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Analysis of the technological impact on industry and its effects on waste production and disposal: a case study of the surfboard manufacturing industry.

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Abstract

Cleaner Production (CP) advocates the application of preventive and integrated strategies to processes products minimizing the generation of waste and pollution. However, not always technological innovations in production bring with it an improvement for CP. The surfboard industry has been dismissive of CP. Studies revealed a concentration of the production residues on the manufacturers due to the vertical process of the production stages. Nonetheless, the incorporation of machining technology of the polyurethane blocks through Computerized Numerical Control (CNC) led to a horizontal process. The aim of this study was to map the current process, identifying the major waste producers, and detailing management for these wastes. A case study was carried out to examine the surfboard industry. The survey revealed that the links of the production chain can be accomplished by the diverse actors participating in the manufacturing industry. However, the largest amount of waste is produced by big manufacturing industries rather than small, outsourced companies. It became clear that the introduction of CNC technology was responsible for the centralization of waste production, previously distributed among all manufacturers. Technological innovation had no impact on the reduction or reuse of waste or even a better management of its disposal.

Keywords: *Cleaner Production. Technological Impact. Waste Management. Surfboard Manufacturing industry.*

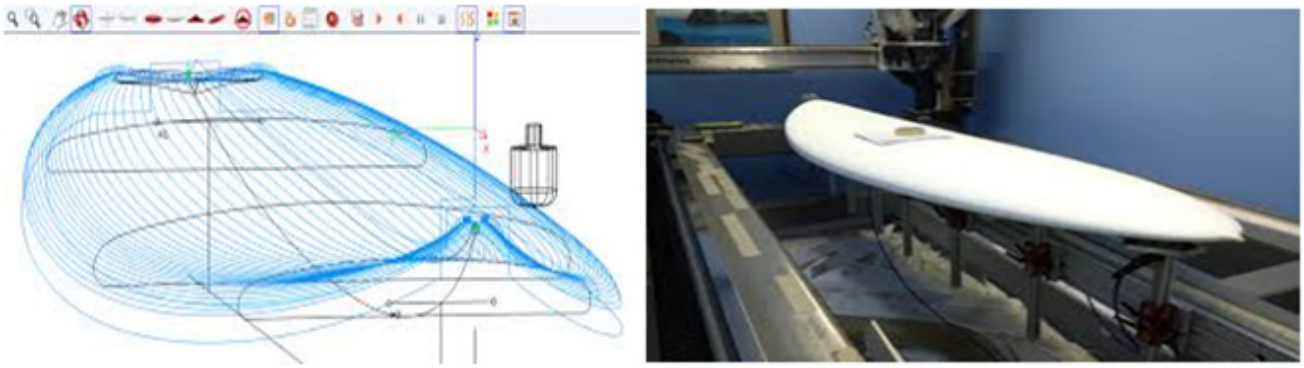
1 Introduction

The concept of Cleaner Production (CP) created by the United Nations Environment Program (UNEP), launched in 1998 through the International Declaration on Cleaner Production, states that Cleaner Production is the continuous application of an integrated, preventive environmental strategy towards processes, products and services in order to increase overall efficiency and reduce damage and risks for humans and the environment (TEUBER et al., 2016; MOLINARI, QUELHAS, NASCIMENTO FILHO, 2013; DOMINGUES, PAULINO, 2009; BAAS, 2007). But production technology innovations not always bring improvement shaped by the precepts disseminated by CP. The surfboard manufacturing industry has been dismissive in relation to CP. Mazzoco (2007), Tiptipakorn (2009), Johnstone (2010), Rocha (2011), Grijó and Brügger (2011), Gibson, Carr and Warren (2012), Warren, Gibson (2013) and Grees (2014) have reported that non-observance of responsibility principles and environmental legislations by the surfboard industry directly impacts those who manufacture the product, the environment, and the neighborhood where the industry is located.

