A PERSPECTIVE ON THE DEVELOPMENT OF SUSTAINABLE CONSTRUCTION PRODUCTS: AN ECO-DESIGN APPROACH

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ABSTRACT

The construction sector has a significant social and economic impact on the European Union (EU), contributing towards employment opportunities (over 20 million directly dependent jobs). However, it is important to take into account the negative impacts of this industry, especially regarding the environment. As an important resources consumer, the construction industry can play an active role developing new strategies for minimizing impacts on the environment throughout the life cycle of buildings and its components.

The Construction Products Regulation (CPR) has contributed to set the quality standards for building products. The inclusion of 'Sustainable use of natural resources' as a basic requirement in the CPR has been an important step towards the acknowledgment of environmental impacts on construction products. Assessing the negative effects in product development at the early stages is one of the most effective methods to improve their environmental performance.

The concept of Eco-design has emerged as an approach to environmental management, by considering environmental aspects in the product development, without compromising other basic requirements, such as performance, quality and cost. The consideration of this approach at the early stages of construction product development contributes to the improvement of their environmental performance. Several methodologies and tools regarding an Eco-design approach have been developed over the last years. However, there are still research opportunities regarding its application within the construction industry.

In this paper, a concise review of the most significant tools, methods and regulation regarding the Eco-design approach is given, considering its application to the development of innovative and sustainable construction products.

Keywords: eco-construction, eco-design, sustainability.

1 INTRODUCTION

The construction sector has a significant social and economic impact in the European Union (EU), providing housing conditions and contributing towards employment opportunities and economic growth (10% of the EU's Gross Domestic Product – GDP). However, this industry is also responsible for negative impacts, especially regarding the environment, that must be taken into account, such as depletion of natural resources, energy consumption and generation of waste.

As an important resources consumer and a significant support for European economy, the construction industry can play an active role developing new strategies for minimiz-

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ing impacts on the environment. One of the strategies followed over the last years regards the concept of 'sustainability'. This term is usually used as an attempt of the construction industry to complete the sustainable development goals, which include buildings' energy efficiency and reducing waste generation through prevention, reduction, recycling and reuse [1].

In order to understand the framework of the 'sustainable building' concept, it is important to recognise the main ideas that support this definition, regarding sustainable development and the role that buildings can perform in this context.

In the literature, it is possible to find many different definitions of sustainable development [2]. The most famous one can be found in the Brundtland Report, more commonly known as 'Our Common Future': 'meeting the present needs without compromising the ability of future generation to meet their needs' [3].

It is a broad concept applied to a wide range of areas that allows drawing some different ideas to support the application of sustainability concepts in the construction sector. The first idea comes with the vision for the future and into the future, involving a high level of uncertainty in a world in constant transformation and innovation. The second is the definition of our needs. Our living requirements rely on multiple factors such as climate, social, cultural and economic context, among other external circumstances, that are expected to change in a long-term approach [4]. The different points of view for each of these aspects have been responsible for the application of different methodologies towards sustainability, especially regarding the building and construction sector.

The growing issues and concerns regarding the environmental impacts in product development have raised the awareness for Eco-design. This concept has been largely studied and adopted over the last decades, particularly as an industrial design strategy. However, its application to the development of innovative and sustainable construction products is also possible and appropriate, especially at redesign or at early stages of product development, since it can contribute to the improvement of their environmental performance.

This work is supported by a literature review regarding the main references on 'Eco-design' and 'sustainable construction', covering different research areas such as industrial design, engineering design, sustainable architecture and environmental management, selected from a wide range of references. Since the aim of this paper is to present a concise review on Eco-design, starting from a comprehensive approach into its application to the development of sustainable construction products, the most relevant journal articles, conference papers, dissertations and technical reports were selected.

2 THE ECO-DESIGN APPROACH

Eco awareness is a clear reflection of the change in the European society. Consumers agree that the environmental impact is the third most important factor when buying, after quality and price [5]. The importance of cost and quality over environmental issues is also highlight by Luttropp and Lagerstedt [6], who considers that 'without customers prepared to pay for the function and if companies cannot make a profit, there will be no market, no matter how well the environmental issues have been addressed'.

