The use of BIM for the sustainable design

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ABSTRACT: The construction industry is a great generator of environmental impacts by excessive consumption of raw materials, high energy consumption and amount of waste generated. In this context, there is an effort to mitigate these negative impacts, seeking better alternatives to create more sustainable buildings. Through the literature review methodology, this study aims to explore the use of BIM – Building Information Modeling – as a facilitator in the sustainable buildings production process. Besides the exhibition of key-concepts about the subject, showing the possible integration and collaboration between them, some case studies are reviewed, presenting the results of practical applications of BIM, aiming sustainability, in other studies. It is concluded that BIM can be a useful tool in the search for sustainability, because, as using a multidisciplinary model full of data and digital representations, it allows decisions be made in advance, avoiding rework. It can be used alone, to extract quantities, or in combination with other performance and LCA software for more complete analysis. Despite the positive aspects, BIM still has limited impact in the process of obtaining sustainable buildings, existing a need for further studies, in addition to the improvement and development of tools.

Keywords *BIM. Sustainability. Sustainable design.*

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1. INTRODUCTION

The civil construction industry has a leading role in the Brazilian economy, generating more than 8 million jobs and being responsible for 6,6% of the Gross National Product in 2012 (CBIC, 2015). On the other hand, it has also a leading role in the consumption of natural resources and energy, in the occurrence of loss and the amount of waste generated, causing a lot of negative environmental impacts. Therefore, construction is put in the center of the debate about sustainable development, existing a growing discussion on how to mitigate the impacts generated by this industry. In this context, there is an effort by the design professionals in the selection of better alternatives, arising the environmental certifications and the life cycle and performance analysis.

Through literature review, this study aims to explore the use of BIM as a facilitator in the production process of more sustainable buildings. The objective is to analyze the state of the art regarding integration of LCA or sustainability assessments in BIM tools. A review of the key-concepts on the subject (sustainability in construction and BIM) is going to be made, showing the possible integration and collaboration between them. It will also be made a brief data collection and discussion of case studies, presenting the result of practical applications of BIM, aiming sustainability, in other authors' studies and, at the end, a summary of the results will be presented.

2. KEY-CONCEPTS

2.1 Sustainability in construction

The construction industry is a big generator of environmental impacts worldwide. Lachimpadi et al (2012) affirm that it uses up to 60% of the raw materials extracted on Earth: 40% of the rocks, 25% of the wood and 16% of the water. Besides, due to its size and the inefficiency of some of its processes, almost all of the activities developed in construction generate waste, being that, according to Wong & Zhou (2015), this waste contributes with 40% of all the solid waste generated in the world. They also say that approximately 10% of the final use of the global energy occurs in the manufacture of construction materials. According to Graf et al (2012), buildings consume more than half of the energy used in developed countries. So, sustainable construction practices are needed, forcing architects, planners and constructors to consider the environmental impacts of the buildings they design and build.

To measure the environmental impact of a building, Graf et al (2012) say embodied energy values can be used, being that these values can come to 40% of all the energy consumed in the 50 years life cycle of a building. Another parameter that can be used is the CO2 emissions. The calculation process of these values, conventionally, is complicated and slow, demanding a lot of knowledge of whom is going to make it.

Oliveira et al (2015) affirm that, to improve the energy performance of Brazilian buildings, new methodologies of design development, that aim the reduction of the embodied energy and the CO2 emissions through the life cycle, must be encouraged. This is because, to Barros et al (2015), Marcos (2009), Azhar et al (2009), Jrade & Jalaei (2013), Dowsett & Harty (2013) and Azhar et al (2011), a significant amount of the life cycle impacts of a

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building (approximately 70% according to LIU et al, 2015) is determined by the decisions made at the beginning of the design phase, being the choices made in this phase and in the preconstruction stages the most effective in relation to a building's sustainability.

In the search for sustainability, there is the Life Cycle Analysis (LCA), which is a very popular tool in the evaluation of the environmental impacts of a building in each step of its life cycle, from the extraction of raw material until the final destination or reutilization of resources after the demolition (CRAWFORD, 2008). According to Barros et al (2015), because it is holistic, systemic and rigorous, the LCA is the internationally preferred method in this investigation, helping in the alternative selection and the decision making process. It is divided in four steps: goal and scope; life cycle inventory; life cycle impact assessment; and interpretation. For its realization, a specialized knowledge and a great amount of information are needed, requiring the use of computational methods, many tools and different professionals.

The conventional LCA work flow, according to Barros et al (2015), starts with the development of the architectural and complementary projects until the executive level, by the designers. Then, these projects are passed to the LCA analyst so the data can be collected from 2D drawings, existing difficulties in the extraction of information, demanding lots of resources e being subject to human errors. For the exposed, it is seen that the project and the LCA are made separately and without any connection.

