Life Cycle Assessment and Building Sustainability Certification Systems: Could Building Information Modelling tools ease this integration?

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ABSTRACT: Life cycle assessment (LCA) is an important methodology for the environment-based evaluation of building materials, components and systems and should be used within the building sustainability certification systems. The present paper reports on the state of the art of LCA as a tool for the assessment of building materials and components and analyzes its application in the sustainability certification systems of building. The analysis of the existing systems for the sustainability certification of buildings has revealed that among the main and most employed certification systems, only a few use the LCA methodology to evaluate the environmental performance of building materials and components. Most of the systems assess building materials and components by the recognition of product attributes, such as cost, durability, renewability and recycled content. The weakness of the attributes approach lies in the fact that these attributes are treated in isolation and lack the holistic concept of impact. In this context, some software tools have been developed to integrate environmental analysis into Building Information Modelling (BIM) platform, in order to facilitate such evaluation during the design process. However, it is still not possible to state whether these tools are actually accessible to the average user, from the point of view of the user interface and the results understanding, and, moreover, how much their results are accurate if compared to a full ad hoc environmental assessment. Such approach is the central point of this paper, which also aims to discuss a theoretical overview of how integration tools of LCA databases into BIM platform would ease the generation of LCA data to be applied at Building Sustainability Certification Systems.

Keywords *Environmental Assessment of Buildings, Life Cycle Assessment, Building Information Modelling*

ISBN: 978-85-92631-00-0

1. INTRODUCTION

The preoccupation regarding sustainable development, especially in its environmental dimension, has resulted in dozens of Assessment Methods of Building Sustainability in different countries, with several criteria and methods of assessment and certification. However, there is no global uniform method for the certification of buildings (Stránská and Sedlák, 2012).

In order to assess the overall impact of measures of resource consumption reduction during the lifetime of a building, Life Cycle Assessment (LCA) has shown to be a valuable methodology (Verbeeck and Hens, 2010). This methodology has been recognized in the European Union in the context of 'Integrated Product Policy' (IPP) as providing "the best framework for assessing the potential environmental impacts of products currently available" (Nissinen et al., 2007). However, such a technique results in a large amount of multi-dimensional data difficult to comprehend and interpret (Bersimis and Georgakellos, 2013).

Previous studies, such as those by Erlandsson and Borg (2003), Haapio and Viitaniemi (2008) and Nibel et al. (2005) have reviewed the LCA methodology for buildings, however there are still some lacks regarding environmental indicators, complexity of LCA disclosure for users, simplifications and adaptations for different purposes (Bribián et al., 2009).

Embodied energy calculations and life cycle assessment have been pointed out as key elements in the building energy assessment, although they are often left out of regulation and certification proposals (Casals, 2006). Life Cycle Assessment (LCA) is an increasingly important evaluation tool for decision making and stakeholder discussions. When applied especially during the planning phase, it can pinpoint process steps of high environmental impact and provide guidance towards optimising the actual technology implementation (Niederl-Schimidinger and Narodoslawsky, 2008)

Given the current scenario of the assessment of environmental performance and life cycle of building systems, this paper reports on a survey of the main methods currently used for the assessment of building materials within the building sustainability certification systems, focusing on the application of life cycle assessment methodology. A previous literature review on the subject was already performed by the authors (Bueno et al., 2013) however such a scenario has been expanded and changed rapidly in recent years, pointing to the need for a new approach.

2. GOALS AND JUSTIFICATION

The purpose of this study is to build a summary table on the methods used by major building sustainability certification systems for the assessment of building components and discuss how BIM could ease LCA implementation in such scenario. The main contribution of this paper is the identification of the possibilities of implementation of LCA methodology within the building sustainability certification systems and the understanding of their strategies for such an implementation.

ISBN: 978-85-92631-00-0

3. METHODOS

The basis of the discussion proposed in this paper is a literature review of the studies on the applications of the LCA methodology in civil construction, as well as the parameters used by the sustainability certification systems for the assessment of building components. The methodological procedures have been divided into three main stages: a) Survey of the state of the art of the building components assessment by the main building sustainability certification systems; b) Development of a summary table of the methodologies of environmental assessment of building components used by the building sustainability certification systems considered in this paper; c) Discussion on the role of BIM platform as support for LCA application in certification systems.