As a result, by attempting to reduce the environmental impacts of current products while considering their economic aspects and functional performance, one can move towards more competitive, innovative and sustainable solutions. This creates an opportunity to improve functional performance provided by a product over its life cycle while its environmental impacts are reduced.

In the following sections, three different parts are presented, in order to provide an organized and general understanding of the eco-design approach. The first section is focused on the Eco-design definition and the description of the design process. Next, the standards, directives and European regulations are shortly described. Finally, the main methods and tools identified are listed and briefly defined.

2.1 Definition

There are many terminologies used to describe the consideration of environmental impacts in products: 'Design for the Environment' (DfE), 'green design' or 'environmental design'. However, the term 'eco-' present in 'eco-design' allows relating not only with ecology but also with economic aspects of products.

The word "design" has a broad meaning that expresses activities regarding design, project and planning drawing a creative path from a problem or a need towards its solution. This path has to be flexible and open to allow different approaches and methodologies to be addressed. One of the most common ways of describing a design process (such as product design, architectural design, urban design, engineering design or other different design areas) is to "see it as a chain of tasks that must be carried out for a new product" [6].

The term Eco-design emerges from these definitions, referring to a new smart and proactive design approach in line with the Bruntland report statement of sustainability [7]. It involves the consideration of environmental issues in the product development process in order to minimize environmental impacts throughout the whole product's life cycle, without compromising other essential criteria such as performance, quality and costs [8].

The eco-design approach widens the scope of traditional design towards a more sustainable design by learning and intending to reduce the environmental impacts of products and solutions through their entire life cycle, instead of being focused on the production and use stages.

The different areas of design (architecture, engineering or industrial design) put forward important challenges to minimize the environmental impacts and develop eco-friendly products and systems, placing the environment at the same level of importance as efficiency, aesthetics, costs, ergonomics, and functionality. At an organization and management level, this approach may help to promote a competitive differential and contribute to add value to the productive chain, from raw material selection to the end of life, proving the environmental responsibility of the manufacturer [9].

ISO 14006:2011 also presents a definition for eco-design as the integration of "environmental aspects into product design and development with the aim of reducing adverse environmental impacts over the lifetime of the product" [10]. This definition is widely accepted and presents the required flexibility to be addressed by different design areas and product types.

Within the design process, the Eco-design approach can be appreciated as a system of principles and rules containing the necessary tools to address a given problem, helping to drive towards smarter and more innovative solutions.

2.2 Standards and directives

The legal and normalized framework that regulates the European market for products has become more environmental conscious and energy efficient over the last decades. This

awareness is expressed in the different documents available to support the integration of environmental aspects during the product design process.

The 'Eco-design Directive' [11] was initially published in 2005 and established a framework for the setting of eco-design requirements for energy-using products within the European market. In 2009 the scope of this directive was extended to 'other energy related products' where construction materials can be included, since they have a significant impact on the energy and resource consumption. The 'Eco-design Directive' outlines the conditions for the implementation of measures regulating the environmental characteristics that energy-using and other energy related products need to have in order to be placed in the European market. This directive can be perceived as an important tool to increase the performance of products, especially regarding their environmental impacts, by promoting the preparation of Environmental Product Declaration (EPD) through a Life Cycle Assessment (LCA) approach. An EPD is a normalized document that expresses the assessment of environmental impacts of products, in compliance with ISO 14025: 2006 [12].

This LCA approach, presented in ISO 14040:2006 [13], was developed for evaluating the environmental impact of systems through the entire life cycle, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Through such a systematic perspective, the potential environmental burden from life cycle stages or individual processes can be identified and possibly avoided. The structure of a typical LCA comprises four different phases, as presented in Fig. 1.

