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A data structures for purpose of the BIM-based Life Cycle Assessment: A review and theoretical background

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Abstract. The article deals with the data structure for the purpose of Life Cycle Assessment (LCA) of buildings using the Building Information Model (BIM). Construction industry produces a significant amount of waste and on the other hand the capacities of landfills are almost filled. It is necessary to deal with the effective use of materials that have already been used and have potential to be reused again. LCA is a method that can be used to demonstrate the suitability of proposed materials, structures or buildings in terms of their whole life cycle and its environmental impact. BIM includes, in addition to geometry, the information part. This data can be used for life cycle inventory (LCI) and then for the assessment itself. The aim of the article is to analyse previous approaches and define which data structure is necessary to be obtained from the BIM model for the LCI purpose of a specific material. The proposed methodology of the data recognition and selection is based on data structure of non-graphical database called SNIM, which was developed for the Czech construction environment. The article is also focused on the theoretical background of the newly developed classification system Construction Classification International (CCI).

1. Introduction

The Life Cycle Assessment (LCA) of construction products represents a current issue related to the requirement for sustainable construction production, resulting from Directive No. 305/2011 of the European Parliament and the European Commission [1]. This new requirement for both construction products and the entire construction structure consists in the sustainable use of natural resources in order to guarantee that the buildings are environmentally friendly. Sustainable use of natural resources is related to the possibility of reusing or recycling already used construction materials, however, also to recycle entire constructions or to use environmentally friendly materials and raw materials already during the construction process. The LCA method [2] represents one possibility how to assess this new requirement.

LCA is an analytical method based on the assessment of environmental impacts of products, services or technologies. Kočí [2] describes the approach of the LCA method to the assessment of environmental impacts with regard to the entire life cycle of products, i.e. from the stage of acquisition and manufacturing the primary raw materials, through the stage of manufacturing products, their use until the actual disposal or reuse of products via recycling.

In the past, the method used for obtaining data for the life cycle assessment of various products was described. The authors described the data entering the LCA. This article focuses on a summary of past, present and also expected forthcoming methods of obtaining data for the LCA assessment. Furthermore, the research described in the article aims to determine how the information from the SNIM database is sorted out for its application into the LCA study.

2. Current state of the researched issue

In 1990, for the first time, a comprehensive environmental analysis of loads and models of full-fledged life cycle assessment and life cycle calculation appeared. At the beginning of the 21st century, the Life Cycle Initiative was created with the aim to introduce life cycle ideas into real life [3].

Many authors have already dealt with the interconnection of the LCA method and the possibility of using the data structure of the BIM model. Antón and Díaz [4] presented two approaches to integration between the LCA and the BIM at the end of her article. One of them is the assessment of the entire life cycle of the construction and the other approach is material oriented. In the article [5], the authors evaluated the latest studies that focus on the BIM-based LCA. At the same time, they focus on how BIM could contribute to simplifying data entry, optimizing both the data output and the results during the LCA application at specific structures.

Finnveden et al. [6] described the development of the LCA. This article provides an overview of recent LCA developments. The authors discuss areas where progress has been made. These areas may include: the difference between attributive and the subsequent LCA, the hybrid development of the LCA database and the categories of impacts (such as spatial differentiation, toxicity, indoor air pollution and impacts resulting from land, resource and water use). The authors highlight the greatest successes. Nowadays we should be able to better understand the difference between the attribute and the subsequent LCA, as well as methods for hybrid Input–Output Analysis (IOA). However, the authors emphasize the fact that there are many areas to focus on. These areas include: the development of LCA tools and methods for assessing the impacts on ecosystems that result from land use and water use. Databases should be the main area of development.

Another article on the LCA [7] summarizes all life cycle assessment research that was applied in the construction industry. The authors state that more than ever before, the construction industry is concerned with improving social, economic and natural indicators of sustainability. If the LCA method was used more, it would be possible to achieve better optimization of these aspects and thus better control of the building life cycle (from the extraction of natural resources to the final liquidation phase and disposal of building materials). Thus, it can be concluded that the authors try to analyse the previous research of the LCA and compare it with the current research of the LCA and thus highlight the main challenges for the development of the LCA and the construction industry. The study therefore provides a basic description of the LCA and its methodology. It also deals with the ways and differences the LCA uses Building Materials and Component Combinations (BMCC) compared to the use of the LCA in the LCA of the Whole Process of the Construction (WPC). The study confirms that the LCA represents a really innovative method that improves the sustainability of the life cycle of a building through all its phases.

In his study, Marzouk [8] describes connecting the LCA with the BIM. This study presents the BIM approach, which allows for estimates of 6 types of emissions. These include the greenhouse gases, sulphur dioxide, particular matter, eutrophication particles, ozone depleting particles and smog. Thanks to this tool, it is possible to calculate the production of direct and indirect emissions during the entire construction process, i.e. from the production phase through the transport, construction, operation, and maintenance phases to the demolition phase. The authors used Athena Impact Estimator and Autodesk Revit applications for the calculations.

