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Integration of environmental life cycle information in BIM objects according with the level of development

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Abstract. The construction sector is a major contributor to global environmental impacts. This is one of the reasons why there is a political trend towards a "greener" sector. One indicator of this trend is the progressive application of life cycle thinking approaches and life cycle assessment of products, assemblies and buildings. The digitalization of construction projects, namely the use Building Information Modelling (BIM), can constitute a support to the automation of the application of Life Cycle Assessment (LCA) at the building's design stage. However, besides the complexity of LCA model and results interpretation, BIM models usually lack LCA data that allow environmental impacts calculation. Currently, few publications explicitly relate the integration of LCA and BIM with the specificities of distinct development stages in the design and construction process or Levels of Development (LOD) of BIM objects. This paper summarizes the possible sources of LCA information to include in BIM models and discusses the complexity of LCA information needed for distinct BIM objects' LOD. A parametrization of environmental information is proposed, to be included in BIM objects, based on an evolutionary level of detail in LCA information for increasing LODs.

Keywords: LCA (Life Cycle Assessment), BIM (Building Information Modelling), LOD (Level of Development), building sustainability

1. Introduction

The construction sector is determinant in the European economy, but it is also responsible for important environmental impacts. The construction and use of buildings in the European Union (EU) account for about half of all extracted materials and energy consumption and about a third of EU's water consumption. This sector also generates about one-third of the waste and is associated with potential environmental impacts that arise at different stages of a building's life cycle including the manufacturing of construction products, building construction, use, renovation and management of building waste[1].

To enable professionals, decision-makers and investors to consider impacts related to the whole life cycle of a building, empirical-based, reliable, transparent and comparable data are needed [1]. Life cycle assessment (LCA) is a commonly accepted and well-established methodological tool that quantitatively applies life cycle thinking on environmental analysis of activities related to processes or products [2].

Building Information Modelling (BIM) may become a valuable tool to improve energy performance and resource efficiency of buildings [3]. BIM is commonly defined as "*a digital representation of physical and functional characteristics of a facility*" as well as the basis for a shared knowledge (and decision support) resource for information, during its life cycle (from earliest conception to the end of life stages) [4]. An essential and distinct characteristic of BIM is its collaborative and life cycle approach, considering the several phases of the life cycle of a building or infrastructure.

High potential has been identified in the combined use of BIM and LCA methodologies, and some research works were published regarding this synergy [5–9]. It is, however, important to discuss the combined practical use of these tools by Architecture, Engineering and Construction (AEC) professionals. The environmental LCA approach, concepts and terminology are usually not applied by these professionals and need to be further explained and integrated into their practice. Currently, few publications [10, 11] explicitly relate the integration of LCA and BIM methods to the specificity and requirements of different stages in the design and construction process (different levels of development - LOD).

This work discusses existing possibilities for LCA integration in BIM tools and the type of LCA information that is relevant for integration in BIM objects, depending on their LOD. A solution is proposed for the parametrization of environmental information in a BIM object, according to its LOD.

2. Methodology

The methodology for this work was based on a literature review on the themes related to its main aim:

- LCA methodology and sources of LCA information for building materials and assemblies;
- Current integration of LCA and BIM;
- LOD of BIM objects;
- Existing proposals on how to include LCA information in BIM models.

Based on available information, a detailed characterisation of the different types of LCA information was completed and included:

- LCA data specificity, i.e., the level to which data relate uniquely to a particular product or production site, or it represents average results for several sites of the same producer or average European data;
- The number of parameters or environmental impact categories to express LCA results and the complexity it adds to the interpretation of results;
- The level of aggregation of environmental information (e.g., the use of weighted single scores that combine several environmental impact categories versus the use of complete disaggregated information).

This analysis allowed the development of the proposed parametrisation of environmental information to be included in BIM objects, according to their LOD, and respective detail and reliability of this information.