ISO 14006:2011 [10] provides guidance for organizations on how to incorporate environmental aspects into product design and development (eco-design) within the framework of environment management systems (ISO 14001:2015) and quality management systems (ISO 9001:2008). It does not give details on how to carry out eco-design at the design level but provides specific guidance on how to address the environmental impacts of products or services within the context of the environmental management system. However, this standard provides generic principles and guidelines that must be considered through eco-design activities in product design and development (Fig. 2).

ISO/TR 14062:2002 presents a design and development strategy based on a life cycle approach that 'aims to provide people directly involved in the design and development phase

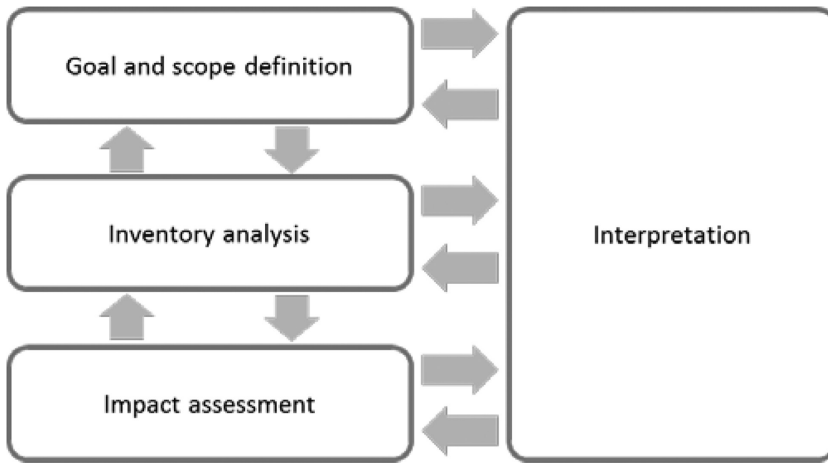

Figure 1: Stages of life cycle assessment (adapted from ISO [13]).

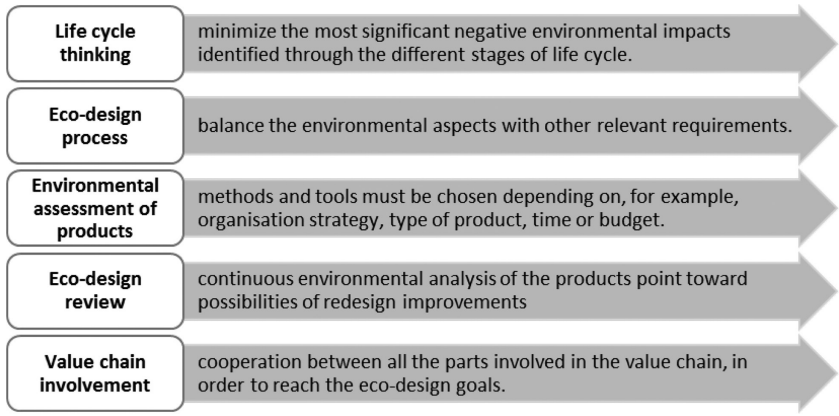

Figure 2: Eco-design activities in product design and development [10].

with a systematic program for predicting and identifying the possible effects their future products could have on the environment, and for making effective decisions in the design and development of these products in order to improve their environmental performance' [11].

According to this reference, the integration of the environmental aspects within the design and development of products, at an organisational level, must comply with the following principles:

- 'Early integration': once the product has been fully developed or marketed, the attempts to improve the environmental performance will be more limited;
- 'Life cycle approach': the consideration of all the life cycle stages is essential to grow a valid awareness on how products can affect the environment;
- 'Functionality thinking': the focus must be on identified needs and performance requirements;
- 'Multi-criteria concept': the design approach must be developed allowing the combination of different criteria, such as quality, costs and environment;
- 'Trade-offs': an integrated perspective can help achieving a compromise between requirements, benefits and needs. The balance between different aspects of the eco-design strategy may vary accordingly to specific products, type of organisations and defined goals. The acknowledgment of risks and trade-offs associated with strategies assumed during the design process is important to perform an adequate evaluation of the environmental performance of products.