The authors of the article [9] came up with a method of automatic LCA calculations at an early stage, i.e. already at the first level of the BIM detail – LOD100. This should lead to easier adjustments of the calculations during the further development of the BIM model. To achieve this goal, new layers of data and their formats are needed. This new data layer should fill the information gaps between the extracted BIM data and the already existing LCA data provided by the common LCA databases. The result of the article was therefore an approximation of this method. The next step is to demonstrate the benefits of this method through further scientific research.

The article [10] concerned the integration of environmental impacts within the BIM. The secondary goal was to find solutions on how designers could mitigate these environmental impacts. The authors designed a BIM-integrated assessment as well as a visualization of the environmental impacts. The results show that it would be possible to use this approach to determine what environmental impacts the building material shall have in the initial stages of designing. Visualization of a geometric model of a building can be used as a representation of a design that can lead to a better decision-making process on material choices for individual building elements.

The efficiency of the LCA was addressed by the article [11]. The authors of this article dealt with the connection between a tool based on the BIM and the LCA tool Gabi 6. The research in the article demonstrated that the BIM plug-in can provide necessary data for each design phase. This means that the designer can perform a full life cycle analysis more efficiently.

Based on the above-stated references, it can be concluded that the authors in the past dealt with the possibility of linking the LCA studies with the information contained in the 3D model in the BIM environment. In their publications, the authors used the division of product life cycle stages using impact categories as well as verified the chosen methodology for calculating the LCA studies using various software tools such as Autodesk Revit, Gabi 6, etc.

3. Theoretical background

Product and its environmental impact. In his publication, Kočí describes the life cycle of products, which have various impacts on the environment, in four main stages. The first stage comprises obtaining raw materials to produce the necessary materials for the manufacturing of the product, which involves the extraction of crude oil, iron ore or wood and their transport from the place where they are obtained to the place of their further processing. The second stage describes the manufacturing of the product from already obtained materials and raw materials in the first stage. The stage involves the transformation of the obtained raw materials into materials that are usable in further industrial production. However, the transformation of raw materials includes, for example, the consumption of electricity or various fuels. The third stage of using a product involves consuming the product or using it for the function for which it was manufactured. An integral part of this stage is energy and raw material requirements, which serve for the operation of the product itself, it's possible repairs, storage or maintenance. The fourth, last stage, describes the final disposal of the product, including energy and material requirements for the removal of the product or its recycling [2].

Life cycle impact assessment using environmental impact categories. The life cycle of the products and evaluation of their impact on the environment using the so-called impact categories is further divided by the author into six specific areas. These include global warming and climate change, stratospheric ozone depletion, acidification, eutrophication, photooxidant formation and depletion of raw materials. Each impact category includes both the processes and consequences that adversely affect the environment. Global warming involves an increase in the average temperature of the atmosphere due to capturing more energy in the atmosphere, which leads to climate change at the global level or to the so-called greenhouse effect. The loss of stratospheric ozone leads to UV radiation reaching the surface of the Earth, which leads to an adverse effect on human health or the quality of the environment. Acidification is the process of acidifying the soil or water environment caused by the release of acid-forming substances into the atmosphere, water and soil. Acidified precipitations condense on solid surfaces or dissolve in water, which leads to soil, water and building materials acidification. Such substances are also harmful to plants and trees. Eutrophication is associated with nutrient enrichment of the environment, which leads to overgrowth of surface water, lack of oxygen in water or deterioration of the drinking water sources quality. Formation of photooxidants involves the adverse effects of ozone or other substances in the ground layer of the atmosphere, which leads to a negative impact on the environment resulting in various diseases and the influence on the health of living organisms. The decrease in the amount of raw materials is associated with the excessive extraction of non-renewable resources by humans, which leads to the disruption of ecosystems and affects the amount of raw materials available in the future [2].

Standardization of Non-Graphical 3D Model information (SNIM) is a set of information and standards that were developed especially for designing using the BIM model in the conditions of the Czech Republic. Parameters (non-graphic information) were assigned to individual elements of the 3D model, which were further divided according to the requirements for individual stages of project documentation in connection with the given construction phase. SNIM contains a list of parameters that are assigned to specific structures and a classification tool of categories of building structures, which divides individual types of structures according to the technical and parametric information.

The classification tool of building structures was created in order to strive for better orientation in the project using a database search.

Construction Classification International (CCI) is an international classification system, which represents a promising solution to the categorization and description of buildings [12]. This classification system is particularly suitable for digital processing. The construction industry involves an inexhaustible amount of information exchange between a large number of entities, each with different information requirements at different stages of the construction life cycle. The success of the whole project depends on the possibility of passing on complete and relevant information at the right time. The Czech construction industry does not have a respected uniform classification system, nor a common "language" between the individual participants of the construction process. The CCI classification system offers a general common "language" to suit all phases and roles of the participants throughout the entire construction life cycle. CCI offers solutions to the classification of both the entire constructions and more detailed parts of the information model of constructions. In order to adopt a new classification, it is necessary to unambiguously identify information for machine data processing with the highest possible degree of automation using a facet classification system. The solution consists of the classification in the form of partial facets for built spaces, technical systems, construction systems and individual detailed construction elements. This information forms an interconnected system enabling clarity and unambiguous classification of information about the construction for subsequent use by various software tools.