Different areas are indicated for the mitigation and reduction of the surfboard productive chain impacts. Grees (2014), Hole (2011), Johnstone (2010), and Kulakool (2007) have addressed the issue of the materials used and the alternatives available to reduce the emissions and dependence of non-renewable sources. Piovesan et al. (2013), Tiptipakorn et al. (2009), Tattian (2008), and Grijó, Brügger (2011) were concerned with waste treatment and proposed techniques for the reuse of polyurethane, fibers, and resins. Environmental management systems have been discussed by Grijó, Brügger (2011), Rocha (2011), Mazzoco (2007) as well. Grijó, Brügger (2011) and Mazzoco (2007) have indicated the manufactures should be blamed for the concentration of residues in the production of surfboards due to the vertical business model, thus discarding other actors that could possibly also emit residues. The available data on the production, reuse, and recycling of waste from the surfboard industry indicate that about 50,000 surfboards were produced in Brazil in 2001, and 50% to 70% of the material used in the manufacturing process was discarded in dumps, or simple landfills, without adequate treatment (GRIJÓ, BRÜGGER, 2011).

What was formerly produced in handmade wares, has now changed. Instead of giving the surfboard shape manually, using tools such as planers and sanders, has undergone changes that affected the surfboard production model and the industry itself. At the end of the 2010's, the incorporation of the block machining technology of the foam core boards through Computerized Numerical Control (CNC), as illustrated in Figure 1, led to adopt a horizontal business model. Since the introduction of this technology, companies specialized in block machining and others exclusively in lamination, block capping with fiberglass, and polyester resins have been created in order to isolate and strengthen the molded block. Barcelos and Leripio (2017) has pointed to this new configuration of both the manufacturing process and the structure of actors involved in this industry.

Figure 1 - CNC Thecnology



If there was a structural change in the participants of the surfboard manufacturing industry, one could ask who are the actors that produce waste and how do they manage it in this new organization model. The objective of this study was to map the current production process, identify the actors responsible for the residues in the production chain, and detail how these residues are managed in comparison with the model described by Grijó, Brügger (2011) and Mazzoco (2007). The bibliographic review provided support and guidance to carry out this study. The first point to check was what stages are involved in the surfboard production process. In this sense, the work by Barcelos and Leripio (2017) was taken as reference for the four stages described in Table 1.

Table 1 - Surfboard Manufacturing Stages

Process	Description
Machining	In this stage, the board format is given to the PU block by using cutting and wear tools (CNC). It is in this stage that the largest volume of PU residues is generated in the form of pieces and powder.
Finishing	At this stage, the board shape is finished. Only sandpapers and manual planes are used for small corrections and homogenization of the board surface. This is the last stage that generates PU residues in the form of powder.
Painting	This stage only occurs if the board is painted. In this stage, in addition to the paint materials, solvents, adhesive tapes, and papers to cover the paint are used. At the end of the stage, the residues consist of tapes and papers contaminated with paints, varnishes, and solvents.
Lamination	In this stage, the insulation and structuring of the board are done by applying a fiberglass blanket and resins on the surface of the surfboard. This stage includes the use of fibers, resins, monomers, catalysts, solvents, tapes, sandpapers, electricity, and water. This stage presents the greatest variety of residual materials, such as resin and fiber powder and pieces, sandpaper contaminated with resin powder, and resin contaminated tapes.

The second point examined in the bibliographical reference was the identification of the actors participating in the surfboard manufacturing industry in Florianópolis, Brazil. Barcelos and Leripio (2017) describes the participants as follows:

Distributors – They are responsible for selling inputs for the production of surfboards. A survey of all distributors revealed that the most commonly sold raw materials are resins, fibers, and polyurethane blocks. In terms of the size of the enterprises, it can be highlighted that there are basically two types, large and small companies. The small ones are primarily dedicated to reselling products, whereas the large ones carry out the machining process of the blocks using thinning tools (CNC machining center) and sell their products directly to the public.

Manufacturers – They were divided into three categories: small, medium, and large manufacturers. The criterion for the size stratification was related to the number of employees: large companies, with more than six employees; medium companies, with three to five employees; and small companies, with less than three employees, as described in Table 2.

Table 2 - Company Size and Description

Large Companies	There is a full vertical management of the production processes within their physical structures (machining, finishing, and lamination), and may eventually outsource some stages. The three companies differed from the rest of the manufacturers because they had their own machining center, and because they bought raw materials directly from manufacturers, thus avoiding intermediary suppliers.
Medium Companies	Vertical management is not present in all the stages, and it is common for the machining stage to be carried out by the distributors. Companies in this category need to acquire their raw materials paying more as compared to what large companies pay. Eventually, medium companies purchase some raw materials from the manufacturers.
Small Companies	Their activities are predominantly outsourced. The machining and lamination stages are commonly performed by other actors in the chain, such as distributors and laminators.

