Environmental sustainability assessment methodologies for steel and timber structures

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Abstract: - The current research investigates the main environmental sustainability assessment methodologies for steel and timber structures in order to determine their potential in terms of effectively displaying the sustainability characteristics of the two construction technologies. The main types of assessment methodologies are cross-checked with a series of key issues such as recycling, reuse, waste, ease, speed and accuracy of construction and the wide variety of projects that can be constructed as steel or timber structures. Conclusions concerning the purpose of application of each type of assessment are drawn.

Key-Words: sustainability, life cycle assessment (LCA), sustainable steel and timber structures

1 Introduction

Research within the construction sector during the last few years has focused on ways to incorporate sustainability into the delivery of technical projects. The aim of the methodologies that have been developed is to ensure that the design and construction of a technical project are carried out according to the principles of sustainable development, while also providing options to minimize the environmental impact created by the realization of the project. A common characteristic of almost all such current approaches is that they are used proactively. As the impact of their application and the subsequent environmental benefit is maximized when applied to the very early stages of a project [1], most methodologies focus on the assessment of sustainability as an aid to the decision-making that occurs during these initial stages. Among the three factors of sustainability - environmental, economic and social- it is the environmental sustainability which is mainly monitored by the sustainability assessment methodologies that are being used for construction projects. 'Green' buildings and 'eco-friendly' projects are being constructed by firms that are involved in environmental sustainability assessment. This can be attributed to the fact that environmental sustainability is currently one of the critical issues within construction, especially since it has been added to a number of official legislation documents such as the European Construction Products Regulation (CPR) [2]. This regulation refers to sustainability within construction and states that construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable. The current research examines the methodologies that have been developed for the assessment of the environmental sustainability of construction projects of steel and timber structures.

2 Environmental sustainability assessment in construction

Although each methodology has its own characteristics and advantages, many are based on similar approaches and can thus be grouped in a few basic categories. An effective categorization for buildings is proposed by Bragança et al. [3] according to which it is possible to distinguish the following three types of sustainability and assessment tools: Building performance management, Rating and certification, Life Cycle Assessment (LCA). This categorization can also be widened for use in relation to construction projects in general. These three categories are briefly

described in the scope of the current research and their relation to steel and timber structures.

2.1 Performance Management

The methodologies used to ensure sustainability through performance management have been developed for building projects and are currently used mostly for this type of construction. They are based on a unique approach which focuses on the desired function of a building and how well that function corresponds to the needs of the building's end users. In this aspect, the requirements of the end users are documented and categorized as 'performance requirements' that determine the desired properties of the building. These requirements are then used to form a hierarchy which eventually allows for the establishment of technical and economic specifications according to the desired building concept [3].

2.2 Rating and certification

The rating and certification systems are essentially detailed checklists of issues and aspects that are – either directly or indirectly- related to the sustainability of a construction project. By going through such a checklist, these indicators, which have been outlined according to the basic concept of each rating system, are verified against the characteristics of a project. A scoring system is finally applied and a final score referring to the project's sustainability potential is calculated. In the scope of the current research, three widely used rating and certification systems (LEED, BREEAM and DGNB) are briefly described and used to determine the range of application of such methodologies to steel and timber structures.

The LEED certification system, which is widely used in the United States, includes systems for 'new construction' and 'existing buildings' as well. In all, it consists of a suite of rating systems for the design, construction and operation of buildings, homes and neighborhoods, with five main categories correspond to the certification systems available (Table 1).

Another widely used rating system, developed in the United Kingdom, is BREEAM (BRE Environmental Assessment Method) [4]. It is an environmental assessment method for buildings which focuses on sustainable design and buildings' environmental performance. It covers a wide range of building types, and can be carried out for almost all types of building projects, from new buildings to refurbishments, extensions or fit-outs. Credits are awarded according to the issues that are fulfilled across ten categories of sustainability: 'Management', 'Health and well-being', 'Energy', 'Transport', 'Water', 'Waste', 'Pollution', 'Land use and ecology', 'Materials', 'Innovation'.

Main category	**Available LEED certification system**
Green Building Design & Construction	• LEED for New Construction • LEED for Core & Shell • LEED for Schools • LEED for Retail: New Construction and Major Renovations • LEED for Healthcare
Green Interior Design & Construction	• LEED for Commercial Interiors • LEED for Retail: Commercial Interiors
Green Building Operations & Maintenance	• LEED for Existing Buildings: Operations & Maintenance
Green Neighborhood Development	• LEED for Neighborhood Development
Green Home Design and Construction	• LEED for Homes

Table 1. Project categories covered by the LEED certification system.

