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A macro-component approach for the assessment of building sustainability in early stages of design

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A R T I C L E I N F O

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A B S T R A C T

In the framework of the European research project *SB_Steel*, a new life cycle methodology was developed aiming at the evaluation of life cycle impacts of buildings in the early stages of design. The proposed approach includes the estimation of the energy needs of the building during the operation stage. The early stages of design have the higher influence on the life cycle performance of the building; however, in these stages the availability of design data is often limited. Moreover, the estimation of energy needs is usually based on a performed-based approach, requiring a full definition of the building design.

In the proposed methodology both problems are addressed by the macro-component approach, which provides a range of pre-defined construction solutions for the main components of a building, integrating life cycle embodied data. The approach enables a simplified estimation of the life cycle environmental performance of a building based on limited design data and provides aid for decision making in relation to the use of different materials and construction solutions aiming to lower life cycle impacts and lower energy consumption.

The proposed approach is illustrated by a case-study, in which a residential building is assessed in the early stages. Finally, based in complete data, an advanced analysis of the building is performed in order to discuss the limitations of the developed approach.

It is shown that the limitations introduced by the simplified approach are not relevant and that, even with lower availability of data, the guidance provided by the methodology is adequate.

1. Introduction

The construction industry is a major contributor to the global economy, but it is also one of the most important contributors in resource consumption and waste production [7], playing a fundamental role in the global sustainable development. Measures to make buildings more sustainable rely mostly in life cycle approaches, covering the three main aspects of sustainability: environmental, economical and social/cultural. Life cycle analysis (LCA) is a systematic approach enabling the quantification of potential environmental impacts of a building over its life cycle – from structure's conception to the end of its service life, and from raw material extraction to the management of building's demolition waste. The use of such an approach at the beginning of a design process is very important in the pursuit of sustainable construction, as illustrated in Fig. 1 [33].

The assessment of building efficiency in terms of the minimization of life cycle environmental impacts and energy consumption is of paramount importance in the context of building's sustainability. Most fundamental decisions influencing the life cycle performance of a building are taken in the very beginning of the design process. As shown in Fig. 1, the earlier the assessment, the higher is the potential to effectively influence the life cycle performance of the building.

However, the assessment of building sustainability in the early stages of building design faces several barriers.

One major problem is the availability of data in the initial stages of design. Life cycle analysis requires a huge amount of data and a certain degree of expertise in the field. Moreover, in case of buildings, it usually requires a good definition of the building plans, including details of external walls, partitions, slabs, roof, cladding system, etc. Often, in the early stages of design, architects and engineers have only a rough idea of the building design and building plans and details are not available at this stage. In addition, most architects and engineers do not have the expertise to perform life cycle analysis and most design decisions at these stages are taken based solely on the designer experience rather than quantitative indicators.

On the other hand, the assessment of energy requirements for the building operation usually requires a performance-based

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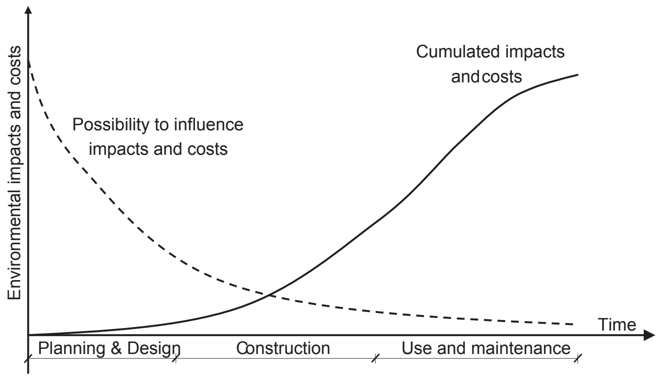

Fig. 1. Influence of design decisions on life cycle impacts and costs [33].

approach, which is usually carried out at the end of the design process to demonstrate code compliance.

The aim of this paper is to present a new approach that enables a simplified assessment of the building sustainability, considering two distinct early stages of design: the concept stage and the preliminary stage. The lack of building details is overcome by the use of the macro-component approach, while the energy required for building operation is estimated by a numerical tool developed with this purpose. Macro-components are pre-defined construction solutions, integrating materials and the respective life cycle environmental information, thus avoiding the need to carry out independent life cycle analysis.