Laminators - Laminating companies are service providers. They can be an individual, a structured company, or even a surfboard manufacturer. They are actors that serve small and medium manufacturers by performing the lamination stage of the surfboards.

Shaper – The shaper is the person responsible for developing the shapes and structure, as well as the final finishing of the surfboards. Regardless of the company's size, these professionals are still needed. The shapers generally own their brands, and sometimes they do not have their own physical space to develop the product. Shapers can be manufacturers, and although they do not have an expressive production volume, they represent a significant portion of the total production of the sector.

Painter – The painters are service providers, responsible for the product finishing, and they work for small and medium companies on a seasonal basis. The painters were not directly surveyed, but we learned that their activities are rendered in the manufacturer's or laminator's settings responsible for the lamination stage.

With regard to the environmental impact of the solid waste disposal, there is almost no soil toxicity given its slow degradation (BARCELOS and LERIPIO, 2017; GREES, 2014). These wastes are dangerous due to the sharp pieces and because of their flammability. When polyurethane undergoes thermal degradation, high toxic chemicals may be emitted, in addition to carbon dioxide, carbon monoxide, and water. Hydrocyanic acid may be formed in temperatures above 800ºC. People exposed to these chemicals may die, depending on the concentration of these substances and the exposure time (AMERICAN CHEMISTRY COUNCIL, 2014).

2 Methodology

This was an exploratory, descriptive study seeking to ascertain, both in the literature and through the collection of primary data, a clarification about the manufacturing of surfboards, and waste generation and management. The study consisted of a literature survey and a case study. Qualitative and quantitative date was collected to map out the surfboard manufacturing process in the selected area. A questionnaire on CP was administered to each unit as a data collection method. The questions addressed primarily the origin and consumption of manufacturing raw materials, and the generation and management of solid wastes as described in Table 3.

Table 3 - Methodological Description of Primary Data Collection

Description and Consumption of Raw Materials	Information on raw materials was collected by analyzing the average amountrequired to produce a single board multiplied by the mean number of units produced monthly. The collected information encompassed the product name, description, and amount in Kg.
Quantification and Management of Solid Wastes	The qualitative and quantitative data were collected based on the analysis of each manufacturing stage, listing the type of residue, its description and amount of waste, measured in Kg. The use of the tools helped describe these wastes and how they were managed throughout the whole process.

The surveyed companies were located in Florianópolis, Santa Catarina, Brazil. Thirty-five companies were initially found to be surveyed. As no formal record were found in Florianópolis, a search was carried out through advertisements in specialized magazines, social networks, online newspapers, and web search. As per the owners' request, the companies were not identified in this study. The different actors in the process were identified in 18 companies, as described in Table 4.

Table 4 - Sample Description

Actors					Total
Distributors	Laminators	Large Manufactures	Medium Manufacturers	Small Manufacturers	
4	2	3	6	6	**18**

Quantitative issues related to the amount of waste produced by the actors were estimated to indicate the average amount of waste per board manufactured, thus allowing to calculate the total amount generated per month. The calculation is shown in the results section that follows.

3 Results

The origin and destination of the residues resulting from the surfboard manufacturing process are analyzed below. The first item to be analyzed is the polyurethane block during the machining process, as shown in Figure 2.