This type of categorization of issues related to sustainability is also used by the DGNB certificate which is a tool that enables the straightforward assessment and planning of sustainable buildings. It covers six key fields of sustainable building, namely 'Ecological quality', 'Economic quality', 'Sociocultural and functional quality', 'Technical quality', 'Process quality' and 'Site quality'. Each field contains special criteria that can be designed and weighted differently depending on the occupancy profile and if a building fulfils the criteria, it receives the certificate in gold, silver, or bronze depending on the total performance index [5]. While the DGNB certificate currently focuses mainly on new buildings, it will also cover existing buildings in the future.

2.3 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) systems for construction projects are based on the concept of the life cycle and life cycle engineering. According to this approach, a project is analyzed and broken down into individual sub-processes, each of which is assessed in terms of environmental impact. When used proactively, this allows for optimizing the environmental performance of a project for the duration of its life and beyond its completion [6]. The assessment of the environmental impact is

ISBN: 978-1-61804-167-8

based on the examination of a project's life cycle, and it consists of four stages as displayed in Fig. 1.

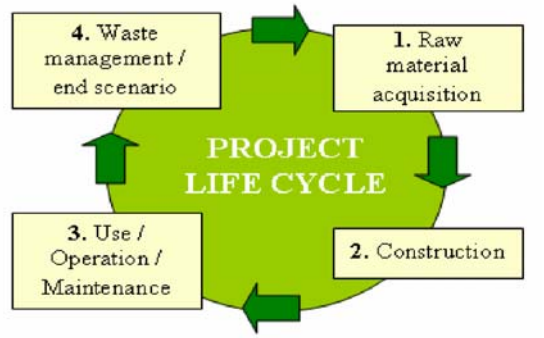

Fig.1. Stages of a construction project's life cycle [6].

3. Key issues in relation to environmental sustainability assessment

In order to identify the potential of the wide range of available methodologies that have been developed for the assessment of the environmental sustainability of construction projects, it is first necessary to define the scope of the current examination. Since the focus of the current research is steel and timber structures, it is necessary to identify the key issues which characterize these two construction technologies in terms of environmental sustainability. The identified issues will later be used to comprehend the potential of each assessment methodology for steel and timber structures.

3.1 Recycling and reuse

Steel and timber construction differ from other construction technologies such as concrete, due to the available options at the end of a project's service life, after the decision for demolition has been made. Steel can be retrieved after the removal of cladding materials and the disassembly of the structural frame. After it has been retrieved, the steel elements that have been collected are inspected and can either be sent for recycling or for repair and reuse, in case it is found that they have retained their initial dimensions and properties. In environmental terms, the recycling process of steel avoids the need for the extraction of new quantities of raw materials for the manufacturing of new quantities of the material.

Wood is another construction material with significant sustainability potential as far as waste treatment is concerned. A wide range of option exists for the viable reuse or recycling of wood that can be retrieved during the demolishing of a structure. These options have been documented in detail [7] and include the wood's direct reuse in other construction projects and the production of wood-based panels from timber chip.

3.2 Waste streams

The quantities and types of waste generated at the end of the service life of a structure can heavily influence the environmental sustainability of a technical project. In contrast to other construction materials, steel and timber can be effectively recycled and reused and thus the waste streams generated are significantly decreased. Landfill and incineration –two waste disposal options that are associated with high environmental burden- are avoided. Instead, steel and timber elements are disconnected, collected and sorted and sent for recycling or reuse in other construction projects.

3.3 Ease, speed and accuracy of construction

A significant amount of work required for the erection of the structures can be done off-site in nearby facilities where controlled conditions apply. This option increases the ease, speed and accuracy of construction which in turn translate into a decreased time of operation of machinery and workforce. In the case of steel structures, the steel elements can be coated, cut and bolted offsite, while wood elements can also be prepared with protection coatings and varnishes and be drilled accurately so that their connections can be completed easily onsite. In terms of environmental sustainability, the significantly less onsite time that is required for the delivery of a steel or timber construction project decreases the environmental impact created by the project. Beside the decreased time of machinery operation and workdays required, there are also issues such as a decreased usage of resources such as water and electricity onsite. The environmental burden caused at the construction stage is therefore decreased and is mainly caused by the transport of the prepared and connected structural elements which would have occurred anyway.

4. Potential of assessment methodologies for timber and steel structures

The key issues that have been outlined in relation to the environmental sustainability of steel and timber structures are used to describe the potential of each category of assessment systems for these two types of construction. What is examined is whether an assessment methodology can facilitate the influence

ISBN: 978-1-61804-167-8

of these key issues on the result that is calculated regarding the environmental sustainability of a steel or timber structure. Furthermore, the level of detail in the results provided by each assessment methodology is examined in terms of its potential for analyses aimed at the optimization of environmental impact.

