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Environmental assessment in the integrated life cycle design of buildings

Ocena środowiskowa w zintegrowanym procesie projektowania obiektów budowlanych

Abstract

The paper discusses the issue of building environmental assessments carried out as part of an integrated life cycle design process. The paper presents the methods used to evaluate environmental impact based on CEN and ISO standards. The paper concludes with an excerpt from an environmental assessment of a reinforced concrete structural frame in an office building.

Keywords: sustainable construction, ILCD, LCA

Streszczenie

Artykuł dotyczy problematyki przeprowadzania oceny środowiskowej budynku, będącej elementem zintegrowanej oceny obiektu budowlanego. Przedstawiono metodykę oceny aspektów środowiskowych, opartą na standardach CEN i ISO. Całość opracowania podsumowuje przykład będący fragmentem oceny środowiskowej żelbetowej konstrukcji szkieletowej budynku biurowego.

Słowa kluczowe: zrównoważone budownictwo, ILCD, LCA

1. Introduction

Up till now, functional and structural issues have taken priority in construction design, with the main objective being the development of structural solutions that possess the required characteristics, at the same time keeping the investment outlays as low as possible. The basic aim of design work was to adopt a solution that is optimal for the particular conditions, taking account of the needs of the investor and users of the building. The time-frame for analysing the efficiency of the solutions adopted was usually limited to the execution phase and the warranty period. However, on the basis of the sustainable development concept, a new approach to design was born, taking account of all requirements imposed on sustainable construction within a single design process, known as integrated life cycle design (ILCD). This new approach combines all aspects of design at the material, component and structural level, and analyses the selected criteria relating to sustainable development on all of those levels – including criteria which reflect the impact of the work on the environment. Therefore, the new concept of design is based on a complex, three-dimensional model [5] (Fig. 1).

The basis for assessing construction sustainability is the PN-EN 15643-1:2011 standard [9], which outlines general principles and requirements with regard to building assessment in terms of its environmental, social and economic properties, taking into account the technical and functional parameters of the building – by referring to the so-called functional equivalent.

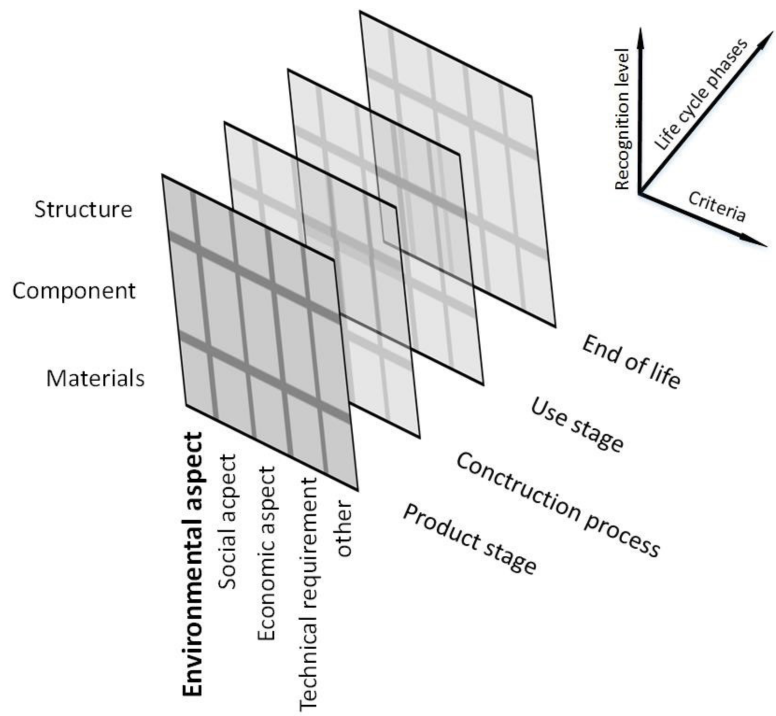

Fig. 1. 3D model of integrated design [5]

It should be noted that while the first part of the title of the integrated design standard refers to construction work, the currently applicable standards actually concern buildings. However, the methods developed are also useful for other engineering structures, even more so that the set of norms referred to above is based on general standards taken from the manufacturing sector and adapted accordingly.

The purpose of this article is to exhibit a synthesis of the environmental impact assessment methods. Based on an example, the adaptation of the LCA result to the structure design is presented. Both methodology and example analysis allowed for a qualitative assessment of the approach.

