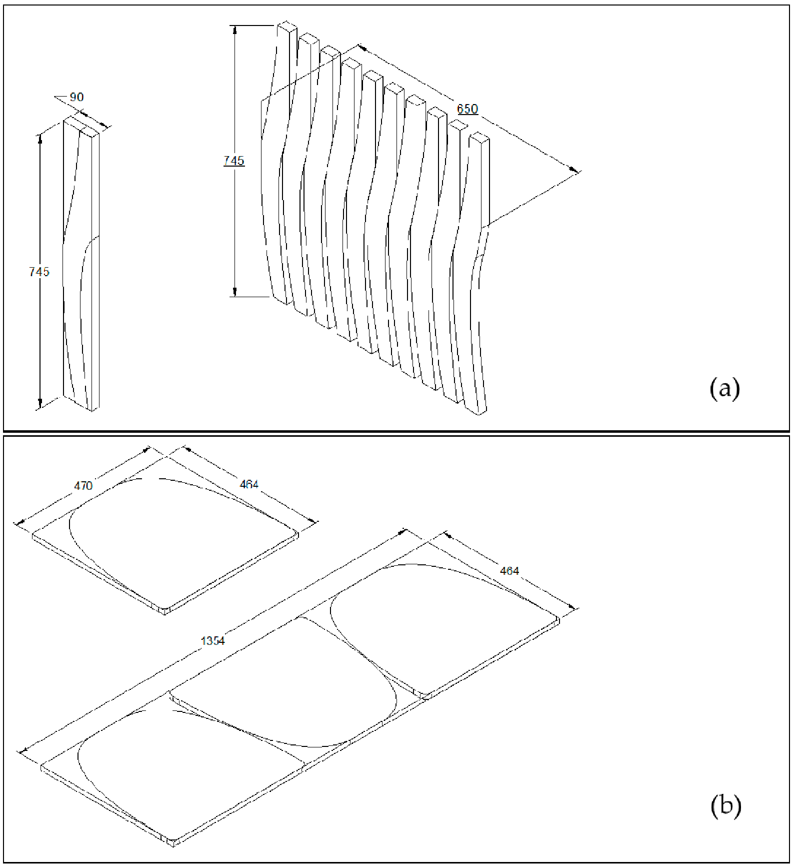


Figure 8. Sketch of the modulation: (**a**) rear leg single production vs. modulated (**b**) seat, single production vs. modulated.

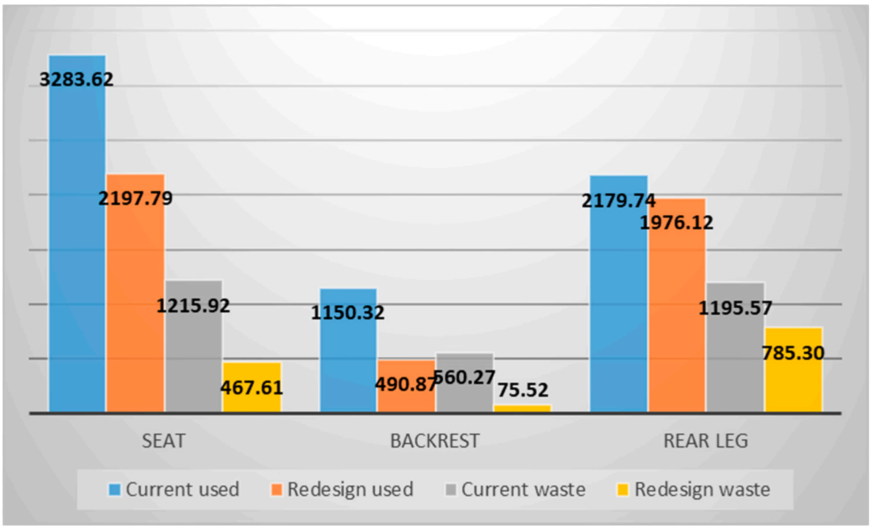


Figure 9. Wood used on the main assembly components to be redesigned (g).

The total decrease in the consumption of wood was 29.95%, going from 10,292 g to 7209 g, also reducing the percentage of waste from consumption from 43.81% to 32.20%, from generating 4509 g to 2321 g as shown in Figure 10. The percentages and characterization of the waste in the proposal is presented in Table 6.

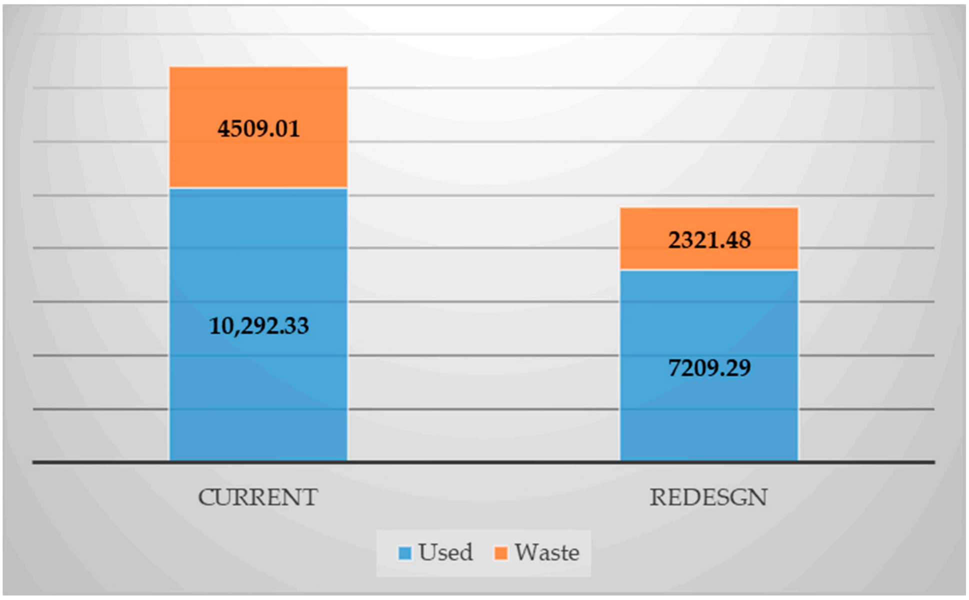


Figure 10. Comparison between actual and proposed design (g).