The certification systems chosen are SBTool (Larsson, 2012), Green Globes (Skopek and Bryan, 2002), AQUA (Fundação Carlos Alberto Vanzolini, 2008), LEED (USGBC, 2009), BREEAM (BRE, 2011), DGNB (2012), CASBEE (JSBC, 2010) and Green Star (GBCA, 2011)

4. LCA AND ASSESSMENT OF BUILDING COMPONENTS IN THE ENVIRONMENTAL CERTIFICATION SYSTEMS OF BUILDINGS

According to Bueno et al. (2011), when the key certification systems of building environmental performance are compared, they can be standardized by organizing their evaluation categories: Design Process, Connections, Implantation, Resource Consumption, Emissions, Comfort and Environmental Quality, Services, Economic Aspects and Operation Planning. Within these categories and for each certification system, there are a number of credits which enable the analysis of the building according to various themes. The credits concerning the assessment of building components are concentrated on the categories related to resource consumption, environmental quality and emissions.

The various certification systems concentrate credits related to the evaluation of building components and materials differently. In the LEED certification system those credits are placed in the Materials and Resources and Indoor Environmental Quality categories. SBTool and Green Globes work in a similar division, concentrating those items on the Energy and Resource Consumption and Emissions (or Loadings) categories. In BREEAM, Green Star and CASBEE, such credits are comprised in the Materials and Resources category, and DGNB inserts them in a broader category named Environmental Quality. AQUA certification system has a category totally dedicated to the evaluation of materials and components: “Integrated choice of construction products, systems, and processes” Bueno et al. (2013).

Regarding the evaluation of building components within the main building sustainability certification systems, recognition product attributes, such as cost, durability, renewability, and recycled content currently prevail. This so-called attributes approach deals with those attributes alone, when in fact they are often in conflict and interfere with each other (Silva, 2007), because those certifications are based on multicriterion analysis of conflicting parameters to achieve simpler and understandable results.

Tables 1, 2, 3, 4, 5, 6, 7 and 8 show the evaluation methods present in the credits related to building components in some of the main building sustainability certification systems,

ISBN: 978-85-92631-00-0

namely: LEED 2009, AQUA, SBTool, Green Globes, BREEAM, DGNB, CASBEE and Green Star.

Table 1: Materials and components assessment methodology in LEED certification system

Evaluative credits regarding building components	Category	Assessment methodology
Recycled Content	Materials and resources	**Attributes –** To evaluate the use of materials with recycled content so that constitute 10-20% of the material's mass.
Regional Materials		**Attributes –** To evaluate if the distance from the extraction and production sites is shorter than 500 miles from the construction site.
Rapidly Renewable Materials		**Attributes –** To evaluate whether at least 2.5% of the total cost of building systems refer to rapidly renewable materials.
Certified wood		**Attributes –** To evaluate if at least 50% of the wooden systems are certified materials.
Low-Emitting Materials— adhesives and sealants, coatings and flooring	Indoor Environmental Quality	**Attributes –** All adhesives and sealants, paints and coatings, and all flooring used in the interiors must comply with the Volatile organic compound (VOC) limits.
Low-Emitting Materials— Composite wood and agrifiber Products		**Attributes –** Composite wood, agrifiber products and Laminating adhesives must contain no urea-formaldehyde resins.

Table 2: Materials and components assessment methodology in AQUA certification system

Evaluative credits regarding building components	Category	Assessment methodology
Constructive choices aiming at durability and adaptability of the building	Integrated choice of products, systems and construction processes	**Attributes –** To consider the lifespan of products and systems and processes regarding their use in the building.
Constructive choices aiming at the ease of building maintenance		**Attributes –** To evaluate the choice for easy-maintenance products.
Choice of construction products to limit the social and environmental impacts of construction.		**Attributes –** To evaluate the greenhouse gases emissions, waste generation, possibility of reuse/recycling of materials, use of renewable resources and depletion of natural resources.
Choice of construction products to limit the impacts to human health		**Attributes –** To evaluate the characteristics of the interior lining products in emissions of pollutants harmful to human health.

Table 3: Materials and components assessment methodology in CASBEE certification system

Evaluative credits regarding building components	Category	Assessment methodology
Reducing use of materials	Resources & Materials	**Attributes –** To encourage the use of high-strength materials to reduce material usage.
Continuing use of existing structural frame		**Attributes –** To encourage the reutilization of the existing buildings structures.
Use of recycled materials as structural frame materials		**Attributes –** To evaluate the use of recycled materials in the building's main structure.
Use of recycled materials as non-structural materials		**Attributes –** To evaluate the use of recycled materials in non-structural applications.