Figure 2 - Flowchart of PU Block Machining

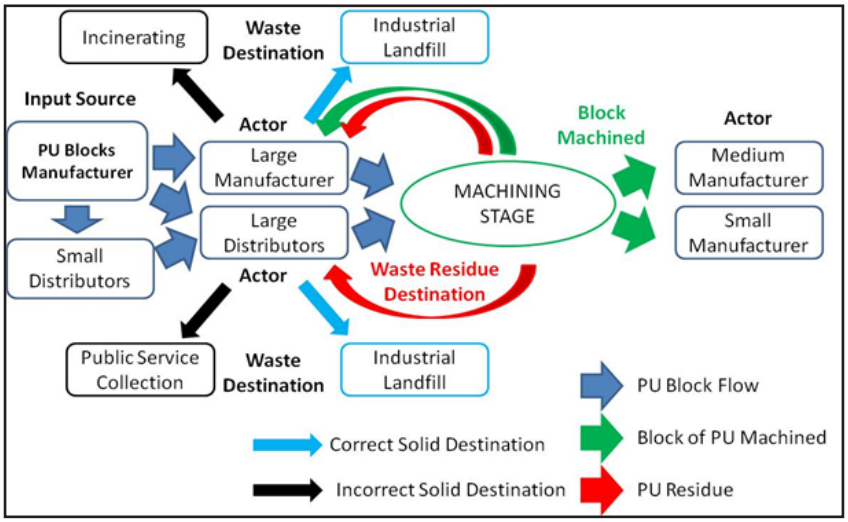
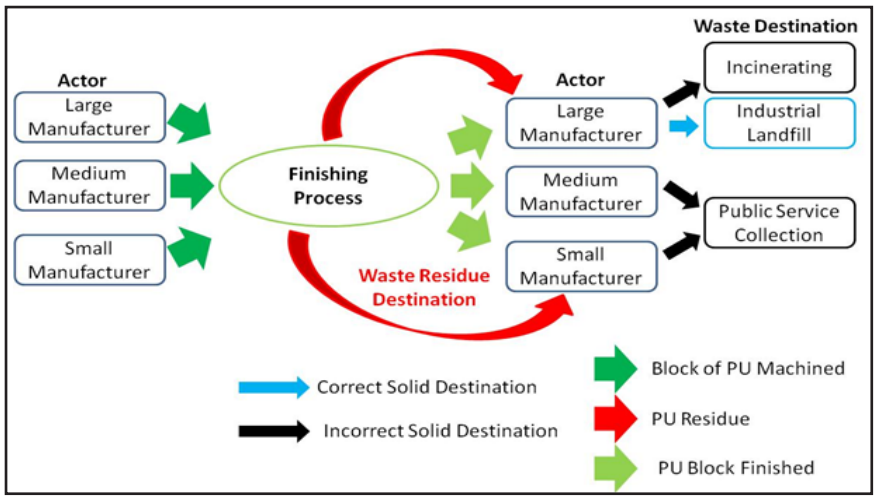


Figure 2 demonstrates the residues are restricted to the machining stage. Polyurethane blocks undergo the machining process primarily limited to two main actors, i.e., large distributors and large manufacturers. Predominantly, the largest number of blocks undergoes a mechanical machining process. Small distributors ship their blocks to large manufacturers or large distributors to be machined.

After the machining process, the blocks are either sent to small and medium manufacturers or stay in the big manufacturing companies. Even if the block comes from a small distributor, the residue will be generated by the intermediate actor that carried out the machining process. Regarding the waste disposal, there are three options for the destination: the correct one, by sending the material to an industrial landfill, or the incorrect options, either by incinerating it at an outsourced company or by the public service collection that ends up discarding the material inappropriately in landfills.

A flowchart of the finishing process is shown in Figure 3.

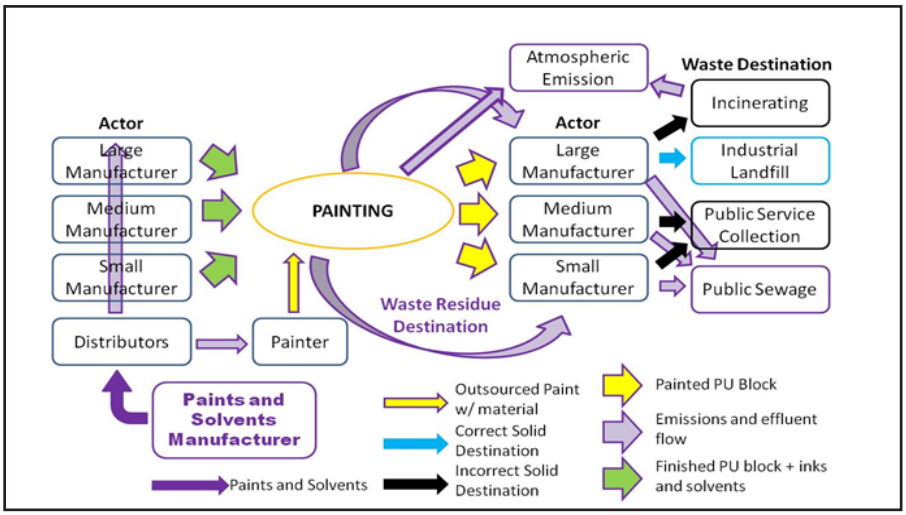
Figure 3 - Flowchart of the PU block finishing



The finishing process is linked only to the manufacturers, as represented in Figure 3. Consequently, the accumulation of residues is the exclusive responsibility of the finishing executors. The waste management is similar to that of the previous item.