The subject of information construction modelling is the exchange of all kinds of information during the project between its participants and the applications used. For the successful exchange of data during the project, it is necessary to require a comprehensive and consistent method for the classification of buildings in the individual projects. Types of information exchanged include geometric data, functionality data, technical data and cost and maintenance data with a focus on the project timeline running from the project plan to the actual disposal of the construction. The basic idea of sorting information in the CCI is specified by the user, who classifies the individual elements according to their purpose of use or according to their way of use. Project information can also be classified according to the CCI classification system, which shall lead to easier determination of the parameters and specific specifications necessary for the calculation of LCA studies. The advantage of information classified in such way can be its easy identification for machine data processing and its easy use for the creation of various types of automated software. Thanks to the newly introduced common "language" for all participants of the entire life cycle of the construction, it shall be possible to use the results of the calculated LCA studies in all phases of the project, including the phase of use of the newly built object.

4. Discussion and proposal of the research direction

A database of standards and parameters serving for civil engineering activities in connection with the use of information from the BIM environment, especially for the environment of the Czech Republic, was created in the BIM environment. The above-mentioned parameters, i.e. non-graphical information, were classified by the authors according to the newly created classification tool of building structures and assigned to individual elements of the 3D model in the BIM environment. The classification tool also includes the recommended format and form of entering individual information. This is the so-called standardization of non-graphical information in the model [13].

It is possible to use categorized information from this environment to simplify the calculations of the LCA studies in connection with the new introduction of the BIM environment for the construction industry in the Czech Republic. This new method uses knowledge of the life cycle stages of products in relation to possible environmental impacts. Furthermore, the division of impact categories into six specific areas was considered. Data sorted according to the parameters assigned to individual elements of the 3D model in the BIM environment of the SNIM database are considered to be further selected for selecting for the LCA calculations and handled according to precisely defined criteria.

To assess the life cycle of products with the possibility of evaluating their impact on the environment using the LCA method, it is necessary to determine the values of individual indicators of impact categories with regard to the individual stages of the product life cycle. These values, which form a set of results, must have, in addition to specific values, also clearly defined units. The individual sets of results are then assigned to specific types of impact categories that have different environmental impacts. The parameters that can be used for LCA evaluation are clearly defined in the graphic and information part of the BIM model of the construction work. In connection with the standardization of non-graphical information of the model and the emergence of the above-mentioned standards and parameters, it is possible to supplement the BIM model with specific information from SNIM for a comprehensive assessment of the construction work in terms of its entire life cycle.

Methodology of data selection from the SNIM environment for the LCI purposes. When selecting data from the SNIM environment, data at the level of study detail are used. The reason is a sufficient amount of information in this phase of construction for the basic purposes of the LCI and also an effort to deal with the real situation as much as possible. In the construction practice, only some information is available in the study phase, however, even in this construction phase, there is an increasing effort to pre-calculate the LCI studies based on the LCA in order to reduce the environmental impact of the planned construction.

The considered methodology is based on the presumption that the volumes of individual constructions as well as data that contain structural markings are taken over from the SNIM database. Together, this is data that contains the name of the element, its volume, marking according to the SNIM, specification or other specific description. This data is used for the purposes of the basic structure of the LCI (LCA study). An example of the data structure scheme for one material category is given in Table 1.

Table 1. Example of data structure scheme for one material category.

	Marking according to SNIM	Sub-category	Description	MIN	MAX
Type of construction	XX000	Construction specification	….	000	000

Unfortunately, the data taken from the SNIM database does not contain indicators of impact categories (emissions). Therefore, this data must be assigned to the calculation from external sources, such as existing databases or specific data obtained directly from the manufacturers of the material.

It is possible to assign a specific LCI value to each specific material based on the specification. The LCI value assigned to a specific material is always only for one basic unit of the amount of the given material (i.e. m^3, m^2, m, t, etc.). Therefore, the LCI value is then multiplied by the volume value of the element. A specific LCI value of all materials of each element in a specific structure is generated using the MATLAB matrix solver based on this information. The final result is the percentage distribution of individual emission factors across the overall material characteristics in the construction.

5. Conclusion

This article presents scientific research and an elementary concept of the methodology of using data from the structure information model for the purposes of calculating LCA studies, with the emphasis on the appropriately selected classification system used in the construction sector. Only one of the two possible variants for the environment of the Czech Republic are presented, using the SNIM standard; on the contrary, the use of the CCI system is not possible to precisely define at the time of this article's publication due to the ongoing development of this system. It is essential to point out that the presented methodology, whether it works on the basis of SNIM or CCI, must be verified by a sufficient number of case studies of specific building structures. This verification will be the subject of further research into this issue. The aim of this article was to summarize the theory, the current state of the issue research and also to outline the framework procedure by which the calculation of environmental impacts can be approached in the future. In the next phase of the research, it will be possible to choose a specific case study, the results of which will be compared with the already presented results of other authors, using various types of software and parameters. In the future, it would also be appropriate to create specialized software dealing with the LCA and the LCI calculations or the development of a plug-in for the Czech environment, which will be easily usable in construction practice.

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