ISBN: 978-85-92631-00-0

Table 3: Materials and components assessment methodology in CASBEE certification system (continuation)

Evaluative credits regarding building components	Category	Assessment methodology
Timber from sustainable forestry	Resources & Materials	**Attributes –** To evaluate the use of timber from sustainably managed forests.
Efforts to enhance the reusability of Components and materials		**Attributes –** To evaluate measures to facilitate recycling at the end of building lifecycle.
Use of Materials without harmful substances		**Attributes –** To evaluate the reduction of chemicals which may affect the interior air quality and overall environment.
Foaming agents (insulation materials)		**Attributes –** To evaluate insulation materials, based on Ozone Depletion and Global Warming Potentials.

Table 4: Materials and components assessment methodology in Green Star certification system

Evaluative credits regarding building components	Category	Assessment methodology
Building reuse	Materials	**Attributes –** To encourage and recognize the reuse of existing buildings.
Reused materials		**Attributes –** To encourage and recognize designs that prolong the useful life of materials.
Concrete		**Attributes –** To encourage and recognize the reduction of embodied energy and resource depletion due to the use of concrete.
Steel		**Attributes –** To encourage and recognize the reduction of embodied energy and resource depletion associated with the use of virgin steel.
PVC		**Attributes –** To encourage and recognize the reduction in the use of Polyvinyl Chloride.
Timber		**Attributes –** To encourage and recognize the specification of reused, legally sourced and certified timber products.

Table 5: Materials and components assessment methodology in SBTool certification system

Evaluative credits regarding building components	Category	Assessment methodology
Embodied non-renewable energy in construction materials	Energy and Resource Consumption	**LCA –** Use and embodied energy estimating system, based on LCA.
Degree of reuse of suitable existing structure where existing		**Attributes –** Structural, functional and economical assessment of an existing structure.
Material efficiency of structural and building envelope		**Attributes –** To analyze efficient use of physical resources by building components make.
Use of virgin non-renewable materials		**Attributes –** To estimate and minimize the use of virgin non-renewable materials in the project.
Use of finishing materials		**Attributes –** To estimate the use of finishing materials in the interior of the building, to minimize resources consumption.
Ease disassembly, reuse or recycling		**Attributes –** To ascertain the degree to which components of the building are easy to disassemble for reuse or recycling.
GHG emissions from energy embodied in building materials	Environmental Loadings	**LCA –** Embodied energy estimating system, based on LCA.

ISBN: 978-85-92631-00-0

Table 6: Materials and components assessment in Green Globes certification system

Evaluative credits regarding building components	Category	Assessment methodology
Minimal Consumption of Resources	Resources	**Attributes –** To evaluate the use of recycled, reused, locally sourced and low-maintenance materials and certified wood.
Low Impact Systems & Materials		**LCA –** To evaluate the use of materials with low environmental impact throughout life cycle.

Table 7: Materials and components assessment methodology in DGNB certification system

Evaluative credits regarding building components	Category	Assessment methodology
Life cycle Assessment	Environmental Quality	**LCA –** Application of LCA on the Building and its materials
Environmentally Friendly Material Production		**Attributes –** To encourage the specification of environmentally friendly produced materials.

Table 8: Materials and components assessment methodology in BREEAM certification system

Evaluative credits regarding building components	Category	Assessment methodology
Life cycle impacts	Materials	**LCA –** To recognize and encourage the use of construction materials with a low environmental impact over the full life cycle of the building.
Hard landscaping and boundary protection		**LCA –** To recognize and encourage the use of landscape and boundary protection materials with low environmental impact over the life cycle
Responsible sourcing of materials		**Attributes –** To recognize and encourage the specification of responsibly sourced materials.
Insulation		**Attributes –** To recognize and encourage the use of thermal insulation with low embodied environmental impact.
Designing for robustness		**Attributes –** To recognize and encourage the adequate protection of exposed elements, minimizing their replacement.