2. Methods used to assess environmental impact of buildings

Environmental impact assessment (EIA) is a systemized assessment involving interdisciplinary identification and evaluation of the impact of planned construction projects and their alternative variants on a specific area and the processes occurring therein [1]. The method used for carrying out environmental assessment of buildings is LCA – it is one of the most objective and accurate environmental assessment methods due to its multi-dimensional and comprehensive character [8]. The general environmental assessment method applicable to the entire life cycle is defined by the international ISO 14040:2006 standard [6] as a "*collection or estimation of initial data and results and the potential environmental impact of the designed system during its entire life cycle*". Therefore, the principles and methods of assessing building environmental characteristics found in PN-EN 15643-2:2011 [10] and PN-EN 15978:2012 [11] are based on the abovementioned ISO standards. However, the standards only cover the analytical part of the assessment, which means that they do not provide information about environmental indicator valuation methods.

Valuation systems and indicator aggregate calculation methods linked to those systems may be determined by national standards or separate legislation of varying scopes of application, or – if there are none – can be adopted according to individual preferences.

2.1. Determination of the purpose and scope of the assessment

Even though the EN 15643-2:2011 standard [2] stipulates that the scope of assessment covers the building with foundations and landscape features within the plot, as well as temporary structures related to the construction works during the entire life cycle, it allows for certain limitations in the assessment with regard to parts of the building and to part of its life cycle. The construction work life cycle (system), according to the PN-EN 15643-1:2011 standard [9], is divided into individual information modules corresponding to subsequent stages of its life (Fig. 2) – from obtaining raw materials required to manufacture construction products, to modules related to the final phase of the building's life cycle. The EN 15978:2011 standard [3], item 7.4, clearly determines the beginning and end of each of those phases. All types of impact of the construction work should be assigned to the relevant modules.

The purpose of an environmental assessment carried out as part of ILCD process is to obtain reliable environmental impact indicators for the construction design options considered or for their components at selected stages of the life cycle. The environmental indicators are then valued at a subsequent stage of the integrated life cycle design process, together with financial and social indicators obtained through appropriate assessments.

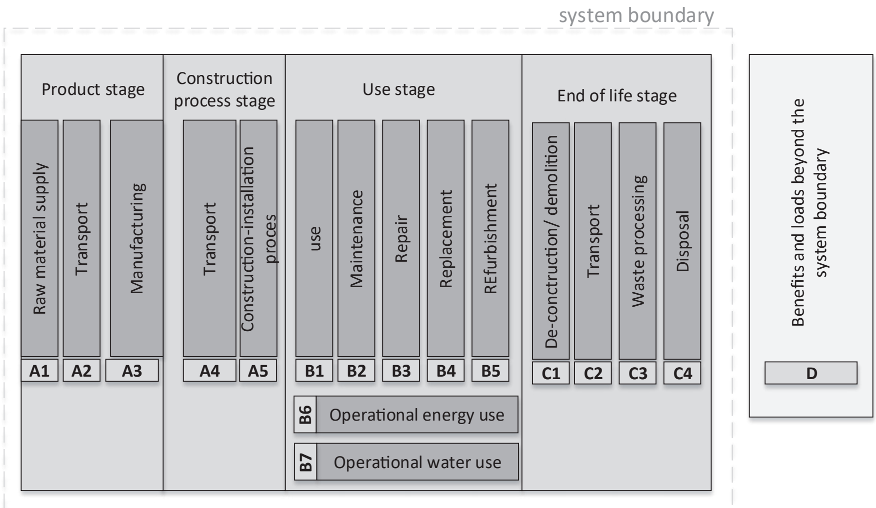

Fig. 2. Information modules of building life cycle [9]

2.2. Input and output analysis – LCI

LCI (Life Cycle Inventory) is a material balance used to collect and organize data on most types of environmental impact, i.e. to establish a set of system inputs from the environment, technosphere, etc., and to inventory environment-related outflow (emissions, waste) for a given process (Fig. 3).

The systemic approach suggested by the EN 15643-2:2011 standard [2], together with the aggregated set of individual processes at individual stages of the construction work life cycle facilitates analysis of the input and output data set, as well as its further interpretation. The information needed to develop an inventory may be found in the literature and ready databases – for example such collections as: ELCD, Ecoinvent, NEEDS, etc. or obtained directly from the product manufacturers. We should remember that collecting data these days is a very time-consuming and costly process. However, the standard allows the use of average and general values for construction work environmental assessment purposes. While selecting data for the assessment, their quality should be specified, i.e. it is necessary to provide information about their correlation in time, geographical and technological correlation, reliability and completeness. An important aspect of LCI is also data significance assessment based on sensitivity analysis; as well as data uncertainty analysis and its impact on the results obtained [7].