According to Azhar et al (2011), in an attempt to simplify the process of impacts assessment, many countries created environmental certification systems for buildings, which assess the energy consumption, hydric efficiency, use of materials, etc. For example, in USA, there is LEED (Leadership in Energy and Environmental Design), which is divided in six categories (sustainable sites, water performance, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in design) and has four levels of certification (certified, silver, gold and platinum), obtained based on the number of points received.

In both processes, LCA and certifications, traditional CAD (computer aided design) often fails in the ability to perform the necessary sustainability analysis in early design stages, because they are only made after the conclusion of the construction documentation (due to the great amount of data needed that are not usually available at the beginning of the conventional process). To Azhar et al (2011), this is an inefficient process, because retroactive design changes are needed so the project can reach performance criteria and because trial-and-error methods are used to predict the environmental performance.

The planners must be capable of making conscious decisions about their projects, formulating many scenarios of development with the collaboration between the interested agents. And it is in this context that BIM (Building Information Modeling) arises as an alternative, since it allows multidisciplinary information to be superimposed in only one model, creating an opportunity of sustainable measures incorporation throughout the design process.

2.2 BIM

According to Eastman et al (2011), BIM is a set of computerized procedures to create a single model of a building that involve three fundamental aspects: parametric modeling,

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interoperability and possibility of the project's management and assessment during its life cycle. It is not software, but a technology of modeling, a computerized design process that allows shared and collaborative creation of a parametric and object oriented model of the building.

> BIM is considered a production, use and update process of an information model of the building during all the stages of its life cycle, being useful for many purposes. It covers and integrates all the subjects involved in the construction context, giving the model geometrical data and different aspects' properties. Its three-dimensional, parametric and storage character facilitates the running of simulations and analysis, in addition to collaborate with the visualization, development and generation of the project documentation. (MACHADO et al, 2015, p. 528, author's translation)

Kivits & Furneaux (2013) said that, in BIM, the information is created only once and can be reutilized several times, resulting in the elimination of rework, fewer errors and more consistency. With it, a virtual model of the building is created from objects filled with geometric and textual information that simulates the behavior of real construction elements (OLIVEIRA et al, 2015). Machado et al (2015) say that BIM allows a systemic and integrated vision of construction, being possible to reduce costs, anticipate solutions and conduct variable testing in early stages of design.

To Oliveira et al (2015), BIM allows the approach of the whole life cycle of buildings, enabling preliminary analysis of the building in each stage of the cycle. In this way, it can approximate the studies of environmental impacts with the activity of construction itself, promoting a bigger integration between them.

For all this, BIM has a considerable potential to enhance the efficiency, sustainability and effectiveness of the entire construction process: design, construction, maintenance and demolition. It can be a horizon to be explored in the search for tools that help the decision making process aiming for the mitigation of the environmental impacts of buildings, since it can create alternatives quickly, assess multiple metrics and visualize plans before the real construction.

3. BIM AND SUSTAINABILITY

As said before, a significant part of the impacts of the life cycle of a building is determined by the decisions made at the beginning of the project, being these early choices the most effective to sustainability. However the conventional methods that use CAD do not support such early choices, with performance analysis being carried only after the conclusion of the design and existing a need for retroactive changes. Azhar et al (2009) affirm that, to perform analysis in early stages of design realistically, there should be access to information such as: building shape, materials, context and technical systems. In this context, BIM can help, because it enables multidisciplinary information in a single model full of parametric data and digital representations of the building. From this model, data can be properly exported and analyzed by many users with specific needs, generating information that can be used in the decision making process.

According to Jrade & Jalaei (2013), the combination of sustainable design strategies and BIM technology has a potential to change traditional design practices and to produce high performance buildings. Marinho (2014) said that the use of BIM aiming sustainability allows: optimization of energy, water, soil and material use in integrated and precise

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analysis; the study of design alternatives earlier in the process; and the tracking, monitoring and improvement of the performance using intelligent 3D models. Still, Dowsett & Harty (2013), Azhar et al (2009) and Marinho (2014) say that BIM makes the information necessary for sustainable design available routinely, as a byproduct of the existing process. This is because, with BIM, most of the data needed to help the sustainable design is acquired naturally as the project is developed, because the information is generated automatically during the model's creation (KIVITS & FURNEAUX, 2013).

For Carvalho & Scheer (2015), the parameterization of a BIM model allows, during the design stage, the simulation of the sustainability indicators that help in the decision making process and enables discussions of design adjustments and improvements. Another advantage is the anticipation of problems, inefficiencies and errors (which are usually discovered only during the construction stage), leading to cost reduction and saving of resources (LIU et al, 2015; CARVALHO & SCHEER, 2015).