3. LCA methodology and sources of LCA information for building materials and assemblies

LCA is a complex and data-intensive method that quantifies resources consumption, relevant emissions, and the related environmental and health impacts associated with any goods or services throughout their life cycle [12]. It is usually applied by research or consultancy experts and not directly by the production companies. The sources of LCA data may be found in: 1) published research works; 2) national or international databases (with distinct levels of reliability and representability); 3) specific LCA studies promoted by the companies to comply with an environmental labelling system, such as Environmental Product Declarations (EPD). The representativeness *vs* specificity of the data is different for each case.

ISO 14040 [12] describes the principles and framework for LCA, including its four main stages: the goal and scope definition of the LCA, the Life Cycle Inventory Analysis, the Life Cycle Impact Assessment (LCIA), and the life cycle interpretation stages.

3.1. National or international generic databases

The International Standardisation Association (ISO) standards applicable to the development of LCA do not specify impact categories to be assessed or impact assessment methods to be used [13]. Thus, even when following the standards, not all LCA data are comparable or based on the same assessment criteria.

In most cases, national and international databases (that provide generic data) used for the development of LCA studies include not LCA results, but Life Cycle Inventory (LCI) data. This allows practitioners to start from LCI stage and perform the LCIA with the intended impact assessment methods. A recent study [14] summarized available international generic databases with environmental information on construction materials:

Europe:

- Ecoinvent [15], developed by the Swiss Centre for Life Cycle Inventories;
- ELCD [16], supported by the European Commission, comprises LCI data from front-running EU-level business associations and other sources;
- GaBi Database [17], developed by PE INTERNATIONAL for GaBi;
- PlasticsEurope Eco-Profiles [18], initiated by PlasticsEurope in 1991, and continuously updated.

North America:

- Athena [19] is the database included in the tool Athena Impact Estimator for Buildings;
- U.S. Life Cycle Inventory Database [20], developed by the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy.

Besides these, some more databases are identified [14] at the national level, namely: Base Carbone (France), BEDEC (Spain), CPM LCA (Sewden) and ProBas (Germany). The representability and use of these databases are limited to its geographic scope and, in some cases, to the language used.

The European Commission (EC) is also currently purchasing data to ensure that default secondary datasets can consistently be freely used by all companies that would like to develop Product Environmental Footprints (PEF) according to the category rules approved during the pilot phase of the PEF methodology development [13]. These data will probably be also suitable for the development of EPDs.

3.2. Specific information from Production Companies

The Construction Products Regulation (CPR) [21], published in 2011, highlights the importance of the environmental characteristics of construction products and of their impacts over the entire life cycle of a construction work. This regulation also states that, "*for the assessment of the sustainable use of resources and of the impact of construction works on the environment, Environmental Product Declarations should be used when available*".

In Portugal, only seven Environmental Product Declarations (EPDs) are available for the Architecture, Engineering and Construction (AEC) professionals [22]. At the international level, however, the development of EPDs by construction materials' companies is well established.

In Europe an umbrella program was developed – ECOPLATFORM, that comprises twelve national EPD programmes and assures their mutual recognition. Out of ECOPLATFORM's scope, it is also possible to find specific information on construction materials and assemblies from EPDs, namely from the programs from U.S.A., Finland, the Netherlands and Japan [23].

In parallel, the EC made efforts for the development of a different approach for the calculation and communication of environmental information of products (throughout their life cycle): the PEF methodology. There are currently no PEF available for construction materials or assemblies that the authors are aware of, but it is expected that they may become available soon.

4. Current integration of LCA and BIM

The integration of BIM and LCA methodologies is a growing research area, but with few works already published [3, 8, 10]. Regarding existing software tools for the integration of LCA and BIM, previous research [8] identified four: Tally, IMPACT, eveBIM-ELODIE and Arquimedes. These tools integrate distinct databases: some EPDs, a database from GaBi software, BRE (Building Research Establishment, from United Kingdom) database or INIES database (the French National Reference Database of Environmental and Health Declarations for Products). Arquimedes presents environmental information on embodied energy and CO_2 emissions only. None of these tools allows the manipulation of the environmental information in BIM objects. This means that the LCA study of a building will not be efficiently performed when it uses materials that are not available in the database of each tool.

