Environmentally friendly construction products selection based on building model data

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Abstract

This paper presents the conceptual framework for the decision making support system which would allow to optimize building's environmental performance by supporting the environmentally friendly construction products selection process. Moreover, it identifies the elements of the proposed system that could be realized with currently available technologies and resources, and reveals the areas in which there is still a need for development.

In order to develop the scheme of the construction products selection support system several issues were analyzed, namely: European standards for the assessment of the environmental performance of buildings, selected building rating systems, Building Information Modeling (BIM) concept; BIM data exchange schemata (IFC, gbXML).

The main components of the system are: the source of the functional requirements for the construction products (i.e. building model compliant with IFC data schema); the source of the product data (i.e. database of the construction products available on the local market); selection optimizing methodology (for this purpose the paper proposes utilizing the construction products property data scope based on EN 15804 standard criteria weighting factors based on the OPEN HOUSE methodology).

There are also identified areas that still need further development in order to fully exploit the potential of BIM-based decision support tools for the environmentally friendly products selection.

Keywords: BIM; construction products; decision support; specification; sustainability;

1. Introduction

Construction, as most of the industry branches, is constantly facing new challenges as consumers expectations and legal obligations are becoming more and more demanding. Nowadays, buildings are expected to be consistent with the sustainable development rules, which means that they have to excel in the three essential areas: social performance, economic performance and environmental performance. The first two issues have existed in the construction industry for a long time. Construction experts are familiar with them and they have at least basic knowledge how to assess potential solutions in their context, whether using calculations or intuition, and how to act to achieve the desired results. Environmental performance however is definitely less understood. There is no global formula that would allow to conclude that one solution is better than the other in the context of environmental impact (Ding, 2008). Furthermore, it is unclear what range of environmental characteristics of buildings and their constituent elements should be taken into consideration, but it is undeniable that many of them. Thanks to the worldwide efforts, numerous tools facilitating sustainable construction have been developed up to this day, e.g.:

- various building sustainability assessment systems, such as commercial systems, of which two are considered to be most common (Schwartz & Raslan, 2013): BREEAM and LEED, or Open House methodology, developed within the EU’s Seventh Framework Programme for Research (FP7) (Open House Project, 2013);
- guidelines for the qualitative assessment of buildings environmental performance, such as LCA methodology and the European standards set “Sustainability of construction works” (EN 15643-2 “Assessment of buildings - Part 2: Framework for the assessment of environmental performance”, EN 15798 “Assessment of environmental performance of buildings - Calculation method”, EN 15804 “Environmental product declarations - Core rules for the product category of construction products”), which specify the system boundaries and calculation rules (Piasecki, 2012);
- simulation tools that allow to assess some environmental characteristics of building design, and therefore give possibility to compare different building design variants (Schlueter & Thesseling, 2009) (Adamus, 2013).
One of the crucial goals that have to be achieved in order to meet sustainability expectations towards buildings is addressing the potential of the innovative data management technologies, improving accessibility of the environmentally relevant data, intensifying its sharing and reuse during all the building lifecycle stages, and supporting its processing (Watson, 2011). At the same time the construction industry experiences rapid development and increasingly wide adoption of BIM (Building information Modeling) concept (Fox et al. 2014). One of its most significant advantages is the automation of building data transfer and reuse. Digital model of building can also be utilized as a source of data for decision support systems.

One of the essential parts of the construction process which greatly affects the buildings environmental performance is the selection of the construction products to be used (Akadiri et al., 2013)(Franzoni, 2011). Due to the specificity of the construction industry and the issue considered, many multi-criteria decisions that require considering a huge number of possible solutions which are characterized with many parameters have been involved (Czarnecki & Kapron, 2010) (Emmitt & Yeomans, 2008). Because of that, it is particularly important to provide building design process participants with software tools which would allow to efficiently perform environmentally friendly construction products selection based on a wide range of precise data.

This paper presents the conceptual framework for the environmentally friendly construction products selection decision support system. Moreover, it identifies the elements of the proposed system that could be realized with currently available technologies, methodologies, standards etc., and reveals the areas in which there is still a need for development.

