Decision making process assisted by Life Cycle Assessment: Greenhouse gas emission

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ABSTRACT: The concept of sustainability has been spreading in the construction industry, introducing tools and methods that may assist in the process of decision making and allowing improvements in management techniques as much as in production processes. Thus, this research aims the selection of materials by means of the proposition of a decision making method – the Choosing by Advantage (CBA) assisted by the Life Cycle Assessment (LCA). It was adopted a commonly employed component in temporary facilities of construction sites in the construction industry, the tiles. The adopted tiles were composed by recycled material (polyethylene – aluminum) and by non – recycled materials (galvanized steel). It was applied a multi-criteria methodology, in which the CBA method proposes the analysis of the best type of tile according to sustainability parameters – ecological, economic and social. In this study, LCA complements the CBA by means of the evaluation of environmental impacts, where the factor "Carbon Dioxide Equivalent (Emission CO_{2eq})" was examined as a factor generated by the transportation of the tiles from the factory to the authorized reseller. By means of the implementation of the decision making method, it was verified the feasibility regarding the application of the LCA as a support tool to the CBA method for the selection of materials that cause less impact as a positively complementary methodology. It is concluded that the adopted methodology assists in the dissemination of sustainability in the stage of execution, according to a systemic approach based on sound information.

Keywords *Sustainability. Decision making method. Life Cycle Assessment. Tiles. Carbon Dioxide Equivalent Emission.*

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1. INTRODUCTION

Abraham et al. (2013) considered that the construction industry sector frequently experiences issues regarding decision making processes. The complexity of the decisions to be taken by designers and others involved consists in the selection process of the building system as much as in the process of material selection. According to the authors, these issues demand a group of approaches called *Multi-Criteria Decision-Analysis* (MCDA).

Models of multi-criteria decision may present the capacity of systematically formulate and compare different options against other vast sets of projects criteria, providing a versatile tool to deal with complex tasks regarding the decision making process (MILANI et al. 2011).

Regarding the production stages of an enterprise, the phase of execution requires the evaluation of sustainability aspects, as emphasized by Zeule (2014), in addition to the occupancy and operation phases. It was verified in the research quoted above the existence of several techniques that may be disclosed and implemented on the construction sites, mainly regarding the existing temporary buildings during this stage, as for example, the application of insulating materials adhered to the facade/roofing.

Even considering the building frequency of temporary facilities and their cycle (mounting process, usage, disassembly process and reutilization), studies regarding the sustainable development of the project process of this system in the construction site are not abundant. Arslan and Cosgun (2008) verified that, in order to improve the performance of emergency or temporary facilities, industry may need to explore the environmental aspects of these buildings throughout their existence phases.

There are several discussions regarding the environmental performance of building materials. In this context, this research aimed to verify the combined applicability of two methods in order to assist the decision making process in the selection of tiles for construction site facilities, considering the environmental impact category of global warming and the "Carbon Dioxide Equivalent Emission (CO_{2eq})" factor generated by the transportation of the tiles from the factory to the authorized reseller. In order to accomplish this analysis, the multi-criteria method Choosing by Advantage (CBA) assisted by the Life Cycle Assessment (LCA) was employed.

Although the application of the CBA method in other countries is present, it was not observed its application in the Brazilian context of construction sites facilities, typifying a technical and scientific knowledge gap. In addition, according to Milani et al. (2011), the selection of materials is fundamental in several engineering projects, defining durability, cost, manufacture of the final product and environmental concerns as the recycling process and/ or the end of useful life, the methods may vary from a selection of the material to another.

2. MULTI-CRITERIA METHODS

The multi-criteria methods, as the decision making studies are designated, have been highly utilized in the solution of problems, since they may clarify to the decision maker the possibilities of choices. When a project staff chooses an alternative, the approach may not be

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always overt, and rarely a formal method of decision making is employed (ARROYO, TOMMELEIN, BALLARD, 2015).

Milani et al. (2011) utilized the MCDA assisted by the life cycle assessment to the selection of composite materials and the considered criteria were cost, mechanical and thermal properties and environmental impact. In the research, it was compared a pure plastic gear with a polyethylene terephthalate (PET) / alternative aluminum powder composite, one of the results highlighted that the performance of the composite material and the attributes of cost are modified during the project process.