After the finishing process is completed, the surfboard may be painted. In that case, a flowchart of the painting process is shown in Figure 4.

Figure 4 - Flowchart of the inks and solvents for the painting process

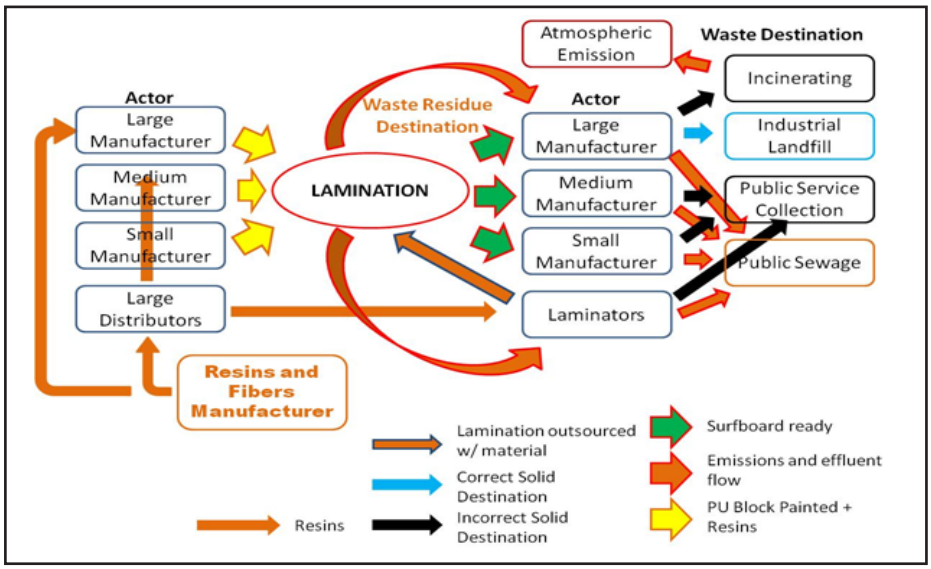


Not all surfboards are painted. As shown in Figure 4, the painting process is quite complex, both to the actors and the impacts it causes. The process starts with the ink and solvent manufacturers. They distribute their products through specialized distributor net. The flowchart indicates the emission of gases, solid waste, and effluents in this stage of the process. These emissions consist of the volatilization of solvent and ink components into the atmosphere, whereas solid wastes are composed of tapes

and insulation papers contaminated with paints, as well as effluents generated by the paint spray gun cleaning with solvents. Management of the solid wastes is similar to that of polyurethane, i.e., they are either sent to industrial landfills or incinerated by large manufacturers. The residues from medium and small industries are collected by municipal waste collection services.

A flowchart of the lamination process is shown in Figure 5.

Figure 5.- Flowchart of resins and fibers for the lamination process



As shown in Figure 5, the flow of materials in the lamination stage begins with the resin manufacturers. They sell their products throughout a network of distributors. Because these products are targeted to the nautical industry, they are primarily sold to surfboard manufacturing companies. The distributors focus on small and medium-sized manufacturers, as well as independent laminators. Large manufacturing companies purchase resins and fibers directly from the manufacturers.

The lamination process generates solid wastes and effluents, such as resin and fiber powder and pieces, sandpaper contaminated with resin powder, and tapes contaminated with resin. When water sandpaper is used, the effluents consist of resins and fibers. Management of the solid wastes is similar to that of polyurethane, i.e., they are either sent to industrial landfills or incinerated by large manufacturers. The residues from medium and small industries are collected by municipal waste collection services. This result is in agreement with those described by Grijó (2011), Rocha (2011), and Mazzoco (2007), who have indicated an inadequate disposal of these residues.

