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DESIGN FOR SUSTAINABILITY AND LIFE CYCLE ASSESSMENT TOWARD INCREASE USE OF RECYCLED ALUMINUM: CASE OF ARCHITECTURAL LIGHT SHELF

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ABSTRACT

This study concerns the design of a light shelf applying concepts of Design for Sustainability and Life Cycle Thinking by using Life Cycle Assessment method as a tool to decision-making for the material choice. Light shelves are building devices installed in window with the goal to provide greater use of natural light. This study intends to consider the urgent need to promote the use of recycled aluminum in order to improve the use of scrap in applications that add value to this as an important raw material. The study has been conducted in the product design and search to understand the impacts caused in parts, using primary aluminum and recycled aluminum, with a view to adopting the best alternative for the product environmental quality. As result, the design has proposed solutions for a product with a potential to disseminate the importance of the recycling, seeking an opportunity to valorize recycled scrap and the use of mono-material. Three scenarios have been analyzed. As conclusion, it is confirmed that the use of part from recycled raw material generates less impact in Global Warming Potential category, about 17% of emission reduction of CO_2-eq. in Scenario 2 and about 81% in scenario 3.

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INTRODUCTION

Architectural light shelf: Construction, as well as the use of buildings, requires huge amounts of energy, water and materials, producing large amounts of waste. Where and how buildings are constructed affect the ecosystem in several ways. It is often said that a tenth of the global economy is destined to buildings, in their construction and use phases, as well as in the equipment of the built environment. Construction consumes approximately 50% of the world's resources, including 45% of energy for construction and use, 40% of water, 60% of arable land and 70% of timber (Edwards, 2004). With regard to the energy used in buildings, its consumption is approximately 39% of the total energy spent in the world. Commercial buildings consume about 18% and residential 21%. In this sense, the installation of efficient equipment can reduce the consumption of energy in the building from 10 to 15% (Schneider-Electric, 2008). The thermal and bright-visual comfort has a direct impact on the energy consumption of the building.

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However, it is possible to promote user satisfaction in these aspects from the concept of "bioclimatic architecture", in which environmental quality and energy efficiency are obtained through the rational use of natural resources, in order to contribute to the balance of ecosystem (Loura and Assis, 2005). Until the beginning of the last century, natural light was the most important light source for daytime use in factories, offices, residential and public buildings. However, the availability of artificial energy at low cost led to the execution of buildings projects primarily dependent on electricity (Fontoymont, 1999). The main task of the natural light project is to determine exactly the path of the light source to the points to be illuminated inside the built space, and to decide on the technical solutions to achieve the objectives sufficiently and efficiently (Souza, 2005). Architectural control devices are necessary for the adequate reach of the solar incidence. These devices are components such as *brise-soleil*, shutters and light shelves. Studies have shown that light shelves are proven efficient in increasing the depth of natural light in the built space (Majoros, 1998; Santos and Souza, 2012). The light shelf is a device installed in window in order to make better use of the natural light, reflecting it to the ceiling and, consequently, projecting this natural light to a greater depth in the built environment. Light shelves seek to reduce the consumption of electric light, increasing the energy efficiency of buildings. Its use in window of commercial and residential buildings aims to control lighting and diffusion of natural light in space, meeting the energy saving parameters of various environmental certifications of civil construction. The analysis presented in this study concerns the design of a light shelf applying concepts of the Design for Sustainability and Life Cycle Thinking by using Life Cycle Assessment method as a tool to decision-making to the material choice. The study seeks to reflect on the urgent need to promote the use of recycled aluminum in order to revalue the use of scrap in applications that add value to this input as an important raw material, improving efficient use of natural resources.

Life Cycle Thinking and Design for Sustainability: Life Cycle Thinking is an idea that intents to evaluate the flows of matter and energy exchanged with the environment in a production system throughout its life cycle, taking into account raw materials, energy, water consumption, the amount of aqueous and gaseous pollutants, as well as the waste produced during industrialization processes. This idea began to be known in the early 1970's in a method called the "Resource and Environmental Profile Analysis" (Hunt *et al.*, 1974) and has been absorbed by the International Organization for Standardization (ISO) into the 14040 standards launched in 1996 (ISO, 2006), that has defined the concept of Life Cycle Assessment (LCA). For Bhamra and Lofthouse (2007, p. 39), design for sustainability "considers the environmental (for example resource use, end of life impact) and social impact of a product (for example usability, responsible use)." This can be referred to as a sustainable product design that goes "beyond how to make a 'green' product and embraces how to meet consumer needs in a more sustainable way" (Crul *et al.*, 2009, p.16). In this context, ISO (2002, p. 8-12) indicates that the integration of environmental aspects into the product design can be initiated either top-down by management or bottom-up by designers, considering the following product-related issues:

- Meeting the environmental standards early on in the design process allows for changes and improvements to be made to products before the major technical decisions are made.
- Analyzing product life cycle from raw material acquisition to end-of-life to recognize how products can affect the environment at different stages: raw material acquisition, manufacturing, trade and delivery, use and maintenance, re-use, recycling, and energy recovery and disposal, including the transportation between all stages. Analyzing the inputs in terms of materials and energy, and the outputs as co-products, by-products, air emissions, effluents, waste materials and other releases. Analyzing the environmental impacts: depletion of resources, ozone depletion, smog formation, eutrophication, climate change, alteration of habitats, acidification, reduction of biological diversity, air, water and soil pollution, etc. Dealing with these aspects can ensure that materials are not arbitrarily excluded, and that the most relevant environmental impacts are identified; consideration is given to impacts generated by intermediate products even if they are not present in the finished product; environmental impacts are not shifted from one life cycle phase to another, ultimately, consideration is given to the system in which the product is manufactured and in which it will act.
- Thinking about functionality required to fulfill customer or user demands and needs, allowing environmental benefits, such as extending product life time or integrate services, to replace sales.
- Considering the multi-criteria concept, taking into account all relevant environmental impacts and aspects, as well as ensuring that one impact does not lead to an increase in another impact.
- Considering the possibility of trade-offs among environmental, technical and/or quality aspects, economic and social benefits, that can be "tangible (e.g. lower cost, waste reduction), intangible (e.g. convenience) and emotional (e.g. image)".
- It also indicates actions to be taken related to the integration of environmental aspects in the methodological stages of the product design and development process (ISO, 2002, p.15):
- Planning: when design ideas emerge and actions are linked to considering environmental aspects in a life cycle framework, environmental requirements are formulated, external factors analyzed and appropriate environmental design approaches chosen, etc.
- Conceptual design: when life cycle oriented-analyses are conducted, measurable targets formulated, design concepts developed and environmental requirements met.
- Detailed design: when design solutions are applied and product specifications are finalized, including life cycle considerations.
- Testing/prototype: when specifications are verified and life cycle considerations for the prototype are reviewed.
- Production Market launch: when communication materials on environmental aspects are published.
- Product review: when experiences, environmental aspects and impacts are considered and evaluated.