It is possible to appoint some methods of decision making employed in the analysis of sustainability oriented to the construction industry - Analytic Hierarchy Process and Analytic Network Process (SAATY, 1977), Multi-Attribute Utility Theory (VON-NEUMANN, MORGENSTERN, 1953), *Élimination Et Choix Traduisant la Réalité* (ELECTRE) (ROY, 1968), inter alia.

In addition to economic and structural factors, due to global changes, other factors may also be part of corporate responsibility, as issues oriented to natural environment and society. Regarding sustainability, one alternative is to perform modifications in the production processes of companies in order to reach ecologically sustainable options.

2.1 Choosing by Advantage (CBA)

The CBA system, according to Suhr (1999) is based on four principles: (1) the decision makers must learn and skillfully utilize tangible methods, (2) the decisions must be based on the importance of the advantage, (3) the decisions must be anchored on relevant facts and (4) different types of decisions demand different methods of decision making.

The difference of CBA, when compared to other methods, is the systemic analysis reconsidering the decision. Suhr (1999) indicates that the difference between sound methods and unsound methods[1] are the weighting rating given to wrong items, for example: advantages and disadvantages, pros and cons, criteria and objectives. In advance, CBA is a system that compares the advantages of the alternatives.

The CBA method for moderately complex decisions divides the process of Decision Making in five phases: 1) stage-setting, 2) innovation phase, 3) decision making phase, 4) reconsideration phase and 5) implementation phase (SUHR, 1999). This article emphasis Phase 3, the decision making phase.

3. LIFE CYCLE ASSESSMENT (LCA)

LCA is a tool utilized to assess the potential environmental impacts of a product system throughout its life cycle. This tool may be divided into four phases: definition of objective and scope; analysis of Life Cycle Inventory (LCI); Life Cycle Impact Assessment (LCIA) and interpretation of results (ABNT, 2009).

Onwards the results obtained by LCA it is possible to recognize the aspects that may cause more impact throughout the life cycle and, according to NBR ISO 14.040 (ABNT, 2009), by

[1] They are inconsistent methods, unstable (SUHR, 1999)

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means of the interactivity among the phases of the LCA, it may be possible to achieve the completeness and consistency of the research and of the results.

According to Passuelo et al. (2014) there is a lack of studies about the LCA of construction materials in Brazil, what determines the necessity of studies that relate the practice of LCA in the local scenario in order to transform this object into a management tool applicable to the Brazilian reality.

4. RESEARCH METHOD

The employed research procedure was based on three available methods:

- Five stages of Phase 3 – Decision Making of the CBA (SUHR, 1999);
- Proposal of the authors Arroyo, Tommelein, Ballard (2015), suggesting the complementation of Phase 3 – Decision Making process with two more stages considered in Phase 2 – Innovation of CBA (SUHR, 1999), making the decision making procedure more comprehensive, embodying seven stages; and
- LCA as a tool disclosed by technical standards, allowing the evaluation of environmental impacts caused by materials and systems of products– NBR ISO 14.040 (ABNT, 2009), in order to assist the decision making process regarding environmental aspects.

Figure 1 exemplifies how the method was composed in order to be applied in this research.