In the LEED certification system, the credits related to the issue addressed in this study use the attributes evaluation, as shown in Table 1. The first, "Materials with recycled content," evaluates the use of materials so that the sum of the pre-consumer and post-consumer recycled content constitutes 10-20% of the material, whose score varies according to the achieved percentage. The "Regional materials" credit assesses whether the distance from the place of extraction and production of the building materials is shorter than 500 miles from the construction site for at least 10-20% of the materials used. Similarly, to the previous credit, the building can reach a better score, according to the percentage achieved. In the evaluation of "Rapidly renewable materials", the objective is to use products with main rapidly renewable raw materials for at least 2.5% of the total cost of the materials and building systems. The use of certified wood is also evaluated in at least 50% of the wooden systems. Some of the credits of LEED concern the evaluation of building components comprised in the Indoor Environmental Quality category. Some of those credits, which also use the attributes method, regard the VOC (volatile organic

ISBN: 978-85-92631-00-0

compounds) emissions from materials, such as adhesives and sealants, paints and coatings and flooring systems. The last credit of this category requires that the composite wood, agrifiber products and laminating adhesives used in the building contain no added urea-formaldehyde resins.

AQUA certification system presents an evaluation methodology that uses attributes in all its credits related to building components, as can be seen in Table 2. The first credit, "Constructive choices for durability and adaptability of the building" considers the lifespan of the products, systems and processes according to their use in the building. The "constructive choices for easy maintenance of the building" item evaluates the choice of products of easy conservation and maintenance, whereas in "Choice of construction products in order to limit the social and environmental impacts of the construction", the evaluation of the environmental attributes of the construction products is related to the emission of greenhouse gases, generation of waste, reuse/recycling of materials, use of renewable resources and depletion of natural resources. This is one of the credits that most resembles the concepts of LCA in this certification, however without its holistic character and observing such characteristics individually. The last credit of this certification, called "Choice of construction products in order to limit the impacts of construction to human health" considers the information on the product characteristics for linings regarding the emissions of pollutants harmful to human health.

CASBEE and Green Star rating systems are also completely based on the attributes approach, as shown in Tables 3 and 4. Green Star certification only touches the theme of LCA in the credits regarding the reduction of the building embodied energy, however it does not recommend the application of full LCA studies. The same occurs in the CASBEE rating system, which uses Global Warming and Ozone Depletion indicators to measure environmental impacts from insulation materials, indeed does not provide any guidance in the use of LCA or requirements for the evaluation of the whole life cycle of such materials.

Regarding the SBTool certification system (Table 5), several changes can be identified in comparison to its first version, the GBTool 2002, comprising important advances concerning the incorporation of the life cycle thinking in the assessment methodology. Several changes have also occurred in the attributes approach credits, in which previous credits, as “Use of salvaged materials from off-site sources”, “Recycled content of materials from off-site sources” and “Use of certified or equivalent wood products” - all concerning the limitation in the use of resources – have been replaced by more general and actual credits, as “Reuse of suitable existing structure”, “Material efficiency of structural and building envelope components”, “Use of virgin non-renewable materials” and “Use of finishing materials”. Such changes, even when implying generalizations and simplifications have pointed out to the updating and improvement of this evaluative tool in the current design practices as they facilitate its application to various building typologies, implantations and construction techniques. The “Avoidance of solid waste resulting from construction processes” credit has also been replaced by “Ease disassembly, reuse or recycling”, pointing to new strategies and building systems suitable to be disassembled for reuse and recycling.

Some credits, such as those regarding emissions of ozone-depleting substances (mostly CFC) and gases leading to acidification (mostly SO_2) have been removed from the certification system, probably due to the rise of a more restrictive standardization

ISBN: 978-85-92631-00-0

regarding such emissions. However, the consideration of those potential impacts must be assessed in order to assure their constant reduction. Finally, two credits have shown an evolution in the application of the life cycle methodology to the building rating systems: “Embodied non-renewable energy in construction materials” and “GHG emissions from energy embodied in construction materials”. Both credits existed in the previous version, however the evaluation method applied was based on the counting of the annualized energy consumption or emissions normalized for building areas, covering only the inventory phase of an LCA. In the SBTool 2012 version, the applied method is based on a complete LCA study, providing more reliable results, as identified by Stránská and Sedlák (2012). These last two credits must be highlighted as the main evolution in the SBTool. The use of LCA to analyze embodied non-renewable energy may lead to conclusions not only on the consumption of fossil fuels and energy, but also on the potential impacts during the production process of such materials and their embodied energy.