Concerning the possible ways to integrate LCA information in BIM, Antón and Díaz [5] propose two alternative approaches:

Direct access from the LCA tool to the BIM model: the LCA tool extracts information from the BIM project (types of materials and quantities) and allocates it to the available LCI databases, to calculate the LCA of the building. One disadvantage of this approach is that each change in BIM model implies a new LCA independent calculation (the relation is not dynamic);
Environmental properties included in BIM objects – this allows an automatic calculation of LCA of the building. In this case, the properties of BIM objects include environmental information based on LCA results; an eco-design approach (environmental aspects used in decision-making) is possible using global environmental information at the early design stages.

Available guidelines for practitioners recommend the inclusion of environmental information according to the second approach above mentioned, expressed in the draft UNI 11337 – Part 3 [24]. This document intends to identify standard criteria to describe construction products through structured models for collecting and treating technical information, following the harmonized standards for CE marked products or in agreement with other relevant reference standards. The referred technical information comprises the following "*Information about sustainability according to EN 15804*":

- Parameters describing environmental impacts (7 impact categories);
- Parameters describing resource use (17 parameters);
- Environmental information describing output flows (4 parameters);
- Environmental information describing waste categories (3 parameters);
- Parameters describing pollutants emission from materials (3 parameters).

5. LCA information according to the LOD of BIM objects

According to the degree to which the element's geometry and attached information have been developed, BIM objects are classified as belonging to a specific LOD [25]. The LOD, as specified by BIMForum, is a reference for the specification and articulation of the content and reliability of BIM Models at various stages of the design and construction process. LOD specifications are not applicable to models, but rather to objects of the models.

While the project is developed, available information on materials and elements is better defined, and the LOD of objects becomes higher [26].

The BIMForum recognizes five LODs with growing levels of information:

- LOD 100 elements are symbols or generic representations, and information derived from these elements is approximate;

- LOD 200 elements are represented graphically but are generic placeholders (e.g., volume, quantity, orientation or location), and information derived from these elements is still approximate;
- LOD 300 elements are graphically represented as specific systems, objects, or assemblies from which quantity, shape, size, location, and orientation can be measured directly. LOD 350 elements include further information regarding interfaces with other building systems;
- LOD 400 elements are modelled with enough detail and accuracy to allows their manufacturing;
- LOD 500 can also be considered, when objects include additional information such as mounting specification and on-site verification [11].

This specification suggests that the use of environmental information in BIM models should also be somehow evolutional in such a way that it could provide approximate and generic environmental information for lower LODs and more specific and reliable information for higher LODs.

5.1. LCA information for each specific LOD

LCA application within the building sector, as a strategy to reduce environmental impacts, is commonly identified as complex and time-consuming. Moreover, most of the impact assessment methods result in a set of environmental categories that are not readily understandable or interpretable [9]. The same authors refer that the integration of BIM-LCA only seems appropriate in models which define the most relevant materials and components, including wall thickness (and corresponding layers), and the definition of structural elements in their actual engineered sizes, shapes, and locations (LOD 300).

Therefore, it may be useful to simplify LCA results, at least for earlier stages of the project development, providing enough support for decision-making processes at these stages. That simplification may be done by considering:

- Growing specificity (and decreasing genericity) on the LCA information used;
- Growing number of parameters and environmental information presented;
- Decreasing aggregation of environmental information (e.g., weighted single scores for lower LODs and complete disaggregated information for higher ones).

As mentioned in Section 2, LCA calculations may be developed based on LCI data from generic databases, site- or company-specific LCI or on average LCI (country or sector average, or company average for several sites). In lower LODs, environmental information from generic databases can be used, either at the material level or for building elements (e.g. average current walls and average current roofs). This approach simplifies however only the LCI data collection process and not the interpretation of LCA results for use in decision-making processes by the AEC professionals.