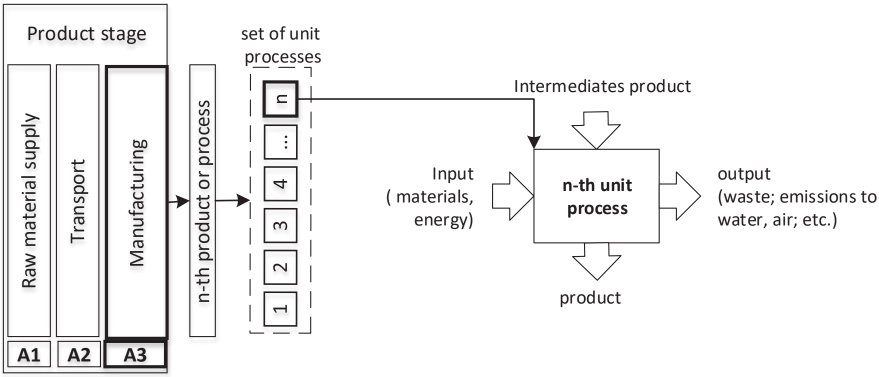

Fig. 3. Aggregation of units processes in information modules [own source]

2.3. Determination of environmental indicators

The following indicators should be used to examine a building's environmental impact:

- environmental impact indicator – LCIA categories,
- resource usage indicator,
- indicators referring to other environmental data.

The life cycle environmental impact assessment – LCIA, constitutes the third step of LCA assessment, which involves quantification of the correlations between the input and output data set and its environmental impact expressed in the input category. In order to convert LCI results into category indicators, according to (International Standard ISO 14040:2006 [6]), we should:

- select the input category, category indicators and characterization models,
- allocate LCI results (classification) to individual input categories,
- calculate the category indicator value (characterization).

There is now a range of environmental impact categories representing different approaches. Table 1 shows LCIA categories requested by the PN-EN 15643-2:2011 standard [2].

Table 1. LCIA categories [2]

Category	Examples of classification	Unit
Global warming (GWP)	CO_2, NO_2, CH_4, CFC, HCFC, CH_3Br	kg CO_2
Ozone depletion (ODP)	CFC, HCFC, CH_3Br	kg CFC 11
Soil and water acidification (AP)	SO_x, NO_x, HCL, HF, NH_4	kg SO_2
Eutrophication (EP)	HNO_3, NO_2, NO	kg $(PO_4)^{3-}$
Photochemical ozone production (POCP)	NMHC	kg ethylene
Resource depletion – ADP elements	Quantity of minerals used	kg Sb
Resource depletion – ADP – fossil fuels	Quantity of fossil fuels used	MJ, (net)

Apart from environmental impact indicators arising from LCIA, the PN-EN 15643-2:2011 standard [2] requires that the environmental assessment also covers resource use indicators and other indicators which represent important environmental information – they are summarized in Table 2.

Table 2. Other indicators of environmental assessment [2]

Indicator of resource use	**Unit**
Use of renewable primary energy excluding energy resources used as raw material	MJ
Use of non-renewable primary energy excluding primary energy resources used as raw material	MJ
Use of non-renewable primary energy resources used as raw material	MJ
Use of renewable primary energy resources used as raw materials	MJ
Use of secondary materials	kg
Use of renewable secondary fuels	MJ
Use of non-renewable secondary fuels	MJ
Net use of fresh water	m^3
Indicators of other environmental information	
Reusable components	kg
Recycling materials	kg
Materials for energy recovery	kg
Non-hazardous waste for disposal	kg
Hazardous waste for disposal	kg
Radioactive waste for disposal	kg
Exported energy	MJ

It is required that the result of environmental assessment is presented in the form of a summary of environmental indicators (Table 1 and 2) for individual information modules as vectors, while the following formula is used to determine their value:

$$\begin{bmatrix} \mathrm{GWP}_{a_{1,i}} & \mathrm{GW}P_{a_{2,i}} & \mathrm{GWP}_{a_{3,i}} & \mathrm{GWP}_{a_{\dots,i}} & \mathrm{GWP}_{a_{n,i}} \\ \mathrm{AP}_{a_{1,i}} & \mathrm{AP}_{a_{2,i}} & \mathrm{AP}_{a_{3,i}} & \mathrm{AP}_{a_{\dots,i}} & \mathrm{AP}_{a_{n,i}} \\ \mathrm{ODP}_{a_{1,i}} & \mathrm{OD}E_{a_{2,i}} & \mathrm{ODP}_{a_{3,i}} & \mathrm{ODP}_{a_{\dots,i}} & \mathrm{ODP}_{a_{n,i}} \\ \dots & \dots & \dots & \dots & \dots \end{bmatrix} \cdot \begin{bmatrix} a_{1,i} \\ a_{2,i} \\ a_{3,i} \\ a_{\dots,i} \\ a_{n,i} \end{bmatrix} = \begin{bmatrix} \mathrm{GWP}_i \\ \mathrm{AP}_i \\ \mathrm{ODP}_i \\ \dots \end{bmatrix} \tag{1}$$

where:

$\mathrm{GWP}_{an,i,}$ $\mathrm{AP}_{an,i,}$ $\mathrm{ODP}_{an,i,}$ – values of environmental impact indicators (per unit) for n-th products or processes (labour) in i-th information module,

$a_{1\text{-}n,i}$ – vector comprising the total use n of products and/or processes (labour) n i-th module,

GWP_i, AP_i, ODP_i – value of environmental impact indicators for i-th information module, where: $i = [A_1{:}A_5, B_1{:}B_7, C_1{:}C_4, D]$.