Lewandowska and Kurczewski (2010) argue that, according to ISO/TR 14062, ecodesigns depend on the integration of various requirements and needs from environmental, economic and social aspects that should be analyzed within the entire life cycle, taking into account the LCA, Life Cycle Cost (LCC) and Social Life Cycle Assessment (SLCA). It is important to consider product policies that integrate Life Cycle Thinking in an attempt to improve product performance in all stages of the product's life cycle, including social and economic performance. For United Nations Environment Programme (UNEP), the perspective is to expand the idea to reach principles of sustainability in its triple bottom line (people, planet and profit), as well as the "6 RE philosophy" (Remmen *et al.*, 2007, p.13):

- RE-think the product and its functions: the product may be used more efficiently;
- RE-pair: make the product easy to repair, e.g. via modules that can easily be changed;
- RE-place harmful substances with safer alternatives;
- RE-use: design the product for disassembly so parts can be reused;
- RE-duce: energy, material consumption and socioeconomic impacts;
- RE-cycle: select materials that can be recycled.

ISO (1999, p.3) also announced the Environmental Performance Evaluation as "an internal management process that uses indicators to provide information comparing an organization's past and present environmental performance with its environmental performance criteria" which can appear in its management and operational performance indicators. In this sense, communication, collaboration and information exchange are essential to tracking and managing environmental impacts. Networks are essential in helping companies accomplish the goals of sustainability (Patala *et al*., 2014), because several stakeholders construct a product value chain (Remmen *et al*., 2007). UNEP proposed a step-by-step approach to help organizations implement a Life Cycle Management program (Remmen *et al*., 2007), and ISO (1999) provided a guidance to environmental management in terms of the plan and use of Environmental Performance Evaluation. Both approaches are based on a "Plan-Do-Check-Act" management model.

Life Cycle Management by UNEP:

Plan

1. Set policies – set goals and determine the ambition level.
2. Organize – get engagement and participation.
3. Survey – overview of where the organization is and wants to be
4. Set goals – select areas where the efforts will be directed determine goals and make an action plan.

Do

5. Make environmental and social improvements – put the plan into action.
6. Report – document the efforts and their results.

Check

7. Evaluate and revise – evaluate the experience and revise policies and organizational structures as needed.

Act

8. Take it to the next level - Set up new goals and actions, more detailed studies, etc.

Environmental Performance Evaluation by ISO

Plan

1. Plan the Environmental Performance Evaluation.
2. Select indicators for Environmental Performance Evaluation (the process of selecting indicators may include both choosing from existing indicators and developing new indicators).

Do

3. Collect data relevant to the selected indicators.
4. Analyze and convert data into information describing the organization's environmental performance.
5. Assess information describing the organization's environmental performance in comparison with the organization's environmental performance criteria.
6. Report and communicate information describing the organization's environmental performance.

Check and Act

7. Review and improve Environmental Performance Evaluation.

Wimmer *et al*. (2004) proposed a set of environmental parameters supporting the design team in collecting all relevant environmental information and data for a product life cycle analysis. That is a framework which can include general product information (name, weight, volume, supply part's environmental performance, lifetime and functionality), use of raw material (materials used and problematic materials), manufacturing (production technology and production waste), distribution (packaging and transportation), product use (usability and energy consumption), waste generated, noise and vibration, emissions, maintenance, reparability, end of life (fasteners and joints, time for disassembly, rate of reusability and of recyclability), information of other realistic scenarios, and additional information (business case and current sales per year). For Crul *et al*. (2009), innovation is necessary for a sustainable product to reach the triple bottom line and it can be achieved in a short-term by redesigning existing products or in the long-term by developing completely new products. An ecodesign checklist is proposed by EIO and CfSD (2013) in an attempt to aid Small and medium-sized enterprises (SMEs) and business coaches who are in search of eco-innovation. The key points to consider are related to the fulfillment of customer needs in terms of dematerialization, shared use, integration of functions, functional optimization of components; issues linked to the production and supply of materials and components in terms of clean/renewable/low energy, recycled/recyclable materials, less production waste; issues linked to distribution of the product to the customer related to reduction in weight and volume, less/clean/reusable packaging and energy-efficient in transport mode and logistics; issues linked to using, operating, servicing and repairing the product, as well as about the recovery and disposal of the product. From the viewpoint of product design, indicators are related to operational performance. Initiatives to give quantitative and qualitative environmental references could help product designers in their tasks (Askham *et al*. 2012; Chang et. al., 2014; Sousa and Wallace, 2006). In this view, LCA can provide quantitative indicators to analyze the environmental impact of a product (Dahlbo *et al*. 2013; Huulgaard *et al*. 2013; Sanfélix *et al*. 2013; Willers and Rodrigues 2014).