The definition of product-related objectives is also an important step regarding the integration of environmental aspects and consideration of environmental impacts, such as the conservation of resources, recycling and energy recovery and prevention of pollution, waste and other negative impacts. These objectives are be determined by the different inputs and outputs of the product life cycle (Fig. 3).

Within the design and development process of products, the integration of the environmental aspects follows six distinct phases, each with different possible integrations of environmental aspects. The sequence of the different stages allows a continuous improvement of the process, by establishing an iterative model to evaluate results against environmental targets and reference products (Fig. 4).

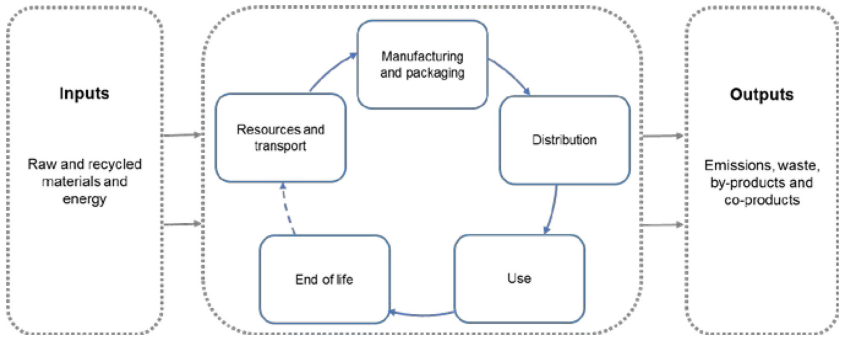

Figure 3: Association of inputs and outputs with product life cycle [11].

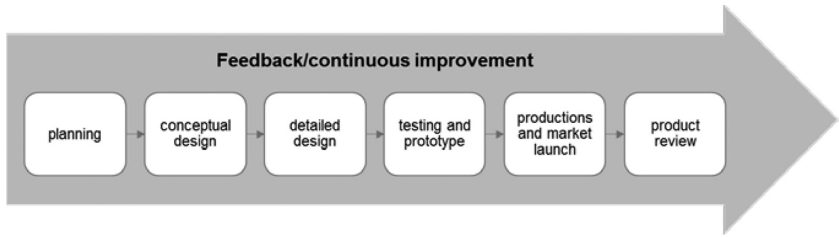

Figure 4: Typical stages of the product design and development process (according to ISO [11]).

2.3 Methods and tools

To enable an Eco-Design approach, it is necessary to assess the environmental problems and its causes in order to influence the design, materials selection, production, use, reuse, recycling and final disposal of the products. This evaluation can be performed by a wide range of tools and methods. Baumann *et al.* [14] identified nearly 150 eco-design tools. Considering the eco-design goal, the selection of the most adequate tools can be made depending on the type of assessment and outputs, the suitability and the phase of the eco-design [15].

In this section, a concise sample of the most mentioned tools is presented. Following the classification proposed by Knight and Jenkins [16] the tools can be divided in three broad categories: analytical tools, checklists and guidelines.

One of the most relevant analytical tool for the assessment of the environmental impacts of products/systems along their service life is LCA, presented in ISO 14040:2006 [13]. As previously described in this paper, LCA is a framework that was developed to evaluate the environmental performance of systems throughout their service life, providing quantitative data as an output of the assessment. LCA has been recognized as an efficient method to determine environmental impacts supporting impact calculation in several software tools (SimaPro and GaBi, for example). However, this methodology involves a large amount of information that is still not completely quantified at early stages of the design process. Therefore, the assessment is more efficient when applied as an assessment tool at the advanced stages of product design or during redesign processes. At these stages, it is also possible to identify improvement opportunities for the product under development. In alternative, a simplified version of LCA can be used, though it may increase the uncertainty of the assessment results.