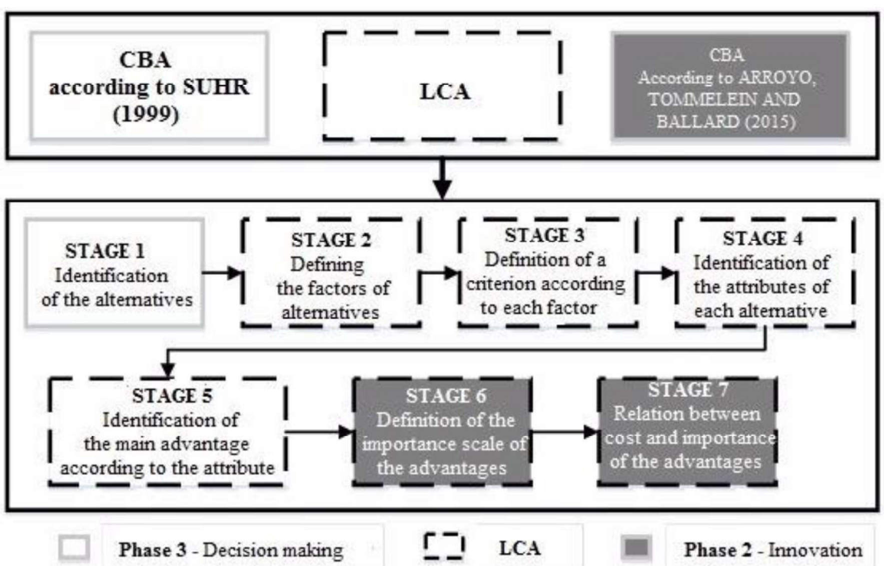

Figure 1. Participation of CBA and LCA in the method: Authors, 2016

The alternatives are the types of materials to be compared (Stage 1), and the definition of the elements that will be compared, these elements are present in the materials (Stage 2) subsequently, the essential criteria to attend the factors are defined (Stage 3) and, consequently the attributes of each alternative are detected (Stage 4), therefore the main advantage is determined by means of the less preferable attributes among the alternatives (Stage 5). Stage 6 defines a range scale by means of the advantages importance, utilizing the main advantage as support, in order to assess the cost data. In Stage 7, a graphic (Importance of the Advantages x cost of the material) is designed. The final result of this analysis is the

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selection of one of the compared materials (alternatives), based on the defined attributes, which present the best option to be employed.

This research was focused on the "Carbon Dioxide Equivalent Emission (CO_{2eq})" of the analyzed tiles, which was the factor chosen to be studied on Stage 2 of Phase 3, regarding the Decision Making method CBA aggregated to the LCA which assisted the decision making process until the last stage.

For the effective application of the LCA, it was utilized a software in order to manipulate the data, as well as a database of life cycle inventories. The employed software was the Open LCA® and the ELCD 2.0 (ELCD, 2016) database; both were chosen because of the free availability.

In this research, it was analyzed the transportation stage of the tiles from the factory to the authorized reseller. Therefore, the data collection considered the calculation of the average distance between the factory and the cities in which the tiles were resold; the distances found are analyzed in Table 1. This analysis was made by means of a direct contact with the manufacturer of the tiles.

The analyzed tiles were constituted by: recycled material of long life package (polyethylene – aluminum); metallic corrugated in galvanized steel and; metallic trapezoidal in thermo-acoustic galvanized steel. Thus, by means of the software, the data provided by the manufacturers were compiled in order to obtain the CO_{2eq} emission regarding the category of global warming. In order to achieve the CO_{2eq} emission data caused by the transportation of the tiles, it was utilized the method consolidated by the Intergovernmental *Panel on Climate Change* (IPCC) (IPCC, 2013).

5. CASE REPORT

The selection of the tiles for the application of the method concerns the fact that the tile is one of the required components in temporary facilities of construction sites, and during the transportation process, the emission of greenhouse gases occurs.

The typology of the three analyzed tiles were: 1) tile containing recycled substances of long life package (polyethylene – aluminum); 2) corrugated galvanized steel tiles; 3) thermo-acoustic trapezoidal galvanized steel tiles, aiming to compare the different variety of tiles available on the market, which are employed in temporary facilities of construction sites.

5.1 Characterization of the tiles

The tiles presenting recycled material of long life package are composed by plastic (low density polyethylene LDPE) and aluminum of the packages, with an external layer of virgin aluminum, which is not part of the residues of the long life packages, adhered to the tiles in order to improve the thermal performance. The measures of these tiles were 2, 20 of length, 0, 92 of width, 6mm of thickness and 14 kg per unit.

The corrugated tiles constituted of galvanized steel are not painted metallic tiles, manufactured from a steel sheet covered by a thin layer of protection composed by pure zinc (galvanized sheet). The function of the zinc is to avoid the corrosion process. The tiles used in

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this research were corrugated and natural (no painting), they presented width of 1,10m, length of 2,20m, thickness of 0,50mm and weight of 9, 9 kg per unit.