Aluminum and recycling: The aluminum is obtained from bauxite extraction and processing, and "alumina (aluminum oxide) it obtained from its processing. This is the base for electrolytic aluminum production (primary aluminum)" (BNDES, 2010). Brazil, for example, is one of the greatest bauxite producers, but it is sixth in aluminum production and fifth in world consumption of aluminum. In 2008 Brazil consumed about 1,098,700 tons. About 5kg of bauxite are necessary to produce 1kg of aluminum. The aluminum industry consumes a lot of energy and, in Brazil, although hydroelectricity is used, it consumes about 6% of the total energy generated (BNDES, 2010). This means that "primary aluminum plants in Brazil operate at a mean intensity similar to the global average, 15.5 MWh/t" (ABAL, 2012, p. 37). Aluminum is markedly important for the industry as a whole and for the packaging sector, and this is due to properties such as lightness, great resistance to corrosion and low fusion point. In Brazil the packaging sector is the greatest consumer of aluminum, and represents about 30% of the total amount of aluminum consumed (ABAL, 2007). In 2011, Brazil recycled 98.3% aluminum cans and has been the number one recycler worldwide since 2001. However, also as regards the varied aluminum scrap consumed by households, the country is above the world average (28.3%), in 2010 recycling 36.4% of the scrap (ABAL, 2012). Aluminum recyclability is indeed an important aspect to reaching high recycling rates. The advance in aluminum recycling technology allowed companies that melt down scrap again to become more competitive, improving the production chain as a whole.

Currently, scrap is classified and delivered, selected and compressed into bales, which ensure greater productivity. The collection schemes are very important to reduce "contamination" of the material. Niero and Olsen (2016) simulated the influence of the collection system on future scenarios and observed that a can-to-can recycling would provide a reduction of the impacts, for example, of 26% for climate change. This organization of the process, besides the own value of aluminum, means that scrap achieves highly enhanced prices, that are the highest among the recyclable packaging materials, for example. This aspect of aluminum recyclability, added to the organization acquired by the sector, brings the material increasingly close to a standard considered ideal, in a closed cycle, in which the entire chain re-feeds from the recycled material, in a continuous flow, during the pre-production, production and post use phases (Pereira, 2014).

In this sense aluminum recycling is very advantageous, since besides saving natural resources (bauxite), reducing social impacts (Henriques and Porto, 2013) and reducing the environmental disasters as from the tailings dam (Coelho *et al.*, 2017) – observed in the last years –, energy consumption in the recycling process is 5% of the energy needed to produce primary aluminum (ABAL, 2012, p. 46). Sevigné-Itoiz *et al.* (2014) assert that "recycling should be promoted because it means less energy consumption and thus leads to significant savings in GHG emissions compared to primary production". Likewise, a study made by Ciacci *et al* (2013) show the high potential to enhance recycling activities in Italy, based on dynamic quantification in-use stocks that will supply secondary resources. Aluminum demand is expected to triple at least by 2050 and "the lack of primary aluminum supplies has enhanced the secondary production from metal scrap and waste management". It is possible observe "a progressive increase in old scrap generation from about 15% to 45–50% in last thirty years" (Ciacci *et al* 2013). Also, Stotz *et al.* (2017) observe that "as recycling rates continuously increase, production may soon replace materials extraction and production" and Sverdrup, Ragnarsdottir and Koca (2015) analyzed the global reserves of aluminum and verify its scarcity: "after 2030, recycling or urban mining will be the major source of aluminium. This will be the age of scrap metal, and probably provide the basis for growing many new companies".

METHODS AND METHODS

This study involves two stages: light shelf design based on the Design for Sustainability principles, and environmental impact analysis applying Life Cycle Assessment.

Design for Sustainability: The product design method applied on this study has been found on methodological process employed by author in previous research projects since 2005 (Pereira, 2006). It is structured in three main steps:

Step 1: Product Concept is characterized by the storage of multiple and dispersed information, which are grouped into the categories as *Usability / identity*; *Raw materials / components*; *Production / quality*; *Purchases / suppliers*; *Marketing / sales*.
Step 2: Product Configuration refers to a second phase of data selection, performed through the functional analysis of the product based on the concept defined in the previous step. Functional analysis is a parameter for decision making, which corresponds to the generation of analytical and graphic alternatives about the new product, the selection of the best alternative and the description of the design prescriptions.
Step 3: Execution of the Product corresponds to the final definition of the product and its specifications for the production, as well as the construction of prototypes to verify the decisions taken.

This process also includes criteria to be taken into account in product designing, considering its life cycle:

Production

- Reduction at the source: To diminish the weight of material per product / to seek technological solutions / propose new more structural geometries.
- Use of renewable raw material: To reduce pressure on reserves of non-renewable materials / to seek technological solutions and replace materials.

Use

- Incentive to household sorting: To contribute to the success of selection collection after sorting by the user/ to propose intuitive solutions that simplify household sorting.
- Use of mono-material: To contribute to the success of household sorting and reduce contamination problems / to prioritize mono-material and fitting, diminishing adhesives.

Post-use

- Observation of contaminations: To contribute to improving recycling / taking into account the factor of contamination of material to minimize it in product design.
- Enhancing the value of recycled material: To add value / to seek an opportunity and propose solutions for products with a potential to add value / to disseminate the importance of recycled use.