2. Environmentally friendly products and materials selection as a decision problem

Every construction process aims to meet the needs of the investor related to the functionality and sustainability in the most effective manner. This also applies to all individual stages of the process, including the two phases of construction products and materials selection (Franzoni, 2011):

- on the general design level, when the major assumptions are made (e.g. if the building will be wooden or concrete) and building elements dimensions and functional requirements towards them are defined;
- when specific construction products and materials available on the market are selected.

In the former phase the designer makes his decisions taking into consideration many parameters, such as functionality, visual features, environmental performance, etc. These decisions can be based on his professional knowledge and experience or external guidelines. They can also be supported by decision support systems (Basbagill et al., 2013). In this phase only statistical data about materials and products is available, which causes uncertainties in building assessments (Hoxha et al., 2013).

The latter phase could be performed by one of the designers (specifier) or by the contractor (Emmitt & Yeomans, 2008), depending on the adopted workflow model. Selected products and materials have to comply with the requirements set by the designer in the most effective manner, i.e. having the lowest cost and the least environmental impact. Because of a growing pressure on reducing costs and achieving higher environmental performance this kind of decision problems is becoming more and more difficult.

The conceptual framework for decision support systems presented in this paper relates only to the second phase of the selection process. It is assumed that before the decision process certain information about building (i.e. location and estimated service life) and its elements (i.e. type, shape and minimal performance requirements) is determined and provided to the decision maker. Therefore, the role of the decision maker in the last phase of the selection of the products and materials is to choose adequate products from the local market which will meet the functional requirements while minimizing cost and environmental impact.

In the above context, this phase of materials and products selection can be considered as a multi-criteria decision problem, where the cost and the environmental performance are the selection criteria, and products accessible on the market that meet the functional requirements are the feasible solutions. In this approach the environmental quality is a complex criterion which encloses many internal criteria adequate to the various environmental impacts. The value of the specific solution can be calculated as follows:

\[ V = a_c C + a_E E \]  

where \( V \) is the solution value in terms of cost, \( E \) is the solution value in terms of environmental performance, \( a_c \) and \( a_E \) are the respective weighting factors. Analogically, environmental performance can be calculated as follows:

\[ V = a_c C + a_E E \]
where $n$ is the number of environmental assessment criteria, $E_i$ is the value of the solution in context of the $i$ criterion, $b_i$ is its respective weight.

Both cost and environmental performance of product or material considered as a potential solution have to be assessed taking into account the cost of transport from the distribution point to the construction site and its environmental impact, the necessity of replacement, if the reference service life of product is longer than the reference service life of the designed building (Hoxha et al., 2013).

During the second phase of construction products and materials selection, the primary problems for the decision makers are (Emmitt & Yeomans, 2008):

- acquiring information about construction products and materials accessible, especially their environmental properties;
- assessing the environmental performance of products and materials (even if numerical values of their environmental properties are known);
- quantity of building elements types which causes the necessity to perform the selection multiple times;
- processing a large amount of data in order to evaluate all possible solutions against appropriate criteria.

In practice, the most common approach is not to make a decision based on comprehensive knowledge about the problem, but rather to choose well known, previously used solutions. It hinders the diffusion of innovations and sustainability in construction industry (Akadiri et al., 2013) (Emmitt & Yeomans, 2008).

The process of products and materials selection is considered to be difficult and requiring the support of information technologies (Akadiri et al., 2013) (Franzoni, 2011) as buildings are more and more commonly designed in line with BIM concept (information about building design). This paper proposes the conceptual framework for the construction product selection decision support system which would improve the process and eliminate main problems faced by the decision makers, using digital building model as a source of information about the elements needed.