Trapezoidal tiles manufactured in galvanized steel are not painted metallic tiles produced by two steel sheets (sandwich tiles), coated by pure zinc (galvanized sheet). In order to be designated as thermoacoustic, it must be filled with an insulating material as Expanded Polystyrene (EPS) or Polyurethane (PU), for example, thus characteristics that may improve the thermal and acoustic performance will be developed. The tiles applied in this study presented the shape of a trapezium, width of 1,10m, length of 2,20m, thickness of 0,50mm and a layer of EPS with 50mm of thickness, each piece weighted 21kg.

5.2 Application of the method

Stage 1 – Identification of the alternatives – The alternatives chosen to the application of the CBA method were the three types of tiles specified in item 5.1, utilized in temporary facilities of building sites.

Stage 2 – Definition of factors - The "Carbon Dioxide Equivalent Emission (CO_{2eq})" factor was analyzed.

Therefore, in Stage 2 the LCA was integrated in order to assist the CBA decision making method, in which the potential category of global warming was analyzed with regard to the transportation process. This factor was investigated regarding the transported distance and the weight of the tiles from the factory to the authorized reseller.

Stage 3 – Definition of a criterion regarding the factor – The criterion adopted to analyze the potential factor of global warming was: lower emission of $CO_{2eq.}$

According to the principle of sustainability, lower emissions of CO_{2eq} are related to a lower contribution to the global warming effect.

Stage 4 – Report of the attributes of the alternatives –In Table 1 the attributes of the alternatives were expressed, in other words, the quantity of $CO_{2\ eq}$ emitted by the transportation of the tiles to the reseller.

Stage 5 – Decision of the main advantage – The main advantage indicated by the decision maker regards the tile presenting a lower $CO_{2\ eq}$. emission.

Stage 6 – Definition of the importance scale of the advantages – In this research, as a single factor was analyzed ("$CO_{2\ eq}$ emission"), consequently it was evaluated by a maximum punctuation of 100 points.

Stage 7 – Relation between cost and importance of the advantages – After the attribution of the scores to the advantages, a calculation was made and the total of the importance of the advantages was obtained. The value of each alternative was also obtained, in other words, the price of each tile (unit) per square meter was achieved, a graphic IofA x R$ was schematized, which enabled the choice of the most suitable tile.

Table 1 exhibits important data as the average distance traveled by the truck in order to transport the tiles from the factory to the sales area, considering that this resale may be direct as it is the situation of the metallic tiles in galvanized steel or may be performed indirectly, as

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the recycled tiles, which the manufacturer transports the product to another specific sales area.

Table 1. Distance Data

Types of Tiles / Distance and Lorries	Recycled material Polyethylene-aluminum	Corrugated Galvanized Steel	Thermo-acoustic Trapezoidal Galvanized Steel
Average transportation distance from factory to resale	1.225 km	535 km	535 km
Lorry utilized in the transportation	Truck 22 tonnes or Truck 14 tonnes	Truck 25 tonnes or Truck 12 tonnes	Truck 25 tonnes or Truck 12 tonnes

Authors, 2016

The inventory "*Articulated lorry transport, Euro 0, 1, 2, 3, 4 mix, 40 t total weight, 27 t Max payload – RER*" owns a representative data set for the European area (RER) (ELCD, 2016)**.** The quantity of reference is the "cargo" and the data corresponds to the annual average.

According to the metadata of ELCD 2.0 (ELCD, 2016) the utilized methods were prepared according to the weighted average of the trucks in accordance to the emission standards EURO, in other words, EURO 0 to EURO 4. The valid cargo considered to the transport was 17,3 tonnes and 27t, due to the types of trucks utilized and detailed on Table 1, and, mainly, for being modules that represent "process systems" and for considering the early life of the diesel. The emission of combustion corresponds to data measured from the truck: ammonia, benzene, carbon dioxide, carbon monoxide, methane, nitrogen oxide, nitrous oxide, Non-Methane Volatile Organic Compound (NMVOC), PM 2.5 particles, sulfur dioxide, toluene, xylene. The emission of NMVOC, toluene and xylene results into combustion losses and imperfect evaporation by diffusion through the tank. The analyzed process was performed in a diesel-powered truck.