3. Example environmental assessment at the engineering stage

In order to demonstrate the selected components of construction work environmental assessment, an analysis of a 12-storey office building is presented here. The building – built on a plan of 50×20 m, with single storey height of 3.7 m – was designed as a slab and column structure with an internal core. For the purpose of this analysis it was verified whether two concrete classes, C30/37 and C70/85, could be used in its construction while assuming the same usage of reinforcing steel in individual projects. The scope of the analysis presented includes determination of LCIA category indicators for the product stage (A1÷A3). Three variants of the structure were analysed: the ultimate limit and serviceability states were verified for all three variants to determine the use of concrete in each scenario:

- variant I – C30/37 concrete used on slabs and columns (2643.0 m^3),
- variant II – C70/85 concrete used on slabs and columns (2348.0 m^3),
- variant III – C30/37 concrete used on slabs (2436 m^3), C70/85 concrete used on columns (140.0 m^3).

A summary of the input and output data set was prepared for each concrete class, database was used for inventorying: EU27: Sand 0/2, EU-27-Diesel mix at refinery , EU-27: Gravel 2/32, EU-27: Tap water, GLO:Truck, Portland Cement (CEM I) ELCD/CEMBUREAU. An LCI for superplasticizer manufacture was prepared on the basis of Environmental Consultant INTRON B.V [4]. The classification and characterisation stage was carried out based on the CML method, which ultimately led to determining environmental indicators (LCIA) – Fig.4.

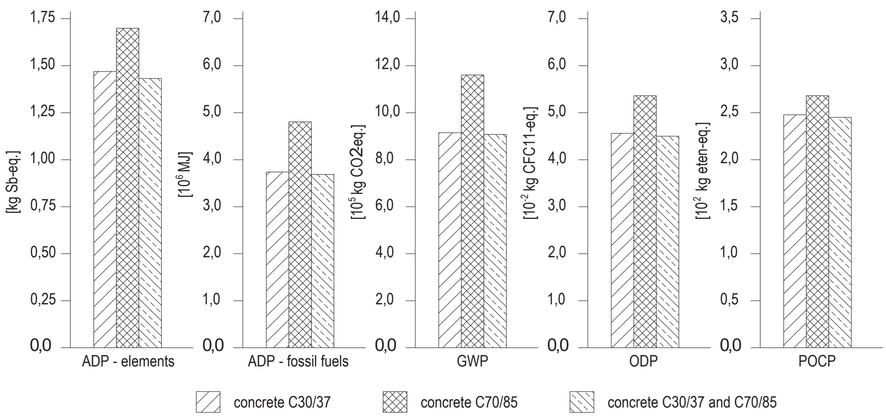

Fig. 4. Selected environmental impact indicators for individual variants [own source]

It should be stressed that the results presented above only refer to the engineering stage (A1÷A3), therefore, in order to carry out a comprehensive environmental impact assessment similar calculations would have to be made for the other phases of the life cycle and supplemented with other indicators. However, the analysis enables us to draw certain conclusions valuable to the architect, namely that the use of high-strength concrete in this case reduces concrete usage only insignificantly (due to the bending of the slabs), therefore, due to an increased use of cement used in high-strength concrete, the use of such materials increases environmental impact at the engineering stage. A small improvement is seen in case of using HSC in compression components (columns) due to significant cross-section reductions.

4. Summary and final conclusions

There is no doubt that integrated construction design seems a proper and valuable approach to the design process. However, it requires knowledge of new methods of structural and material analysis, including environmental assessment methods. The assessment is a complex, interdisciplinary process. It requires close cooperation between the construction engineer and environmental engineer, otherwise the construction engineer needs to become familiar with additional methods and tools used to determine environmental impact indicators. The assessment process could be somewhat simplified by using a ready-made wide set of individual environmental impact indicators for construction products and processes, sensitive to the parameters that determine them to a great extent. Currently, the lack of free access to databases and a limited number of available databases leads to prolongation of the design process, increasing the related costs and limiting the scope of assessment, also resulting in a suggestive assessment.

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