The recognition of the complexity related to LCA tools has led to the development of simplified guidelines and checklists that more easily support designers to make decisions, especially at the early stages of product development [17].

The MET matrix, presented by Brezet and van Hemel [18], is a different analytical tools that provides a qualitative and quantitative evaluation of a product. This matrix focuses on three aspects of a product, such as materials (M), energy (E) and toxicity (T), and their inputs and outputs through five broad stages of product life cycle. The final output is a table composed of five rows and three columns to help the design team to obtain a global view of the inputs and outputs in each stage of product life cycle.

The implementation of this matrix is simple and can easily summarize the key environmental aspects to take into account during the design process. It is not specifically oriented towards the end of life of product and can be used throughout the life cycle. The estimation of the environmental aspects must be combined with other fundamental aspects in product design (technical and economic, for example), requiring a multidisciplinary team. Its implementation is simple and fast but may result in subjective outputs, making it hard to compare different products, depending on the teams.

The checklists are another different simplified approach to eco-design that allows a fast estimation of the environmental profile of a product. These tools are usually applied for specific business activities at the initial design stages, such as Fast Five Phillips [19] and Volvo's Black, White and Grey List [20]. Despite the product's complexity, it is possible to create specific checklist to address the key issues along the design process. The use of checklists is usually recognized as being useful and easy to understand and implement, being often the first tool used when starting and eco-design approach [16].

The use of guidelines provides a broad support that may cover some parts of product development process or the whole life cycle. The design and development strategy presented in ISO/TR 14062:2002 presents a systematic guideline tool applicable to the whole product life cycle. The guideline "Eco-design and 10 golden rules" [6] is a highly generic guideline established to work as a starting point to develop more specific and customised guidelines, depending on the product type and specific performance requirements.

The advantages of these simplified methods rely on a quick evaluation of the product's environmental profile that helps to easily assess improvement actions during the product's development process. However, team experience is required in order to develop specific checklists and guidelines, to insert relevant information and to interpret the outputs of these tools.

3 THE ECO-DESIGN STRATEGY FOR THE CONSTRUCTION INDUSTRY

For marketing construction products in Europe, the industry must observe the rules defined in the Construction Products Regulation (CPR) [21]. This document provides technical indicators to assess product performance ('Declaration of Performance') that allows comparing different products. The inclusion of 'sustainable use of natural resources' as a new basic requirement to settle the quality standards of building products has been an important step towards the acknowledgment of the environmental impacts and the improvement of the functional and environmental performance for construction works. This particular requirement promotes the reuse or recyclability of building materials and parts after demolition, the durability of the construction works and the use of environmentally compatible raw and secondary materials. Besides the technical information regarding the product performance, the 'Declaration of Performance' should also be accompanied by information on the content of hazardous substances in the construction product, in order to improve the possibilities of sustainable construction and enable the development of eco-friendly products.

Buildings are responsible for a significant amount of energy consumption and CO_2 emissions in the EU. Aiming to reduce the energy consumption of buildings, the Energy Performance of Buildings Directive (EPBD) [22] encourages the improvement of the energy performance of buildings within the EU, taking into account local climatic conditions, as well as indoor climate requirements and cost-effectiveness. One of the most relevant requirements that emerge from this directive states that all new buildings must be nearly zero energy buildings by December 2020 and, in the case of public buildings, this requirement must be fulfilled by December 2018. These provisions are causing a great impact in the construction sector, demanding improvements of the energy performance of elements in the building envelope in case of new constructions, conservation actions or major renovations.

In the same line with the EPBD, the extension of the scope of the 'Eco-design Directive' in 2009 to 'other energy related products' [23] allows considering construction products, such as building elements that form part of the building envelope, since these construction elements have a significant impact on the energy performance of the whole building.

The European legal framework promotes the integration of environmental considerations into building systems and construction products, which can be converted into an eco-design approach within the construction industry. The consideration of eco-design in the building and construction sector refers to 'processes which are environmentally responsible and resource efficient throughout a building life cycle' by considering different aspects such as building and products design, materials, equipment, energy generation and services [24].