Prizibela said that

> one of the main advantages of the use of BIM is the possibility of predicting determined situations before the beginning of the construction, this allows a better visualization of the conflicts, a faster search for the intended solution and the reduction of rework. These factors, by themselves, already contribute so a building consumes less environmental, human and financial resources, besides, the BIM system may help to achieve a more sustainable certification, as it enables entering the energy performance of the building as one of the dimensions that interact in the design process. (2011, p. 83, author's translation)

Regarding the integration between BIM and LCA tools, it can enable more control and understanding of alternatives and results that aim sustainability (MACHADO et al, 2015), because, according to Barros et al (2015), the BIM goals and uses are determined at the beginning of the design stage and passed to the whole team involved, considering the LCA from the start. Then, the model is transferred to the LCA analyst, who extracts all the necessary data for the analysis (amount of materials, average materials transport distances, used energy, etc.). The automatic process resulting from this integration allows efficiencies in the LCA procedures and feasibility of changes before the construction.

According to Kriegel & Nies (2008), BIM can help in the following aspects of the sustainable design: (i) building orientation, selecting the best orientation, which results in minimum energy costs; (ii) building mass, analyzing building shape and optimizing its envelope; (iii) daylight analysis; (iv) water consumption, to reduce the need of water in the building; (v) energy modeling, to reduce the energy need and analyze renewable energy sources, such as solar panels; (vi) sustainable materials, to reduce the need of materials and use some recyclable ones.

3.1 Case studies

After the review of the possible relation between BIM and sustainability, in technical literature, this article makes a compilation of studies conducted by several authors aiming this integration.

González & Figueira (2016) made a research with the software CYPE, consisted of various interconnected modules. After the elaboration and introduction of the model, it allows the realization of simulations, obtaining thermal and acoustic data, besides from the LCA. Any modifications in the model reverberate automatically in the conducted analysis. According to the authors, the junction of the three analysis in only one tool allowed more integration and simplicity in the simulations.

In a Sidney Opera House case study, Kivits & Furneaux (2013) verified that the use of BIM promoted a more precise representation of the building in a data integrated environment. They also noticed that the processes are faster and more effective (because of the easier sharing and reuse of information) and that the whole life cycle has its costs and environmental data controlled.

Pires et al (2013) used, in an integrated way, BIM packages (Revit) and simulation software (Energy Plus) aiming to investigate the feasibility of reducing the energy consumption in a selected building. They verified that, although Revit has a model exportation tool, this integration is still not realized properly. The Energy Plus use was difficult because it required that the model volume was simplified so they could run the simulation.

In his research, Aksamija (2012) found that the main programs used in simulations for performance analysis are: Ecotect, eQuest, Energy Plus-Sketch Up, Energy Plus, IES VE, Energy 10, Design Builder, DOE-2, HEED and Green Building Studio. However, the author verified that the compatibility with BIM-based design software is limited, mainly, to Green Building Studio, Ecotect and IES VE. To export the data and models between design and analysis applications, he says that two schemes can be used, a direct one (gbXML) and an indirect one (DXF). He conducted a case study to verify his assumptions and concluded that interoperability between BIM-based design and simulation tools can improve the workflow between the design phase and the performance analysis.

Barros et al (2015) made a comparison between the work flow in a conventional LCA analysis and one with the use of BIM, aiming to verify the impact of BIM adoption in the assessment of embodied energy levels in buildings life cycles. They concluded that there are positive impacts in the second case, in the design and the data collection stages, affirming that BIM was considered a reliable tool measuring the performance and environmental impacts of a building.

Machado et al (2015) also evaluated the potential of BIM and LCA integration. They identified advantages, such as: (i) in the life cycle inventory, BIM can help in the automatic quantification of inputs and in the parameter insertion for correlation of each building component and its CO2 emissions and consumption factor; (ii) in the life cycle impact assessment, it can export data automatically to produce documents, besides the integrated visualization of measured impacts. In addition to observe that the tools combination is valuable in the organization of impact scenarios through simulation and virtual models analysis, they concluded that the interoperability between tools must be improved.

Graf et al (2012) made a Revit model, inserting embodied energy and CO2 emission values (previously calculated), creating shared parameters. Comparing the obtained results with conventional calculation, they realized that the BIM software results were coherent, considering it a useful resource in obtaining environmental impacts results and supporting design decisions aiming sustainability.

Azhar et al (2009) made a case study about the Psychology Building of the Emory University, which received Silver LEED certification. Three programs were tested (Ecotect, Green Building Studio and IES Virtual Environment), being BIM used since the early stages of the design to determine the best solar orientation, skin types, daylight analysis and energy analysis. Virtual Environment (IES VE) received maximum score in the authors' evaluation, being considered the best software for its versatility and potent BIM-based sustainability analysis. The study indicated that BIM can help in the processes of the complex task of the sustainable design, as well as automate the materials quantification process, cost estimates and construction schedules, coordinating information in a single integrated model.