Life Cycle Assessment

The LCA method adopted in this study follows the guidelines of ISO 14040 (ISO, 2006), and has been processed with GaBi 6 software. The objective of the LCA has been to analyze the use of recycled aluminum in part of the light shelf, aiming at the decision on the material to be used for its future production. The study has been conducted in the product design phase and has searched to understand the impacts caused in parts, using primary aluminum and recycled aluminum, with a view to adopting the best alternative for the product environmental quality. For this, three scenarios have been analyzed: 1) using only primary aluminum, 2) using side parts from recycled aluminum, 3) using only recycled aluminum. The limits of the system comprise cradle to gate and relate to the phase of obtaining the raw material and to the manufacturing phase of the light shelf. The function of the product concerns the reflection of natural light in opening windows corresponding to a length of 1500mm. The functional unit is therefore established by the reflection surface of 1.3m^2, defined by the dimensions of 865 x 1500mm of the module considered standard in the design (among other dimensions for different façades of buildings). It is assumed that the use of a part of raw material from recycled scrap generates less environmental impact. In order to evaluate that, the impact assessment has been done by the method of the Center of

Environmental Science of Leiden University, CML 2001, and has been carried out for the impact categories related to the Global Warming Potential (GWP), measured in Kg CO_2-eq. (Kg carbon dioxide equivalent), and to the Ozone Layer Depletion Potential (ODP), measured in Kg R11-eq. (Kg Risk Phrases 11 equivalent). It has been decided to evaluate the impact of the global warming category as a reference, in view of the importance of increasing temperatures on the planet and its current repercussions, not only for the UN Intergovernmental Panel on Climate Change (IPCC), but also for environmental protection organizations (GREENPEACE, 2016). Evaluation has been also made in relation to the impact category related to the depletion of the ozone layer due to the inversion of values presented only in this category, among several others. The scope of the study comprises the manufacture of the light shelf in the city of Belo Horizonte - Minas Gerais - Brazil. The raw material comes from Poços de Caldas - Minas Gerais - Brazil (primary aluminum ingot, rebar and aluminum sheet) and from Pindamonhangaba - São Paulo - Brazil (recycled aluminum ingot). The distances have been computed at the transport entrances. Data has been obtained from secondary sources available in databases made by GaBi 6 software. The average data from Europe has been applied as parameter for processes, with the exception (due to lack of database) of processes related to the foundry of aluminum - data from Germany; transport - global data for trucks; and diesel - data from Brazil. The energy to the product assembly has not been considered. Likewise, no adjustments has been made regarding the energy matrix and national manufacturing processes, since the product is not yet in production, and such adjustments are not necessary for the purpose of this study, which seeks to make decision at the design level. Subsequently, after manufacture, another LCA study should be performed in order to confirm the results of the design stage. The use of secondary data is justified by its application in ecodesign, since it will serve as a decision-making framework for the choice of material. In addition, the product not being produced makes it difficult to obtain primary data.

RESULTS

Light shelf design: The objective of a light shelf is to reduce the consumption of electric light controlling lighting and diffusion of natural light in a built space. Light shelf design has followed the methodological process presented above. The Product Concept (Step 1) can summarize as: Target audience is linked to architects who seek to meet the needs of environmental comfort in buildings; search for commercial products; Commercial standardization, modularity, ease of installation, use and maintenance; Modularity for internal and external use; Static use, providing easy cleaning; Curve for better reflection of light; Simple fittings; Use of recycled aluminum in foundry process and profiles available in the market; Finishing for better light reflection on top; Valorization of recycled aluminum: environmental argument, use in civil construction, attendance to the Leadership in Energy and Environmental Design (LEED) label for energy efficiency and use of recycled material, recovery of scrap.

Step 1 present Product Concept in details:

Usability / identity

- Commercial standardization, modularity, ease of installation, use and maintenance;
- Modularity for internal and external use;
- To facilitate cleaning;
- Identity: explore horizontal lines; explore curve for better reflection of light; simple fittings.

Raw materials / components

- To prefer use of recycled aluminum in casting process;
- To consider other processes for aluminum;
- To consider profiles available in the market.

Production / quality

- To facilitate production;
- To check for better finishes;
- To check better finish for light reflection at the top.

Purchases / suppliers

- To prefer ease of contact with suppliers and delivery of inputs.

Marketing / sales

- To increased use of recycled aluminum in the construction market;
- To use of recycled aluminum as an environmental argument for sales; To observe LEED label for energy efficiency and use of recycled material.

The Product Configuration (Step 2) can be described as follow:

The designed light shelf (Figure 1) is composed of two sinuous side pieces, similar to a French hand for attachment to the wall. In these parts, longitudinal round rebar are fixed in which flat plate sheets accompany this longitudinal line. One of these longitudinal sheets is perpendicular to the ground; the others are oblique in 10º. The angle of inclination of 10º allows the reflection of light at greater distances in the room in relation to the windows (Figure 2).

Figure 1. Project of the architectural light shelf for natural lighting

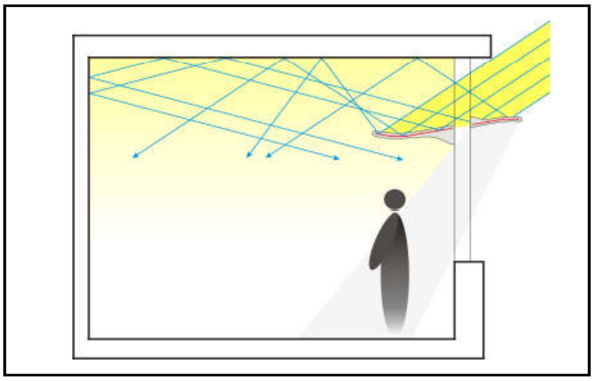

Figure 2. Scheme of the natural light reflection in the built space from the installation of the light shelf

The product presents four modules of different dimensions for better adaptation to the façade orientations. The final definition of the product and its specifications (Step 3) expect that the manufacture of this light shelf will use of recycled aluminum cast in the side parts, round rebar and aluminum plates available on the market for the other components. From the ecodesign view point, the product design has searched to reduce the use of materials in more structural geometries, to reduce pressure on reserves of non-renewable materials, to use mono-material in order to contribute to the success of collection after use and to contribute to improving recycling of the own light shelf. Finally, the design has proposed solutions for a product with a potential to add value and disseminate the importance of the recycled, seeking an opportunity to valorize recycled scrap and the use of mono-material following contemporary ideas as the example of Nave chair (EMECO, 2013).