Regarding the sustainability of building construction products, international standard ISO 21930:2007 [25] provides the principles and requirements for EPD of building products. As previously mentioned, an EPD is a declaration providing quantitative environmental data by defining parameters and other relevant environmental information, if relevant. This document can be an important tool to assess the environmental impacts after the design process, being more adequate for product improvement through redesign processes.

The architectural design of buildings, regarding its overall aesthetics, material selection, geometry and detailing, determines many functional performance requirements, such as durability and energy consumption. An eco-designed building has to be a smart and efficient building, or a 'well-designed system' in order to ensure an adequate durability, a good environmental and energy performance with acceptable costs, without compromising other relevant aspects, such as the desired aesthetics and safety. Regarding these concerns, the International Union of Architects endorsed a 'Manifesto for responsible architecture' presenting the Architects' commitment to the climate of the future. This document was presented in the UN Climate Change Conference (COP21) in November 2015 [26] and establishes design guidelines towards a more sustainable architecture, which enable the application of eco-design principles at the design stages through six different principles:

- Favour innovative proposals: the aim is for a more rational use of resources during the design of new buildings or renovation operations and encouraging innovative solutions that favour shared and adaptive spaces and facilities;
- Give value to design studies: the consideration of environmental performance of a building should be closely linked to architectural solutions, regarding the building orientation, geometry as well as the thermal performance of materials and systems;
- Favour the use of local resources and solutions for construction: the use of endogenous resources allows shortening supply chains, in order to significantly reduce the building's carbon footprint, and focus on locally proven technical solutions;

- Construct buildings that satisfy needs and anticipate their future adaptation: sustainable construction requires buildings designed to correspond to the present local needs of the region and looking towards the future, aiming for energy efficient housing;
- Study the life cycle and demolition of buildings: a sustainable building design pays attention to recycling and reuse of building materials, during use and end of life stages of buildings;
- Renovate existing building stock: the renovation of the building stock is an important strategy to improve its energy and environmental performance.

These documents present different approaches, methods and guidelines that attempt to assess and reduce the environmental impacts of existing building systems, products and solutions. Starting from this knowledge, one can begin to understand how to move beyond current solutions and towards more innovative and sustainable ones.

4 CONCLUSIONS

The definition of goals and specifications of products at the beginning of the design process is an essential step and also the ideal time for the introduction of eco-design concepts in the product's development process. Along this process, many opportunities exist to fully integrate environmental considerations into product design. This can lead to radical reductions of the amount of natural resources consumed, avoiding the use of toxic materials, reducing energy consumption during use to a minimum, and planning for re-use, recycling or final disposal from the early life cycle stage.

The main challenge is to deliver a product that responds to functionality, efficiency, aesthetics and other requirements with low economic and environmental costs. The balance between the environmental cost and functional income is essential for sustainable development.

These concepts can be applied to construction industry, considering buildings as a complex system that is object of different levels of design. Considering the existing framework referred in this paper, the application of an eco-design approach to the development of sustainable construction products is not only possible but desirable, since it can contribute towards sustainability, energy efficiency, economic competitiveness and an environmental-friendly building stock and cities.

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REFERENCES

[1] United Nations Statistical Commission (UNSC). Technical report by the Bureau of the UNSC on the process of the development of an indicator framework for the goals and targets of the post-2015 development agenda (Working draft), 2015.

[2] Hopwood, B., Mellor, M. & O'Brien, G., Sustainable development: mapping different approaches. *Sustainable Development*, **13**, pp. 38–52, 2005. http://dx.doi.org/10.1002/sd.244

[3] World Commission on Environment and Development (WCED), Our Common Future, 1987.