RESULTS

Due to the fact that tiles present the function of covering the facilities, a reference unit of coverage of $50m^2$ was adopted in order to perform the calculation. In addition, an analysis was made regarding the sensibility of the disclosed data. Thus, the calculation was performed considering the average distance and a distance of 100km (standard), in order to make it possible to analyze the interference of the characteristics of the tiles, as the transported weight and volume.

In order to quantify the CO_{2eq} emission level, it was employed the? Life Cycle Impact Assessment (LCIA) method developed by IPCC, which utilizes the *Global Warming Potential* (GWP) in order to transform the emissions of greenhouse gases into emissions of CO_2eq , considering a time line of 100 years (IPCC, 2013).

The modules adopted as reference to the calculation of CO_{2eq} emission were ""*Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t maxpayload - RER*", a more decisive module when compared to the "*Articulated lorry transport, Euro 0, 1, 2, 3, 4 mix, 40 t total weight, 27 t maxpayload – RER*", according to Table 2**.**

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Table 2. Global warming according to real and standard distances with the maximum cargo weight of the truck

TILES	IPCC 2013 - GWP 100a (CO_2eq)					
	Distance of 100km			Real Distances		
	Tonnes x km	Max. 27 tonnes	Max. 17,3 tonnes	Ton x km	Max. 27 tonnes	Max. 17,3 Tonnes
Polyethylene - aluminum Recycled material	42,0	0,00492	0,00819	514,5	0,06023	0,10018
Metallic Corrugated	24,8	0,00281	0,00468	132,6	0,01547	0,02573
Metallic thermoacoustic	52,6	0,00609	0,01014	281,4	0,03293	0,05477

Authors, 2016

For the real distances, the module which contributed the most for the category of Global Warming was the module regarding the transportation of recycled tiles, presenting an emission level of 1, 00E-01 (CO_{2eq}), followed by the thermoacoustic metallic tiles presenting an emission level of 0, 55E-01 (CO_{2eq}) and the corrugated metallic tile presenting an emission level of 0, 26E-01 (CO_{2eq}). According to this analysis, the average distance directly affected the results, as the longer distance refers to the recycled tile (1225 km), followed by the metallic tiles presenting the same distance (535 km). In this case, as the distance for the metallic tiles was equivalent, the predominant factor for the result of the emission level was the weight, as in order to cover 50m² it is necessary 0,526 tonnes of thermoacoustic tiles and 0,248 tonnes of corrugated metallic tiles.

However, when the standard distance of 100 km was adopted, the transportation of the thermoacoustic tile was the most critical, presenting an emission level of 1,01E-02 (CO_{2eq}), followed by the recycled tile presenting an emission level of 0,82E-02 (CO_{2eq}) and the corrugated metallic tile, 0,47E-02 (CO_{2eq}). In order to perform this analysis, it was observed that the weight of the tiles was decisive for the results, as to cover 50m², the thermoacoustic tiles own a higher weight of 0,526 ton/m², followed by the recycled tiles, 0,420 ton/m² and the corrugated metallic tiles, 0,248 ton/m². Henceforth, Table 3 exhibits the results of the joint application of the CBA method assisted by the LCA, where it may be seen six of the seven stages briefly explained on the research method.

Table 3, Results of the application of CBA assisted by LCA.

ANALYZED FACTOR	ALTERNATIVES					
	POLYETHYLENE - ALUMINUM RECYCLED TILE		CORRUGATED METALLIC TILE – GALVANIZED STEEL		THERMOACOUSTIC METALLIC TILE – GALVANIZED STEEL	
Carbon Dioxide Equivalent Emission **– according to the average distance** *Criterion*: Lower CO_2 eq emission	Attributes: 1,00 Advantage:	0	Attributes: 0,26 **Advantage: lower CO2 eq emission**	50	Attributes: 0,55 Advantage:	0
Carbon Dioxide Equivalent Emission **– according to the distance of 100km** *Criterion*: Lower CO_2 eq emission	Attributes: 0,82 Advantage:	0	Attributes: 0,47 **Advantage: lower CO_2 eq emission**	50	Attributes: 1,01 Advantage:	0
TOTAL IofA		0		100		0

Authors, 2016

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In order to conclude the selection of the tile, the economic aspect was considered. Stage 7 of the research method presents a graphic containing the cost of the tiles according to the Importance of Advantage (IofA).