Life Cycle Assessment of the Light shelf: The quantitative data has been defined as follows: 6 parts of 19mm rebar = 6.976kg, 5 parts of 1.5mm sheet = 9.518kg and 2 side parts by casted aluminum = 6.005kg.

Figure 3, 4 and 5 show the life cycle inventory for the scenarios 1, 2 and 3. In this system two inputs have been defined: a) laminated aluminum to produce extruded profile and sheet, and b) casted aluminum. The manufacture of the light shelf is in the city of Belo Horizonte - Minas Gerais - Brazil. In this study, the refinery supply located at Poços de Caldas-MG was adopted at a distance of 451km from Belo Horizonte-MG. Recycled aluminum ingot is obtained in Pindamonhangaba-SP at a distance of 513Km from BH. The distance between Poços de Caldas-MG and Pindamonhangaba-SP is about 360km. In scenario 1, all of the parts are from primary aluminum transformation obtained by refinery processes. In scenario 2, rebar and aluminum sheet are found in the market from primary aluminum and comes from Poços de Caldas-MG. The side parts of the shelf will be produced from the foundry process, using recycled ingot from Pindamonhangaba-SP. In scenario 3, all of the parts are made from recycled aluminum. For this scenario it has been considered the distance from Pindamonhangaba-SP to Poços de Caldas-MG to Belo Horizonte-MG. Environmental impacts have been evaluated in two categories: Global Warming Potential (GWP), and to Ozone Layer Depletion Potential (ODP).

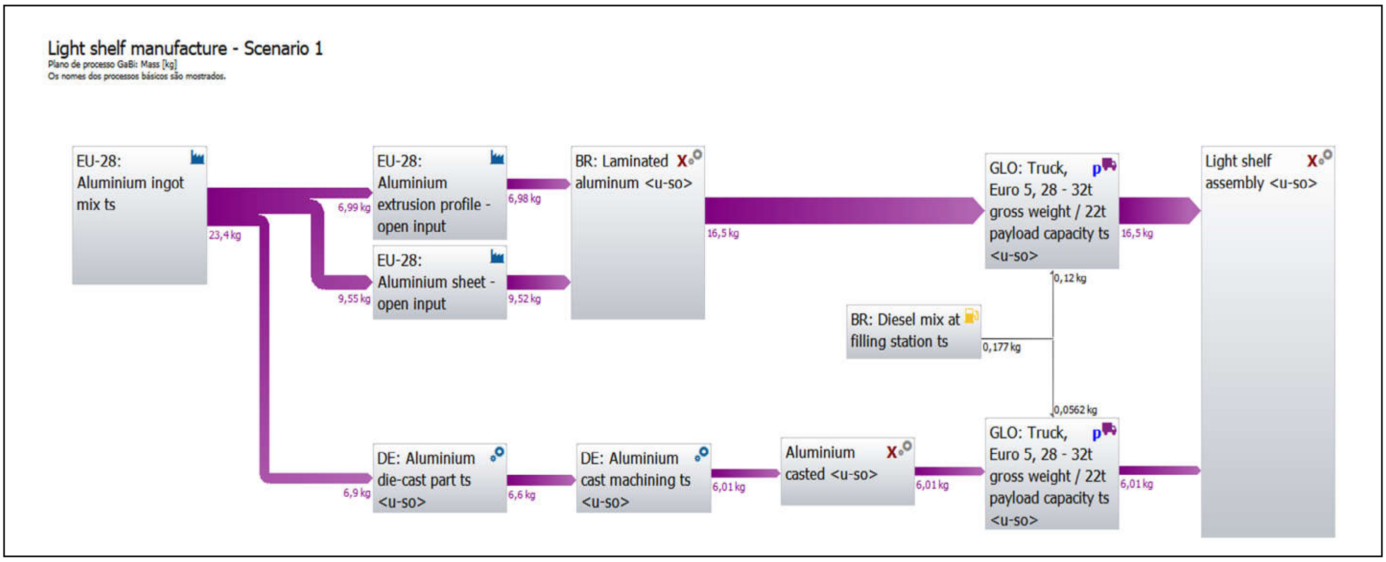

Figure 3. Life cycle inventory of the Light shelf - Scenario 1 (primary aluminum only)