CP application allowed for the quantification of the raw material and residues by estimating the volume of input and the linkage of the production stages. This was required to analyze the waste disposal in percentage related to its destinations.

The machining stage revealed a regularity in the amount of input and output. This pattern is due to the block sizes and the surfboard shape. Based on the weight means, we could define a single weight for the blocks and for the residues generated in the machining stage, in order to estimate the total waste generated by each actor, as shown in Table 5.

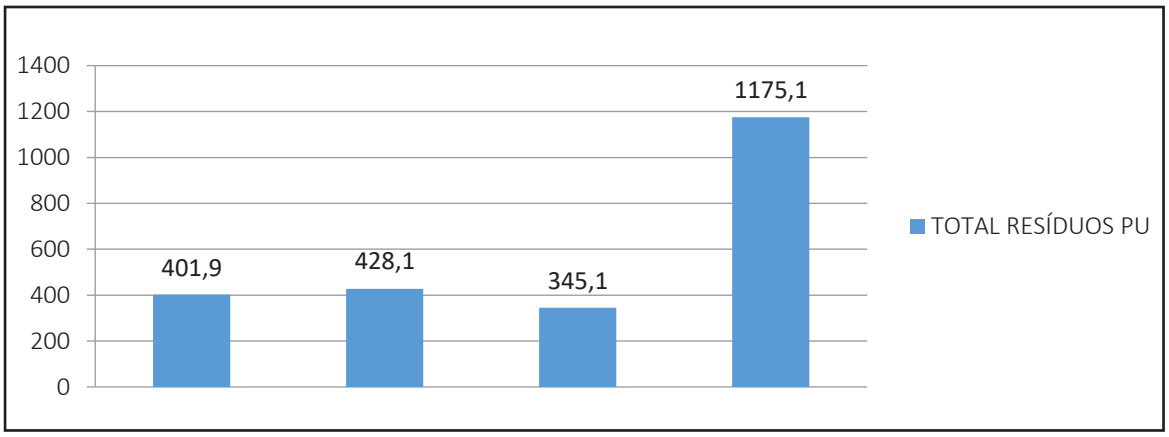
Table 5 - PU input and output from the machining process

ACTOR	MEAN INPUT OF PU/kg	MEAN OUTPUT SHAPE PU/ kg	MEAN RESIDUES kg	AMOUNT OF BOARDS/ MONTH	TOTAL RESÍ-DUES MONTH/ kg	WASTE DISPOSAL
DISTRIBUITOR 1	2.293	1.325	0.968	250	242	Municipal Collection
DISTRIBUITOR 2	1.845	1.136	0.709	300	213	Industrial Landfill
LARGE MANUFACTURER 1	2.293	1.227	1.066	150	160	Municipal Collection
LARGE MANUFACTURER 2	2.293	1.307	0.986	350	345	Incineration
LARGE MANUFACTURER 3	2.01	1.292	0.718	300	215	Industrial Landfill
MEANS IN KG	2.1468	1.257	0.8894	1,350	1,175	TOTALS

Systematic weighing of the raw blocks revealed 2.146 kg in average. Different brand blocks, but with similar dimensions and high sales volume, were weighed in order to determine a mean weight of the blocks used.

Graph 1 shows the distribution and destination of the residues from the machining process, revealing that 34% (401.9 kg) were sent to the municipal waste collection, 36% (428.1 kg) to industrial landfills, and 29% (345.1 kg) were incinerated.

Graph 1- Total PU Residues from the Machining Process (Kg/month)



The Finishing process does not generate a significant amount of waste as compared to the previous stages. Because of the small amount of residues in this stage, the manufacturers did not provided the researchers with the amount generated. Usually, the residues of this stage are incorporated to those generated in the lamination stage, as they are produced in the workshops of the manufacturers or laminators.

Similarly, the painting stage generates a little amount of waste. In addition to the low frequency of surfboard painting and the different types of artwork to be developed (drawing size, number of colors, types of paint). As in the finishing stage, there was no quantification of the residues generated by the painting process because the actors consulted had no exact idea of the amount of residues in that stage. Usually, the residues of this stage are incorporated to those generated in the lamination stage, as they are produced in the workshops of the manufacturers or laminators.