The proposed approach is illustrated by a case-study: the life cycle assessment and energy analysis of a residential building are performed in the concept stage and in the preliminary stage of design. An advanced analysis, taking into account complete data for the building, is performed in the end to identify and discuss the main limitations of the simplified approach.

The approach presented in this paper has been developed in the framework of the European Research project SB_Steel: Sustainable Building Project in Steel. The methodology is currently being implemented into a free-access web-based tool. Although the methodology was developed in the scope of steel buildings, it can be used for any type of buildings.

2. Early stages of building Design

2.1. Design stages

The design process of a building comprises several stages. The first stage in a project is the **Project Start-Up** whereby the project brief is developed by identifying the requirements of the building through consultation with stakeholders. This initial stage basically states the wishes of the Client and will not be addressed in this paper.

The second stage in a project is the **Concept Design** that develops an initial building concept for the project. This design stage defines the overall system configuration and produces schematic drawings and layouts that provide an early project configuration.

The following stage is the **Preliminary Design** whereby schematic diagrams are refined enabling to estimate the main quantities for the building project.

Finally, the **Developed Design** contains all the information required to execute the building and all data necessary for a sustainability assessment is available.

In the concept stage of design the availability of data is poor and any assessment has to be based mainly on assumptions. The preliminary design stage fills the gap between the concept stage and the developed design stage of a building. In this stage, the level of data is higher than in the previous stage, which enables a more accurate evaluation of the solution. The methodology presented in this paper addresses the **concept stage** and the **preliminary stage**.

2.2. Available methodologies for the assessment of buildings in early stages of design

The assessment of the sustainability of buildings needs to address multiple dimensions such as environment, economy, society, cultural, etc, by following a life cycle analysis (LCA).

In normative terms, the international standards [21,22] lay down general guidelines for life-cycle environmental assessment of products. In relation to the construction sector, CEN TC 350 has been developing a series of standards for the assessment of building sustainability [10] addressing environmental aspects [11,14], social aspects [12] and economic aspects [13].

However, all these standards assume that the building bill of materials, construction processes, material sourcing and type of occupancy are known. This is not the case in early stages of design. Another barrier for the use of LCA in early stages is that it relies on inventory data of building materials, which is usually time consuming and requires some level of expertise by building professionals.

Simplified approaches for early design avoiding the need of LCA modelling were proposed by Luttropp and Lagerstedt [26,28] based on basic rules and decision boxes for Ecodesign, respectively.

Focussing only on the calculation of the energy demand of buildings in early stages, simplified tools were proposed by Nielsen [1], Petersen and Svendsen [27], Attia et al. [29] and Carlos and Nepomuceno [5].

On the other hand, the integration of building information modelling (BIM) with other tools has a major potential for sustainability assessment of buildings and it's a subject addressed by numerous authors. This integration faces however several barriers such as the lack of interoperability between the different approaches and the need for a common data format [15].

In terms of the assessment of energy needs in early stages of design [32], proposed a performance-based approach based in BIM that takes into account the quality of the energy sources by an exergy analysis.

With respect to the assessment of life cycle embodied impacts in early stages [2], proposed a method integrating BIM software with a LCA tool and energy analysis. The proposed approach excludes end-of-life stages and it's limited to the accounting of carbon dioxide equivalents. A similar framework to evaluate the impacts of buildings was proposed by Gu et al. [18] but it was concluded that for a comprehensive analysis a full life cycle assessment via LCA software was necessary.

In terms of costs estimation, a BIM model that incorporates cost estimation was proposed by Cheung et al. [6].

Most of the reviewed approaches require the use of BIM software together with other tools, either for energy calculation and LCA. This naturally depends on the availability of such tools and requires, from the point of view of the user, some expertise in modelling and management of the different approaches. A model of the building is required and the interoperability of the different tools must be ensured. This is particularly difficult at early design stages because essential data will be missing for the operation of some of the specific tools. In summary, current available approaches present the following drawbacks:

- they are time-consuming, particularly LCA;
- they require specific expertise to operate the different tools;
- they provide poor results with low availability of data, which very often lead to wrong ranking of alternatives.