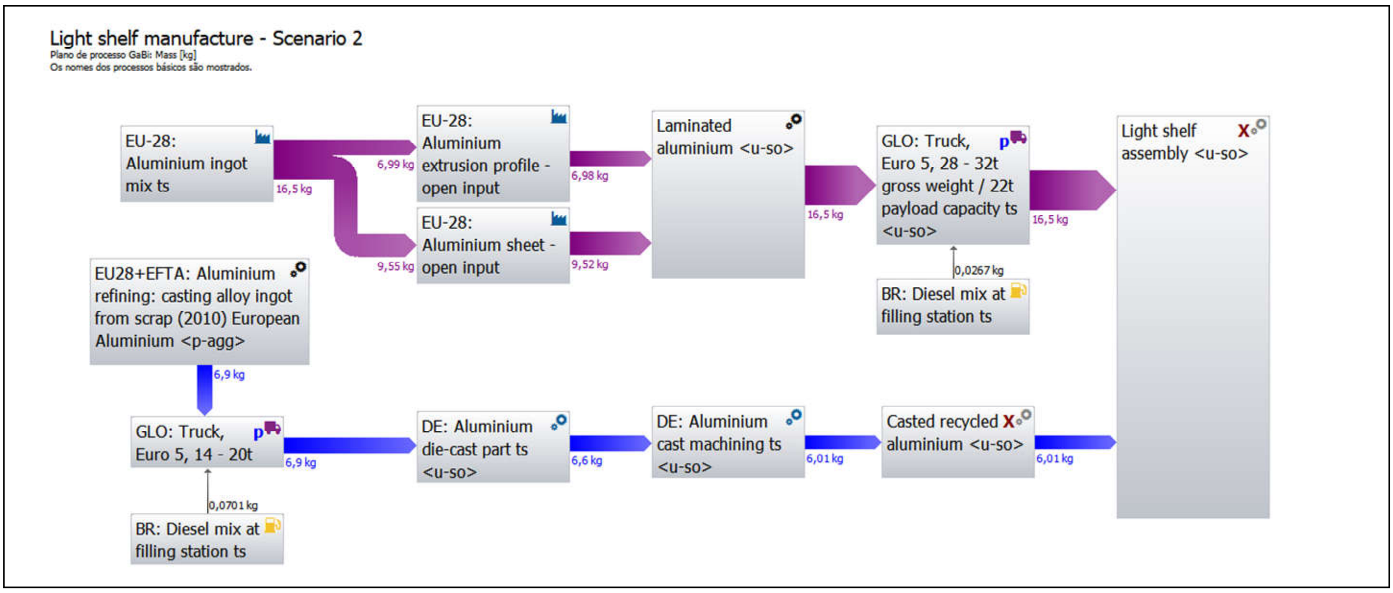

Figure 4. Life cycle inventory of the Light shelf - Scenario 2 (side parts from recycled aluminum)

It is possible to observe (Figure A.1) that for the GWP in Scenario 1, which only use primary aluminum, the light shelf emits 204.2Kg CO_2.eq. It is observed that the laminated parts emitted 147Kg CO_2-eq., being 131kg in inorganic emissions and 15.3kg in Volatile Organic Compounds (VOCs) and casted parts emits 57.2Kg CO_2-eq., being 51.1kg in inorganic emissions and 6.16kg in VOCs. For the ODP the total of emission is 0.0145e-10Kg R11-eq. relative to VOCs. Laminated aluminum emitted 0.0138e-10Kg R11-eq. and casted aluminum emitted 0,0007e-10Kg R11-eq (Figure A.2). The scenario 2 (Figure A.3) shows a total of emission of 169Kg CO_2.eq. It is observed that recycled aluminum (casted parts) emitted 21.9Kg CO_2-eq., being 20.4kg in inorganic emissions and 1.43kg in VOCs, while aluminum from refinery emitted 147Kg CO_2- eq., being 131kg in inorganic emissions and 15.3kg in VOCs. In terms of ODP, the total of emission was 1,72e-10Kg R11-eq. It is observed that the recycled aluminum emitted 1,7e-10Kg R11-eq. relative to VOC emissions, while refinery aluminum emitted 0.0138e-10Kg R11-eq. in VOCs (Figure A.4).

DISCUSSION

It is known that inclined light shelves reach a greater depth of reflection of natural light (Majoros, 1998), due to the law of reflection of light, in which the angle of incidence is equal to the angle of reflection. In addition, studies show that the incidence of sunlight in north, south, east and west façade orientations are different, with different slope angles, which consequently requires different light shelf dimensions according to lighting calculations (Santos and Souza, 2012). The angle of inclination of 10º allows the reflection of light at greater distances in the room in relation to the windows. In relation to the environmental impacts analyzed applying the LCA methods, Table 1 shows the comparison between scenarios 1, 2 and 3 as regards GWP and ODP impacts assessment. It is possible to observe that the emission of CO_2-eq. is higher when it is only use primary aluminum shown in Scenario 1, a total of 204.2Kg CO_2-eq. It corresponds to five times the emission of Scenario 3, which only use recycled aluminum: 39.4Kg CO_2-eq.