Table 6. Percentages of reductions proposed.

	Wood		
	Current (g)	**Proposal (g)**	**Reduction**
Total consumption	10,292	7209	29.95%
Total used	5783	4888	15.48%
Total waste	4509	2321	48.51%
Generated waste	43.81%	32.20%	11.61%

The proposed changes have an impact on the energy consumption, due to the reduction and simplification of some production processes. The energy consumption could change from 5 KWh to 3.23 KWh for the production of a chair as presented in Table 7.

Table 7. Current vs. proposed energy consumption per component.

	Energy	
	Current kWh	**Proposal kWh**
Seat	0.38	0.04
Back Rest	0.36	0.26
Front Leg	1.36	1.36
Rear Leg	0.71	0.34
Side Spindle	0.64	0.00
Rear Spindle	0.32	0.00
X Rail	1.14	1.14
Assemble	0.08	0.08
Total Consumption	5.00	3.23

The final effects of all the proposed changes can be summarized in Figure 11, presenting the final sketch of the eucalyptus wooden chair proposed.

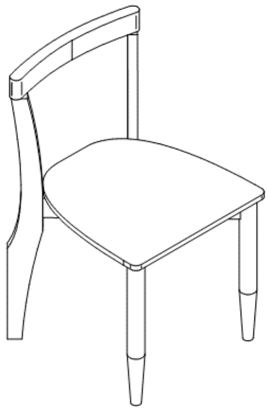


Figure 11. Redesigned chair.

The new chair designed was identified with a new code, and would be commercialized communicating the advantages in resource efficiency to the clients.

4. Discussion

The results of this research were constituted by the findings of the application of a CP program in a wooden furniture industry as per the methodology of implementation of the CNTL. The steps detailed in the methodology were validated by the planning and the conformation of the Eco-team to the application of CP and ecodesign parameters, applied directly to the object of study. Once the diagnosis was conducted through the analysis of the organized data (tables, pareto-charts, etc.) a series of proposals were made with focus on optimizing material consumption and reduce associated waste generation.

The ecodesign parameters developed specifically for the wooden furniture industry supports the efforts of focusing on the product and process instead of end-of-pipe solutions. In this case, the proposals made addressed parameters of reducing, facilitate, select and valorize the difference of the redesigned chair. For this reason, the treatment of waste was not addressed as the focus of the work, even though specific recommendations were made such as the recycling of some pieces of firewood in the construction of the glued and pressed board for the rear leg and backrest. Waste disposal was also part of the recommendation since the Eco-team suggested that nearby industries were interested in the residues of sawdust and wood shavings as fuel for their furnaces.

Despite CP and ecodesign now being widely known due to be capability of achieving environmental benefits, throughout this case study the opportunities in sectors such as wooden furniture highlighted, especially considering its uneven size distribution while representing a market of over 430 million goods worth aproximately US $16.54 billion.

The application of CP programs is not normative in Brazil, and its distribution seems to be slow. One of the reasons could be the eco-paradigm of thinking that environmental improvements cost a lot of money, a perception shared by employees and staff in the company. The analysis presented in Figure 2 represents an attempt to highlight the opportunities of the combination of CP plus ecodesign as suitable for micro and small companies in this sector.

It is also noted, that for better results, more studies are required. More specific tools such as Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) could be a feasible direction in order to include the impact of the improvement. However, considering the financial limitations of most of the micro and small companies, CP plus ecodesign parameters are considered of lesser complexity in terms of the reality of the wooden furniture industry in Brazil. Since the very definition of the CP program is based on a continuous improvement and application of strategies aimed at sustainability, the inclusion of more specific tools for assessing impacts and cost seems to be the natural next step.

5. Conclusions

With the application of the concepts of CP, it is possible to reduce the consumption of raw material and energy as well as the generation of waste. The results obtained in the application of CP + Eco-design in this case study confirms the benefits of CP, presenting a potential reduction in material of 30% and reducing the generation of waste by nearly 50%. This has a special relevance considering the feasibility of implementation in small wood furniture companies like the one presented in this study.

Once CP identified the most relevant sources of waste, the implementation of Eco-design parameters such as the ones applied (change of material, modulation of parts and redesign) are of easy implementation and achievable, allowing the reduction in the consumption of material and energy, without demeaning the quality or the aesthetics of the final product. The final product followed the valorization of the difference since it would be commercialized as a more efficient product in resource consumption.

Although there is plenty of research focusing on productive alternatives using waste from the furniture industries, the focus of this study was on the reduction in the source and the application of methodologies suitable for small companies, as it was presented in Figure 2. The potential of the application of CP + Eco-design parameters could reach micro and small wood furniture companies (representing 96% of wood furniture companies). Even though the level of reduction in waste when applying CP programs will vary according to the different products, the size of the potential market to be reached is a justification for more investment in the promotion of CP programs in Brazil.

The savings achieved in energy consumption were the result of the simplification of the production process, and a consequence of the application of the Eco-design parameters. It is noted that for better results, change in technology for wood machinery with better efficiency could be analyzed. This option will require an economic analysis for the investment required.

Despite the results in resource use and the reduction in waste and energy consumption, LCA and LCC are recognized as the next steps to be taken in order to assess the environmental impact of the product.

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