On the side of result interpretation simplification, it is common to use only one, or only some, of the environmental parameters as representative of all environmental impacts. CO_2 and embodied energy are, for instance, commonly used as a first approach for environmental impacts assessment and communication (as in the case of Arquimedes software tool, see Section 3). Although this option raises the question about one or a limited set of parameters being representative of all others in an environmental impact assessment process, for several reasons there is public awareness about global warming and individuals from outside the scientific community are familiar with its associated language. Moreover, the Carbon Footprint, which is a measure of the total amount of greenhouse gas emissions generated over the life cycle of a product, represents currently around 60 percent of overall human Ecological Footprint and it is its most rapidly growing component. Thus, this approach may be an added value for professionals not familiar with LCA practice to deal with these issues. This is a possible approach for lower LOD BIM objects or elements which would include information on only one, or on a limited set of environmental parameters, and the number of parameters included can grow with the LOD of the objects.

A result simplification alternative is the use of endpoint indicators (focused on environmental burdens or final consequences, e.g., biodiversity reduction or respiratory diseases) instead of midpoint indicators (related to the environmental intervention, e.g., eutrophication, acidification, greenhouse effect) for lower LODs. Even if single indicators are easier to understand and to use in comparisons, their use implies higher uncertainty and lower reliability since they are based on complex characterization models [27, 28]. Within this approach, lower LOD objects or elements include environmental information in the form of a single indicator or endpoint indicators. Higher LOD objects, on the other hand, include mid-point indicators, for instance, according to the results published in EPDs, as proposed in the Draft standard “Building and Civil Engineering Works - Models for Collecting, Organizing and Archiving Product Technical Information” [24]. EPDs’ environmental information can only be included in LOD 400 and LOD 500 objects since only these levels include information on chosen materials’ brands [11]. According to this, LOD 400 BIM elements would present detailed and complete information on environmental impacts.

However, considering the uncertainty and lack of reliability of the latter approach, the authors consider the previously mentioned inclusion of CO_2 and embodied energy information is generally a better. However, the lower LODs objects may start by presenting less reliable but easier to understand information in the form of single indicators, to support the earlier stages of project decision making. With the proposed approach (Table 1), final results from LCA will be directly used for integration on BIM objects, elements or models and not LCI databases’ information (that can, however, be useful as the basis for background information in LCA calculations). AEC professionals using BIM modelling will be provided with specific environmental information to support decision making, as complete and detailed as the stage of model in which they are working in, i.e., according the LOD of the BIM objects and elements they are using.

Table 1. Proposed approach for environmental information parametrization on BIM objects.

Object LOD	LOD100	LOD 200- LOD 300	LOD 400- LOD 500
LCA information on BIM object	Single indicator such as Eco-indicator (unit: Eco-indicator point) or Eco-costs (unit: monetary unit, e.g. EUR)	CO_2 (or global warming potential, GWP, in kg eq. CO_2), and embodied energy (in MJ)	Parameters describing environmental impacts, resource use and pollutants emission from materials, and environmental information describing output flows and waste categories, as defined by EPDs contents
Type of data	Generic databases	Generic databases	Product Specific / sector specific (sectorial EPDs)

6. Conclusions

Considering the economic and environmental relevance of the construction sector, there is a growing need to provide the AEC professionals with tools that support the improvement of its sustainability, namely, in environmental terms. BIM and LCA are important and complementary methodologies with a great potential. However, LCA is a data-intensive, time demanding and complex methodology that is not yet familiar to these professionals.

In this work, it was possible to identify several sources of LCI information that may be used in the construction sector’s environmental assessment (national and international databases and specific producers’ information), as well as some solutions for the integration of LCA and BIM methodologies (namely four software tools with distinct characteristics and associated databases).

Considering the different LOD of BIM objects and the complexity of impact assessment results interpretation, it is possible to conclude about the need for simplification of these results to allow AEC professionals to use these combined methodologies (BIM and LCA) in their regular practice. Specifically, in BIM modelling, it is important to have an evolutional use of environmental information. This means that approximate and generic environmental information shall be used for lower LODs and, more specific, complete and reliable information for higher LODs, supporting decision making at each stages of the development of the model.

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