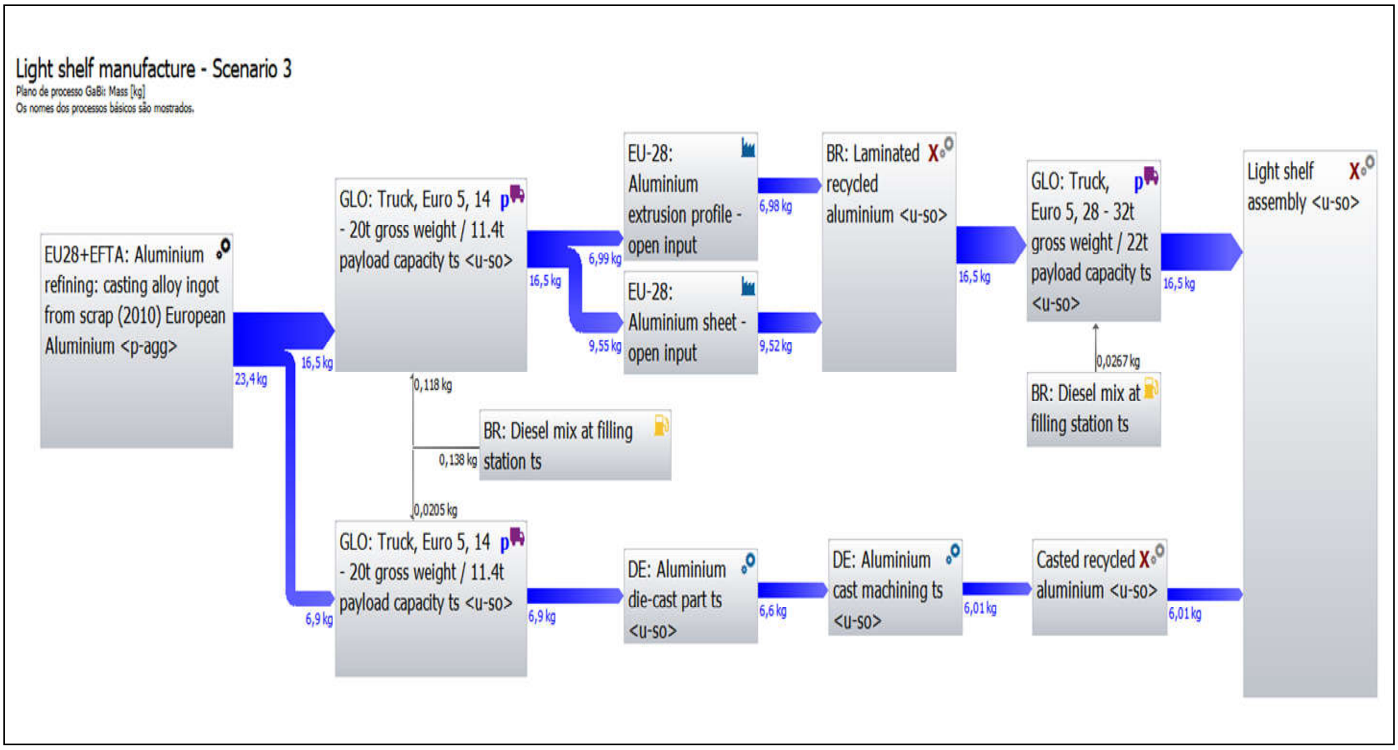

Figure 5. Life cycle inventory of the Light shelf - Scenario 3 (recycled aluminum only)

Table 1. Comparison between scenarios 1, 2 and 3 as regards impacts assessment

Impacts	Scenario 1		Scenario 2		Scenario 3	
	Laminated aluminum	Casted aluminum	Laminated aluminum	Casted aluminum (recycled)	Laminated aluminum (recycled)	Casted aluminum (recycled)
GWP CO_2.eq.	147	57.2	147	21.9	17.1	21.9
ODP Kg R11-eq.	0.0138e-10	0,0007e-10	0.0138e-10	1,7e-10	0.62 e-10	1.7e-10

The scenario 3 (Figure A.5) shows a total of emission of 39.4Kg CO_2.eq. It is observed that casted recycled aluminum emitted 21.9Kg CO_2-eq., being 20.4kg from inorganic emissions and 1.43kg in VOCs (as in scenario 1), while laminated parts from recycled aluminum emitted 17.1Kg CO_2-eq., being 16.1kg in inorganic emissions and 1.09kg in VOCs. For the ODP, the total of emission is 2.32e-10Kg R11-eq. relative to VOCs emissions. Casted recycled aluminum emits 1.7e-10Kg R11-eq. and laminated recycled aluminum emits 0.62e-10Kg R11-eq (Figure A.6).

The problem is finding laminated parts on the market made from recycled aluminum. Initiatives should be applied to increase the use of recycled raw material in market products. "Old scrap should be considered as a key resource" or "if there is no consolidated industry, this valuable resource will be lost" (Sevigné-Itoiz *et al*., 2014). In that perspective, this makes, in this moment, the best option to use laminated parts found in the market, usually in primary aluminum, and to produce the castings in recycled aluminum, option indicated in scenario 2.

With regard to the impact analysis of the ODP category, recycling processes are more notable. There was emission of 2.32e-10Kg R11-eq. in the use of recycled aluminum (Scenario 3), this value is much higher in relation to the use of primary aluminum, 0.0145e-10Kg R11-eq. (Scenario 1). However, these emissions are millions of times smaller than emissions in the GWP category, which makes the GWP impact more relevant to the conclusions and decision making. This study sought to apply LCA as a decision-making method for the selection of materials in the ecodesign of the light shelf, in order to support the impact reduction argument, notably in the global warming category, not only by the reduction of energy in the use phase of the building, described previously, as well as the choice of processes used in the raw material and production phases. It is believed that this study can contribute scientifically to the advancement of researches in the areas of product design, architecture and civil construction, demonstrating the adoption of LCA to support decision-making at the design level for sustainability, even adopting data from secondary sources (as the product is not yet in production). Although a careful and conscientious interpretation is necessary, taking into account the omission of the primary data. It is noted that, despite LCA, most methods used in ecodesign only consider qualitative aspects throughout the product life cycle (e.g. MET Matrix or Wheel Ecodesign Strategy - Brezet and van Hemel, 1997). Initiatives that provide quantitative environmental references can assist product designers in their tasks (Sousa and Wallace, 2006; Chang *et al*., 2014). The quantitative evaluation presented by the LCA results is important for a more complete analysis of the environmental impacts caused by the product system, in the design stage, and can contribute to the decision making as to the best alternative to be adopted in its manufacture.

Conclusion

The analysis presented in this study concerns the Life Cycle Assessment (LCA) of an architectural light shelf in the design phase. The LCA has demonstrated that the use of recycled materials represents a considerable gain compared to the use of primary aluminum in terms of impact analysis in the Global Warming Potential (GWP) category, contributing to the United Nations Sustainable Development Goals (SDGs), the 2030 Agenda, searching to achieve sustainable management and efficient use of natural resources. In the analyzed system, the use of only primary aluminum causes the emission of 204.2Kg CO_2-eq. It corresponds to five times the emission of another scenario that use only recycled aluminum: 39.4Kg CO_2-eq. An alternative scenario, which employs part of the primary aluminum parts (73% laminated parts) and another recycled aluminum (27% casted parts), emits 169Kg CO_2eq. In this scenario, the reduction of CO_2-eq. emission is about 17% in relation to the use of only primary aluminum. With regard to the impact analysis of the Ozone Layer Depletion Potential (ODP) category, recycling processes are more notable. However, these emissions are millions of times smaller than emissions in the GWP category, which makes the GWP impact more relevant to the conclusions and decision making. The results of the study confirm the hypothesis that the use of part of the recycled raw material generates less impact. It is concluded, therefore, that the use of 27% recycled aluminum for the production of castings (17% reduction of CO_2 emission) is the best alternative for the manufacture of the studied light shelf, since laminated pieces, such as rebar and sheets, are not yet found in the market made from recycled aluminum.