In their research, Jrade & Jalaei (2013) collected data from the materials used in their model in literature and suppliers' pages, organizing and applying them in a component library of a BIM tool. They made it possible to search and select, in the database, many sustainable components with their associated specifications, potential points in LEED and manufacturer's data. The main product of the model is a 3D BIM project containing lists of the sustainable materials chosen with theirs associated environmental impacts, cumulative points and associated costs. This was linked to ATHENA Impact Estimator, generating quick results through tables and graphics. The development of the described model aimed to present a database with "green materials" used to create families of components, linking them to the BIM tool to enable the elaboration of models of sustainable buildings in 3D.

Azhar et al (2011) made a research to demonstrate ways the designers can use BIM to perform analysis aiming to obtain LEED certification. Their study developed a conceptual platform of the relation between BIM and the LEED process, validating it through a case study. The authors found that the documentation to 17 LEED credits and 2 prerequisites can be direct or indirectly prepared exploring BIM software. They said that, due to the limited availability of the building's data, only 5 credits and 1 prerequisite could be validated in the case study. They also concluded that there is no direct (one-to-one) relation between LEED and BIM analysis, but that these programs can generate results very quickly if compared to traditional methods.

Bynum & Olbina (2013) investigated the perceptions of the use of BIM for the sustainable design and construction between designers and constructors. They observed that many respondents knew the possibilities of BIM in relation to sustainability, some making certain performance analysis, and that 91% of them believed that BIM is best used supporting sustainability in the early stages of design. Despite that, they also concluded that many of the interviewed still believed that sustainability isn't the first application of BIM and that the coordination between project, visualization and integration of the supply chain are the most important uses.

4. CONCLUSIONS

Analyzing the relationship between sustainability and BIM found in technical literature and in the case studies conducted by other researchers, it is clear that BIM can be a useful tool, allowing error reduction, automatic data generation, faster results, anticipated decision making and life cycle monitoring.

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For this to happen, the designers must have their goals well established and aligned from the beginning. Also all the team members must work collaboratively in an integrated way. They need to define which analysis they want to develop and what is necessary for this, filtering and selecting the relevant information, because different types of analysis can be developed in different stages of the design, due to the Level of Detail (LOD) of the model. In the early phases, the analysis should focus on the bigger aspects of the design, as orientation, mass, climate, etc. During more advanced stages of the design, the analysis should explore more complex aspects, such as thermal and energy analysis.

For the different stages mentioned, different tools are needed. The team members also need to choose which software is going to be used. If it is only one, they must choose the one that has all the tools needed to model the building and conduct the analysis wanted. If it is two or more, they have to verify, apart from the possibility of realizing what is needed, which programs have more compatibility with each other, since interoperability can be a problem.

Below, there is table 1, with a summary of the concepts and obtained results.

Table 1. Results summary. Source: the authors.

Topic	Description	Considerations	
DESIGN AND MODELING PROCESS	3D model, parametric, unique, collaboratively developed	Precise representation	Errors reduction
		Changes reverberate automatically	
		Simulation of orientation, mass, daylight, water and energy consumption, materials	Early choices, alternatives
		Data available automatically, faster and easier process	
		Parameter insertion (CO_2, energy)	
LIFE CYCLE	Monitoring	Cost control	
		Data control	
LCA AND PERFORMANCE	Goals determined from the beginning	More integration, efficiency and control	
	Quantification and data exportation		
	Automated process		
INTEGRATION	One tool	Simplified analysis	No compatibility issues
		Can be insufficient	Analysis can need non-available resources
	Two or more tools	More complete analysis	Combination of resources
		Inadequate integration	Exportation issues
			Complex models
CERTIFICATION	Aid in the quest for LEED certification	Faster results	
		Documents obtained directly or indirectly	

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In summary, this study conceptualized and explored the key-elements about the theme, presenting the collaboration that can occur between the search for sustainability and BIM-based processes. It was found that BIM can be useful in quest for sustainability because it allows multidisciplinary information in a single model full of data and digital representations. From it, data can be properly exported and analyzed by various users with specific needs, generating information that can be used in the decision making process aiming the improvement of the building's performance and sustainability.

Despite the positive aspects and the potential relationship between BIM and sustainability, the case studies showed that there are still limitations and uncertainties due to issues of inadequate geometrical representation, interoperability limitations, model's level of detail (LOD), etc. There is still need for methodological and operational improvement of procedures, making it necessary to develop more robust and sophisticated platforms. For this reason, and because it is still in an initial phase of application within the theme, BIM technologies have limited impact on the process of sustainable buildings production.

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