The identification of residues by category, operation, and volume in the lamination stage demonstrates homogeneity in relation to the amount of raw materials used in the production process. This pattern is due to the block sizes and the surfboard shape in large manufacturing companies. In this case, it was possible to determine a mean value of inputs and outputs and, consequently, the average amount of residue per board in the lamination stage. The list of materials and respective amount used for the board lamination is shown in Table 6.

Table 6 - Material Used in the Lamination Process

RESIN	FABRIC	TAPES/GLOVES/SANDPAPERS/OTHERS	TOTAL
1.8 kg	0.35 kg	0.15 kg	**2.3 kg**

Another item consistently inferred by the manufacturers is the final weight of a surfboard that should be between 2.5kg and 2.7kg. In order to calculate the average solid residue generated in the lamination process, the following variables were taken into account: the average weight of the machined block (BU), determined in Table 1 as 1.257 kg, plus the average amount of material used in the lamination (ML), which is 2.3kg (see Table 2), minus the final mean weight of the surfboard (PF), here estimated as 2.6kg. This calculation led to the following amount of residues (QR), demonstrate at equation 1:

$$BU + ML - PF = QR$$
$$1.257kg + 2.3kg - 2.6kg = \mathbf{0.957kg} \quad (1)$$

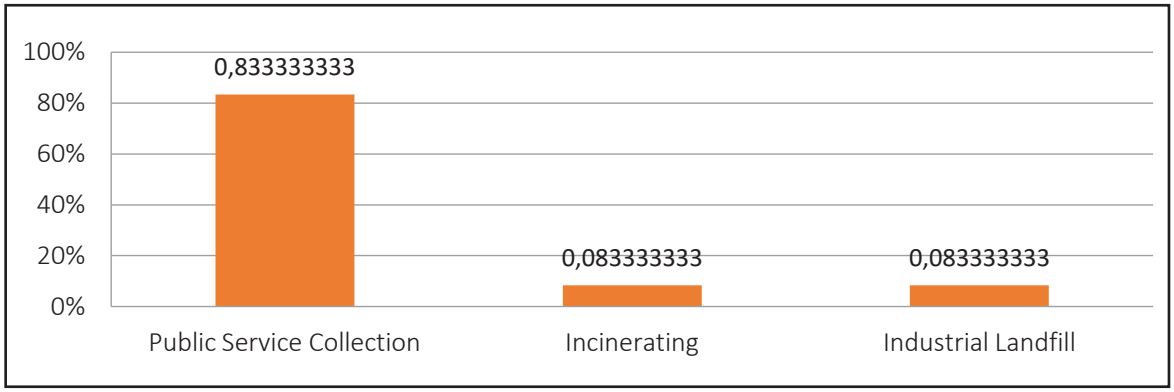
Based on the average amount of solid waste generated per surfboard, we could estimate the total amount generated, as seen in Table 7. Table 7 also shows the destination given to the waste by the manufacturers.

Table 7 - Volume of Solid Residues Generated in the Lamination Stage and its Destination

ACTOR	RESIDUE Kg/ SURFBOARD	SURFBOARD MANU-FACTURED/MONTH	TOTAL RESIDUES Kg/MONTH	WASTE DISPOSAL
LARGE MANUFACTURER 1	0.957	120	115	Municipal waste collection
LARGE MANUFACTURER 2	0.957	350	335	Incineration
LARGE MANUFACTURER 3	0.957	200	191	Industrial landfill
MEDIUM MANUFACTURER 1	0.957	29	28	Municipal waste collection
MEDIUM MANUFACTURER 2	0.957	22	21	Municipal waste collection
MEDIUM MANUFACTURER 3	0.957	17	16	Municipal waste collection
SMALL MANUFACTURER 1	0.957	10	10	Municipal waste collection
SMALL MANUFACTURER 2	0.957	7	7	Municipal waste collection
SMALL MANUFACTURER 3	0.957	5	5	Municipal waste collection
LAMINATOR 1	0.957	25	24	Municipal waste collection
LAMINATOR 2	0.957	20	19	Municipal waste collection
	TOTAIS	805	770	