Appendices

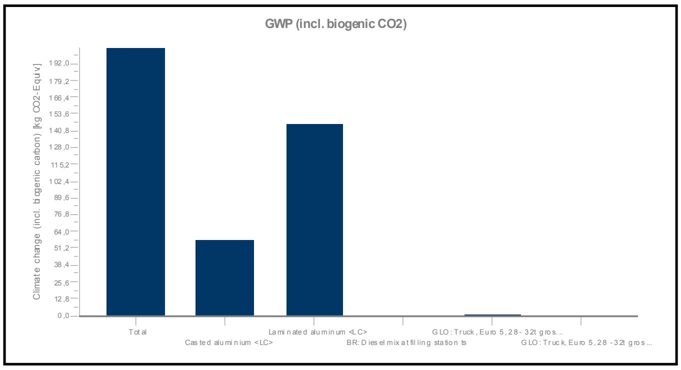

Figure A.1. Global Warming Potential assessment - Scenario 1 (primary aluminum only)

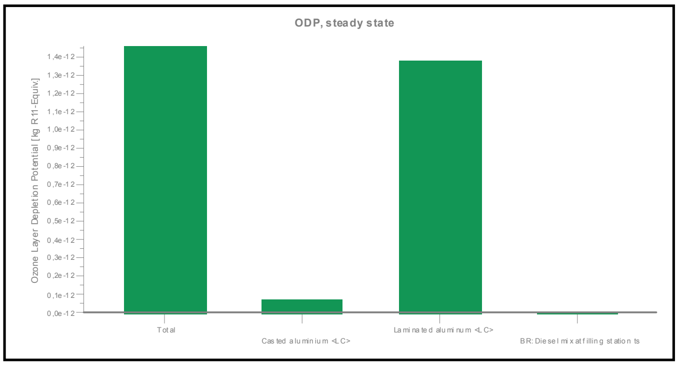

Figure A.2. Ozone Layer Depletion Potential assessment - Scenario 1 (primary aluminum only)

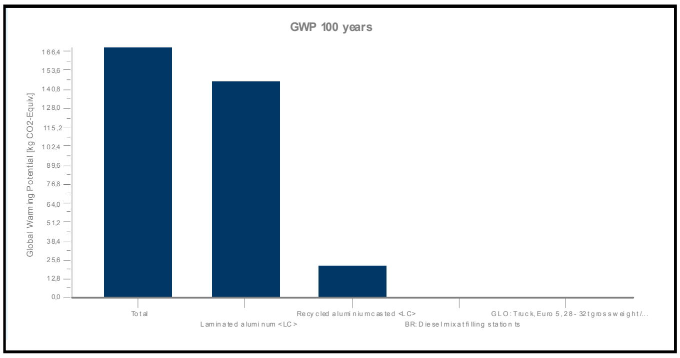

Figure A.3. Global Warming Potential assessment - Scenario 2 (side parts from recycled aluminum)

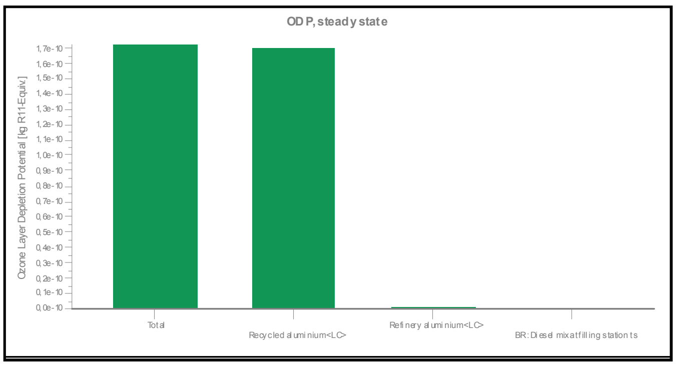

Figure A.4. Ozone Layer Depletion Potential assessment - Scenario 2 (side parts from recycled aluminum)

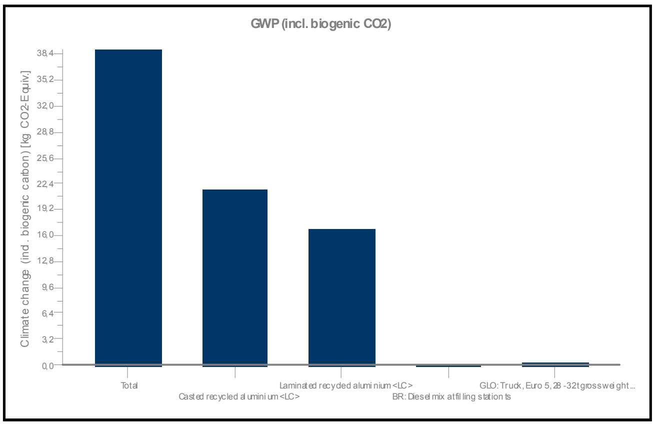

Figure A.5. Global Warming Potential assessment - Scenario 3 (recycled aluminum only)

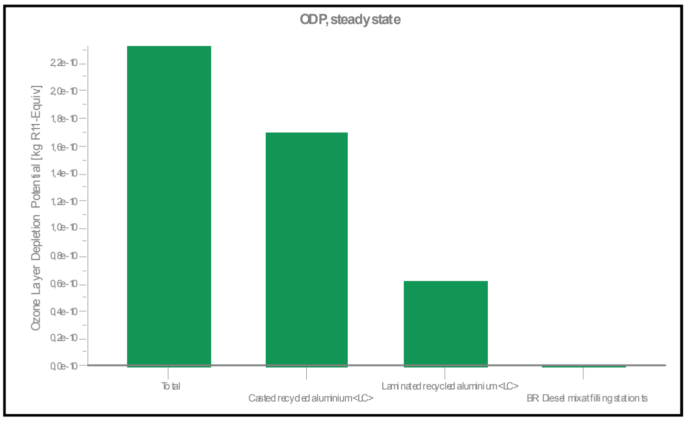

Figure A.6. Ozone Layer Depletion Potential assessment - Scenario 3 (recycled aluminum only)

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