Green Globes uses only two credits for the assessment of the environmental performance of building materials and components, as shown in Table 6. This is probably due to the use of a full LCA study, which derives as much information as possible about the product concerned by analyzing holistically its potential environmental impacts. This certification system comprises the "Minimum consumption of resources" credit, which applies the attributes evaluation approach by considering the use of recycled, reused, locally sourced and low-maintenance materials and certified wood. However, the main evaluation credit of this certification is "Low-impact materials and systems", which uses a full LCA to evaluate the use of materials with less environmental impact.

Table 7 shows the building materials issues assessed by the DGNB certification system. This system uses the same concept adopted by Green Globes certification, with the optional assessment of building materials by using LCA or attributes approach. Such an approach has as its weak point presenting the LCA as an optional method of assessment, giving the user the opportunity to avoid it. At this point it is important to highlight that, as the LCA methodology is highly time- and resource-consuming, the user tends to avoid its application.

Finally, Table 8 shows the credits regarding the assessment of building materials in the BREEAM rating system, which also uses both attributes and LCA approaches. The credits evaluated by attributes are related to the insulation materials, responsible sourcing of materials, and design for minimizing the maintenance of exposed building materials. On the other hand, this certification system also includes a full LCA-based credit for all building materials. The credits evaluated by attributes play a complementary role in relation to the LCA credits, once the last provide almost complete results in terms of building materials environmental impact assessment. BREEAM exhibits the most complete and consistent structure in terms of implementing LCA for the evaluation of building materials in the sustainability certification systems.

5. CONCLUSIONS

This paper has shown that, among the currently most employed building sustainability certification systems, only a few use LCA methodology to evaluate the environmental performance of building components. Most systems are based on the assessment of

ISBN: 978-85-92631-00-0

building components by isolate attributes, with some timid implementation of optional LCA-based credits. Among the main reasons for the limited use of LCA in the building sustainability certification systems is its implementation complexity, as it demands considerable time and effort. Such complexity is inherent to LCA methodology, but it is worsen due to the lack of available inventory data and consensus on best practices in Life Cycle Impact Assessment (LCIA). The LCIA methodologies currently available are still limited to specific contexts and have divergent characterization methods, making it difficult the practical choice of the most appropriate method to a particular study. In addition to the complexity and high demand of time, an LCA study also requires the involvement of a multidisciplinary team, with specialized professionals, due to the need for specific knowledge of the application protocols, use of software and databases, characterization of substances potential impact, etc.

A promising possibility of incorporation of this methodology to design is the insertion of LCA data of construction systems in Building Information Modelling (BIM) platform. The recent proliferation of BIM platform applications is seeking to achieve LCA integration in the construction and it is encouraging that this is expanding to more areas of engineering and building business activities (Jung and Joo, 2011). Wu and Issa (2012) point to the BIM platform as an enabler for a more viable approach to commissioning of buildings. The authors show that, as a life cycle information management tool, the BIM features come legitimize its application in the commissioning of buildings as BIM models are comprehensive in information as they cover all Physical and functional features of a building, being to store, share and exchange data with other applications. They also can perform several complex analysis of the building simulations, producing significant results and covering of all life cycle stages.

As the purpose of implementing LCA data in the BIM platform is providing quantitative environmental information for supporting environmental prioritization of a type of element or construction system in the building design process, the functional unit should be as bounded as possible. The functional unit must be chosen and calibrated to be used in the analyses of the same in construction systems in different types of buildings. For this reason, construction systems should be considered independently (e.g., independent structure, sealing, covering, flooring, etc., as a separate function). Therefore, the potential life cycle impacts of any construction system should not interfere with other systems. Other important points are the geographic, temporal and regional scopes for data collection. Once the functional unit is defined, it is important to ensure that the same scope is used to collect data for all construction systems, especially for those with the same function.

Thereby the integration of LCA data on the BIM platform is a promising field in order to facilitate and encourage such a quantitative environmental assessment in the early design process. However, the development of methodologies and tools for such purpose is still in the early stages and there are many issues, constraints and obstacles to be overcome by researchers, developers and professionals of environmental assessment and project building design.

ISBN: 978-85-92631-00-0

6. ACKNOWLEDGEMENTS

The authors acknowledge FAPESP (São Paulo Research Foundation) for the financial support given to this research under the process number 2013/24046-0.

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