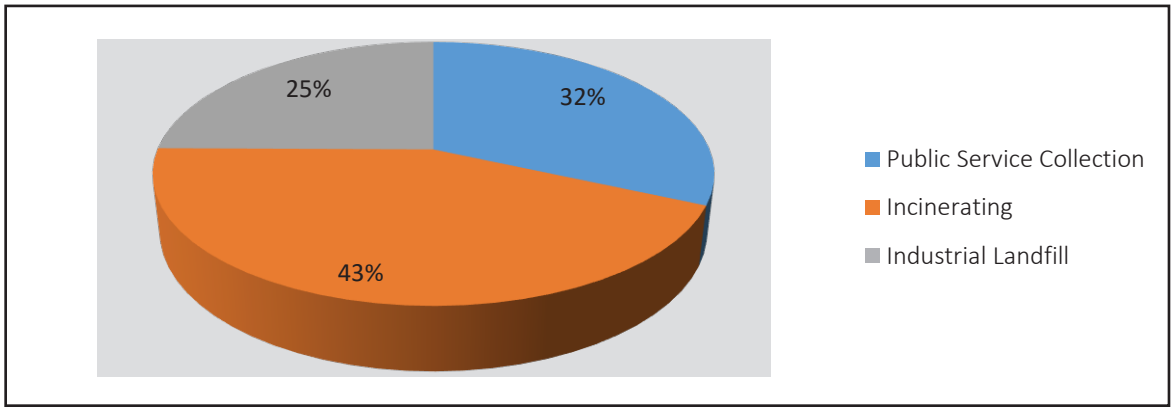
Table 7 shows a monthly amount of 770kg of residues generated in the lamination stage by 11 actors. Four distributors are not included because they do not participate in this stage, as well as 3 small manufacturers that outsource the lamination stage. Percentages of waste disposal are shown in Graph 2.

Graph 2 - Percentages of Waste Disposal in the Lamination Stage



Similarly to what was shown in the Finishing and Painting stage, Graph 2 shows that 83.33% of the actors that generate residues in the lamination stage (10 out of 13) send their waste to the municipal collection. This group consisted of three small, four medium, and one large manufacturer. Two large manufacturers, representing 8.33% each, give different destinations to the residues. One sends to industrial landfills and then incinerates them.

Graph 3 - Distribution of Waste Amount by Disposal Mode in Kg/month



As shown in Graph 3, stratification of the amount of waste by disposal mode reveals that 191 kg (25%) are sent to industrial landfills, 244 kg (32%) go to the municipal collection system, and 335 kg (43%) are sent to incineration.

The next item of this work presents the conclusion of this research evaluating its results versus the proposed objectives.

4 Conclusion

This research evidenced that the links in the surfboard production chain can be executed by different actors, with a diffusion of the productive links in relation to the manufacturers, mainly those related to the production volume. In other words, there is a high concentration of outsourcing by the small manufacturers. As a result, the largest amounts of waste from the machining and lamination stages are generated by large manufacturers and distributors, in the case of PU, and by large manufacturers and laminators, in the case of lamination residues.

The introduction of CNC technology for block machining was responsible for concentrating the generation of residues in the machining and laminating companies previously distributed by the manufacturers. In that situation, technological innovation had no impact on waste reduction or reuse, or even on a better disposal management. Most of the waste continues to be improperly discarded through incineration or municipal waste collection and sent to sanitary landfills instead of industrial landfills.

Given the amount of waste produced by the surveyed companies and the lack of data about the number of manufacturers in operation in the region, there is no idea of the total amount of waste produced and discarded in the Florianópolis area. This fact brings serious concerns, especially because of volatilization and effluent emissions from the lamination stage that could not be examined in this study. In other words, the impact of residues from surfboard production in the Florianópolis region may be much more critical than that detailed in this study.

The inefficiency of inspection by sanitary agencies is of great concern. Even if aware of the risks, they do not make the necessary effort to mitigate the devastating impact on the environment.

In this sense, future studies should be conducted to estimate the amount of gas and effluent emissions during the lamination stage. Providing trustful data on the total number of surfboard manufacturers in operation is of outmost importance to estimate the amount of residues and take the necessary measures to protect the environment. Reviewing the public structure responsible for the supervision and management of the productive sectors is vital to identify and propose policies that best address waste management related to the surfboard industry.

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