[4] Berardi, U., Clarifying the new interpretations of the concept of sustainable building. *Sustainable Cities and Society*, **8**, pp. 72–78, 2013. http://dx.doi.org/10.1016/j.scs.2013.01.008
[5] Eurobarometer, Europeans' attitudes towards the issue of sustainable consumption and production, European Commission Web Site, Brussels, available at: http://ec.europa.eu/public_opinion/flash/fl_256_en.pdf
[6] Luttropp, C. & Lagerstedt, J., Ecodesign and the ten golden rules: generic advice for merging environmental aspects into product development. *Journal of Cleaner Production*, **14**, pp. 1396–1408, 2006. http://dx.doi.org/10.1016/j.jclepro.2005.11.022
[7] Karlsson, R. & Luttropp, C., EcoDesign: what's happening? an overview of the subject area of ecodesign and of the papers in this special issue. *Journal of Cleaner Production*, **14**, pp. 1291–1298, 2006. http://dx.doi.org/10.1016/j.jclepro.2005.11.010
[8] Johansson, G., Success factors for integration of ecodesign in product development: a review of state of the art. *Environmental Management and Health*, **13**, pp. 98–107, 2002. http://dx.doi.org/10.1108/09566160210417868
[9] Platcheck, E.R., Schaeffer, L., Kindlein, W. & Cândido, L.H.A., EcoDesign: case of a mini compressor re-design. *Journal of Cleaner Production*, **16**, pp. 1526–1535, 2008.
[10] ISO - International Organization for Standardization, ISO 14006:2011 - Environmental management systems - Guidelines for incorporating ecodesign, 2011.
[11] ISO - International Organization for Standardization, ISO/TR 14062:2002 - Environmental management - integrating environmental aspects into product design and development, 2002.
[12] ISO - International Organization for Standardization, ISO 14025:2006 - Environmental labels and declarations - Type III environmental declarations - Principles and procedures, 2006.
[13] ISO - International Organization for Standardization, ISO 14040:2006 - Environmental management: Life Cycle Assessment - Principles and framework, 2006.
[14] Baumann, H., Boons, F. & Bragd, A., Mapping the green product development field: engineering, policy and business perspectives. *Journal of Cleaner Production*, **10**, pp. 409–425, 2002. http://dx.doi.org/10.1016/S0959-6526(02)00015-X
[15] Bednárová, L., Witek, L., Pietowska-Laska, R. & Laska, A., Assessment methods of the influence on environment in the context of eco-design process. *Production Management and Engineering Sciences*, eds M. Majernik, N. Daneshjo & M. Bosak, Taylor and Francis Group: London, 2016.
[16] Knight, P. & Jenkins, J.O., Adopting and applying eco-design techniques: a practitioners perspective. *Journal of Cleaner Production*, **17**, pp. 549–558, 2009. http://dx.doi.org/10.1016/j.jclepro.2008.10.002
[17] Pigosso, D., McAloone, T.C. & Rozenfeld, H., Characterization of the State-of-the-art and identification of main trends for ecodesign tools and methods: classifying three decades of research and implementation. *Journal of the Indian Institute of Science*, **95**(4), pp. 405–427, 2015.

[18] Brezet, H. & van Hemel, C., Ecodesign: a promising approach to sustainable production and consumption, UNEP, 1997.
[19] Meinders, H., Point of no return - Philips EcoDesign Guidelines, Eindhoven, 1997.
[20] Nordkil, T., Volvos Vita Lista - Volvo Corporate Standard, Sweden, 1998.
[21] Regulation (EU) No 305/2011, Construction Products Regulation. *Official Journal of the European Union*.
[22] Directive 2010/31/EU, *Energy Performance of Buildings Directive*, 2010.
[23] Directive 2009/125/EC, *Ecodesign Directive*, 2009.
[24] Annunziata, E., Testa, F., Iraldo, F. & Frey, M., Environmental responsibility in building design: an Italian regional study. *Journal of Cleaner Production*, **112**, pp. 639–648, 2015.
[25] ISO - International Organization for Standardization, ISO 21930:2007 - Sustainability in building construction: Environmental declaration of building products, 2007.
[26] International Union of Architects (UIA), Manifesto for responsible architecture, 2015.