The values of the tiles were calculated referring to $1m^2$. The polyethylene – aluminum recycled tile costs R$ 16,58/m^2, the corrugated metallic tile in galvanized steel costs R$ 16,54/m^2 and the thermoacoustic metallic tile in galvanized steel with EPS costs R$ 44,64/m^2. Thus, the graphic presented by Figure 2 illustrates the relation between Importance of Advantage and costs/m^2 of the tiles.

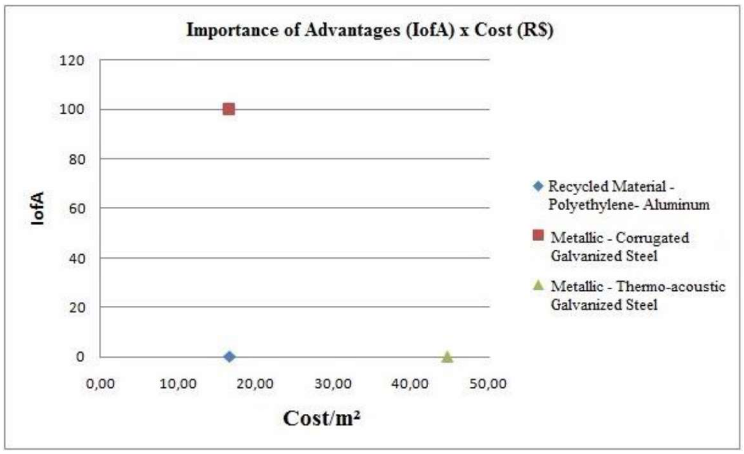

Figure 2: Graphic of the relation between the Importance of Advantage x Cost of the tiles: Authors, 2016

Therefore, after the implementation of the method, it was possible to identify that the most convenient tile regarding the factor of greenhouse gas emission was the corrugated metallic in galvanized steel, which emitted less CO_{2eq}, and presented a reasonable market price. However, it is emphasized that other factors must be assessed in order to complete the process of material selection.

6. CONCLUSION

According to the performed evaluations, the possibility of achieving several results was verified, what presents a direct dependency with the unit of reference. In this work, the application of LCA allowed to determine the quantity of emitted $CO_{2eq,}$ by means of the category associated to global warming. However, the necessity of analyzing other categories of environmental impact that may relate other ways of emission not contemplated by the category of global warming is existent.

Brazil does not own an implemented database that represents the reality in all levels of the country, thus, it justifies the use of an international database. The ideal is the performance of an adaptation of the information presented by the database as reference. However, the objective of this research was to demonstrate the contribution that LCA may provide to the decision making methods, because LCA effectively contributes by facilitating the choice made by the decision-maker.

Characteristics as volume and weight, in addition to the average distance traveled by the vehicle and the utilized vehicle must be considered in order to analyze the transportation process of the tiles. These factors must be simultaneously studied as they directly affect the emission levels, enabling a critical examination by the decision maker at the moment of the analysis according to the unit of reference.

Thus, the accuracy of the method adopted in this research was validated. The LCA verified the CO_{2eq} emission and the method of decision making verified the advantages of the tiles by means of the principle that when the CO_{2eq} emission level is lower, consequently the transport of the tiles causes less social and environmental impacts.

It is important to emphasize that the result obtained with regard to the CO_{2eq} factor, does not characterize the ideal tile for the selection of the material to be utilized in temporary facilities in construction sites, since this analysis must be made by considering other factors that may characterize the environmental, social and economic impacts. Thus, the decision making process in the sector of construction industry requires attention aiming the improvement of this area.

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