3. Framework for the decision support system

3.1. General schema

Proposed decision support system framework is based on the assumption that during one decision process only one type of construction product is selected (selecting products and materials for the whole building requires a certain amount of repetitions of the process). It consists of 4 main areas (Fig. 1): a source of information about the designed building and the requirements towards its elements, decision maker preferences regarding the relevance of decision criteria, methodology that allows to assess environmental performance of solutions, and information about construction products available on the market. The first two of them are specific for every single decision process (but may be constant for many decisions regarding the same object), another two are immanent components of the system. Important issue which concerns many components of the system is the scope of the parameters characterizing construction products and materials, both functional and environmental, that are taken into consideration. Information about functional performance of products and materials accessible on the market must be sufficient for the purpose of verification if they meet the requirements specified in the building design. Information about their environmental features must be sufficient to the purpose of their evaluation in the context of the assessment methodology used by the system.

3.2. Digital building model as a source of requirements towards construction products and materials

Nowadays, in countries with a highly developed construction sector, the majority of building designs are created in line with the BIM concept using BIM based software (Fox et al., 2014). This means that all the information created on the design stage should be stored in a well-structured, digital form and should be accessible for automated use in following stages of buildings lifecycles.
Digital building model is created by adding subsequent building elements and defining their properties, such as shape, size, purpose, functional performance, etc. The components the designer puts into a model can be generic (abstract, not referring to really existing products) or proprietary (representing really existing products of a particular manufacturer, containing their actual properties) (Jones, 2011). They also can have various origin. They can be created by the designer himself for the current model, copied from one of the previous models (reused) or downloaded from repositories of CAD software vendors, construction products manufacturers or independent organizations (Kusy, 2013). Therefore, besides the shape and the size, they can contain various functional properties that are introduced into the building model. For the purpose of using the building model as a source of the requirements towards construction products and materials, it is crucial to identify the set of functional properties which are considered by the designer as critical for the building's performance. The values of these properties can be used as the threshold requirements for the products and materials selection process.

Depending on the relation between a building model component and the products or materials required to realize represented element of the real building there can be distinguished several types of situations, when single building model component represents:

- a building element consists of a single construction product (e.g. window);
- a building element consists of many construction products of the same type (e.g. single layer brick wall);
- a building element consists of many layers (e.g. two-layer wall – brick and insulation);
- prefabricated precast concrete building element;
- a building element made of cast-in-situ concrete.

Each of them requires different approach to the calculation of construction products and material quantity procedure.

Since there are many BIM based design computer programs, and many of them use proprietary data models and file formats to store the building models, there is a need for the platform neutral, open data scheme that would allow for transferring data among the software produced by various vendors. There are two most prevalent open data models available nowadays which are used for the purpose of the exchange of information about buildings, including environmental features – gbXML (Green Building XML) and IFC (Industry Foundation Class). The gbXML schema is easier to implement but does not include all building (and its elements) information relevant for an environmental analysis, and in its current version it is rather targeted towards energy simulations only (Dong et al., 2007). IFC gives more possibilities regarding the scope of design elements data (Adamus, 2013), and therefore its use is suggested as the data model for the input data for the decision support system.

IFC 4 (ISO 16739) is an open data schema developed with the purpose of describing all aspects of building in its whole lifecycle within digital building model. Storing information about building elements functional properties can be done by assigning property information explicitly to the single element, by assigning a group of elements to the previously defined type of elements to which properties are assigned, or by assigning material to the single element (or a type of elements) and assigning properties to the material. What is more, IFC allows to define constraints - limiting values or boundary conditions which may be applied to an object or to the value of a property. This functionality can be used to distinguish properties of building elements that are crucial for achieving buildings performance planned by the designer from those that are simply derived from downloaded building model components. IFC also allows to define geographical coordinates and the estimated service life of the building.

Because of some specific requirements towards the building models that would be used as a data source for the system, there is a need to develop guideline documents specific for IFC: MVD (Model View Definition,
defining the subset of the IFC data schema designed for specific applications) and IDM (Information Delivery Manual) defining the data exchange requirements (its scope, structure etc.).

3.3. Construction products data source

Construction products and materials accessible on the market are the potential solutions of the considered decision problem. To accurately assess the value of a single construction product or a unit of material it is necessary to take into account its summary cost and environmental impacts, resulting from the manufacturing process, transport to the construction site and possible replacements during the building lifecycle. Therefore, the scope of information about the product has to include several elements with various origins:

• environmental and functional properties, estimated service life determined by the manufacturer;
• accessibility (information if it is possible to purchase requested amount of product or material at the moment), unit price and the distribution point location determined by the distributor.

The scope of the environmental properties should be consistent with the adopted assessment methodology. It also should be well defined and recognizable within the construction products industry. The European standards for the assessment of the environmental performance of buildings (EN 15978, EN 15804) define a certain set of indicators describing environmental properties of products and materials.

The scope of the functional properties should reflect potential possibilities of the requirements that the designer can define, so that it should be developed consistently with the Information Delivery Manual for building models.

It has to be guaranteed that the information stored in construction products and materials database is always up to date, especially regarding their accessibility at particular distribution points. Due to this fact, it is necessary to guarantee cooperation between the database and distribution points of warehouse management systems. Another important issue is data quality and reliability (Kusy, 2013). It is advisable to enforce supervision of an independent organization over the products and materials data provided by their manufacturers.

3.4. Evaluation of solutions

The first step of evaluation construction products and materials as the solutions of the decision problem is checking whether their functional properties meet the requirements set by the designer, obtained from the building model. Those that do not satisfy this condition are immediately rejected. The remaining ones have to be evaluated according to their cost and environmental performance.

In order to acquire comprehensive data, the price of product or material in the distribution point and its environmental properties declared by the manufacturer have to be summed up respectively with cost and environmental impact caused by the transport to the construction site. Assessing real values resulting from transport before it takes place may be very challenging or even impossible.

Every product and material has to be evaluated firstly in the context of environmental criteria and secondly in the context of environmental performance and cost, accordingly to the equations (2) and (1). The environmental performance should be calculated on the basis of a widely adopted, reliable methodology which would provide guidelines for the evaluation of construction products and materials in the context of the environmental criteria \(E_i\) in equation (2) and their weights– \(b_i\) in equation (2). Moreover, it is advisable that the results of the construction products and materials assessment methodology reflect their influence on the whole building assessment result and its possible marketing value. This would allow the decision maker to estimate, at least intuitively, potential market benefits resulting from the environmental advantage of one solution of the decision problem over another. For the purpose of this paper three building assessment systems were analyzed: LEED, BREEAM and Open House. In both LEED and BREEAM systems, the assessment methodology used does not allow to estimate how the differences between environmental properties of products and materials will influence the final grade of the building. The Open House methodology allows, assuming some simplifications, to assess the impact of construction products and materials selection on the final buildings score. However, this score is expressed in points, not with a grade on a scale (as it is in case of LEED and BREEAM), and therefore it is difficult to estimate the market value of improving the assessment score.

Preferences towards the importance of cost and environmental performance of the possible solutions should be obtained directly from the decision maker by letting him set the weights of these criteria \((a_C\) and \(a_E\) factors from the equation (1)) in an interactive way.
4. Conclusions

The process of selection of the construction products and materials is a difficult decision problem. At the moment there are no software tools to support it in a comprehensive way. Developing such tool, that would utilize the data from the digital building model, would help to make quick decisions based on knowledge, while taking into consideration the actual products accessible on the market. Providing comprehensive information to the decision makers would also facilitate the uptake of the innovative and environmentally friendly products and materials.

In order to create the support system compliant with proposed framework, several elements have to be developed, namely:

- the guidelines for the building models that would be used as a source of minimal requirements;
- the methodology of construction products and materials environmental assessment criteria, that would allow for their comparison;
- the methodology of estimating cost and environmental impact of transport of the products and materials.

Another issue that has to be addressed is the willingness of the distributors and manufacturers to participate in the system and provide a good quality, reliable data about the construction products and materials.

The framework proposed in the paper not take into consideration potential improvements of the building performance in its use stage, resulting from using construction products and materials with better properties than defined as minimal. To resolve this problem it would be necessary to integrate the decision support system with the building performance simulation tools.

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