4.1 Performance management systems

Although most performance management systems include the environmental loads associated with waste streams, recycling and reuse, which are critical for steel and timber structures, they do so in an indirect manner. The primary indicators used are circled around the use of the building and its desired functions and as a result it is mainly these issues that make up the core of these methodologies. This can also be observed in Table 3. The indicators that are used provide a thorough assessment of a building's function and use, however, issues such as waste streams and recycling can only be considered in the last category which generally covers all environmental burdens. As a result, performance management systems can only be used effectively with steel and timber building projects, while their application is prevented for other types of steel and timber structures such as bridges.

A. Conformity	B. Performance	C. Cost and Environmental Properties
A1 Location	B1 Indoor Conditions	C1 Life Cycle Costs
A2 Spatial Systems	B2 Service life and deterioration risk	C2 Environmental Pressure
A3 Services	B3 Adaptability	
	B4 Safety	
	B5 Comfort	
	B6 Accessibility	
	B7 Usability	

Table 3. The hierarchy of a building's properties as developed and used by the VTTProp performance management system [3].

Ease, speed and accuracy of construction are again found to constitute issues that are not actually included in the list of indicators used by most performance management systems. The construction stage is usually considered more of a 'means' to ensure the efficiency of the performance requirement goals that have been set and not as much as a category of indicators. Systems that do include indicators related to the construction stage of a project could enable the inclusion of the aforementioned key issues for steel and timber structures.

4.2 Rating and certification systems

Rating systems can easily display their potential in terms of any type of project through the examination of the indicators that are included in their checklists and the relative weighting of their importance. Many rating systems have included a wide range of indicators, including some of the key issues related to the environmental sustainability of steel and timber structures.

The LEED system and its 'LEED for New Construction' certification [8], for example, includes the main category 'Materials and Resources' which lists a number of indicators related to recycling, reuse and waste in steel and timber construction. The reuse of walls, floors, roofs and framing is awarded according to its percentage, while diverting construction waste from landfills is also awarded in the same way. The reuse of building materials to avoid the need for manufacturing new quantities is also included, while building products with increased recycling potential is promoted. Regional products and environmentally responsible forest management are also promoted. In terms of the construction stage of a steel and timber structure, the LEED system includes a number of relevant indicators that are presented in Table 4. The ease, speed and accuracy of construction are not included directly; however, there are relevant indicators that do provide opportunities to include the effects of these issues on environmental sustainability.

The BREEAM system also includes similar indicators that facilitate the inclusion of the key issues identified for the assessment of the environmental sustainability of steel and timber structures, only, however, for the case of buildings. The recycling and reuse potential of steel and timber structural elements is included in the 'materials' category with the 'embodied lifecycle impact of materials' and 'materials reuse' indicators. In the 'management' category of indicators there is also the 'construction site impacts' indicator with which the effects of issues such as ease, speed and accuracy of construction can be taken account. Finally, issues associated with construction waste can be considered in the BREEAM methodology's 'waste' category which includes indicators that refer to the handling of construction waste allow for the consideration of recycling scenarios.

The inclusion of these key issues in the DGNB methodology can be achieved in a more generalized way. This certificate covers a very wide range of issues related to a building project and as a result, many indicators –especially in regard to

ISBN: 978-1-61804-167-8

construction or materials- only allow for a general reference of the key issues identified for steel and timber structures.

Indicator	Intent
Construction Activity Pollution Prevention	To reduce pollution from construction activities in air, water and soil.
On-site Renewable Energy	To encourage on-site renewable energy and reduce impacts from fossil fuel energy use.
Building Reuse—Maintain Existing Walls, Floors and Roof	To extend the lifecycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings.
Building Reuse—Maintain Existing Interior Nonstructural Elements	
Construction Waste Management	To divert construction waste from landfills and incineration. And redirect recyclable and reusable materials to appropriate sites.
Materials Reuse	To reuse building materials to reduce demand for virgin materials and reduce waste.
Recycled Content	To increase demand for recyclable building products and thus reduce impacts from new extraction.
Regional Materials	To increase demand for local building materials to support indigenous resources and reduce environmental impacts from transportation.
Certified Wood	To encourage environmentally responsible forest management.

Table 4. The indicators included in the 'LEED for New Construction' certification and are related to the key issues identified for steel and timber structures [8].

Overall, it can be observed that most rating systems have included indicators that cover the key issues related to the environmental sustainability of steel and timber structures to a very good degree. What should not be neglected, however, is that due to the manner in which certification systems have been developed and are being used, these issues are only assessed on a 'yes-or-no' basis or according to a very rough and wide categorization. As a result, it is not possible for this type of assessment to provide analytical results. For the same reason, in cases of comparison analyses it can also be expected that rating systems will provide a limited amount of comparable in-depth results, as their main function is to categorize buildings according to a set of three or four categories that cover significantly wide ranges of environmental sustainability.

4.3 LCA systems

Methodologies that are based on the life cycle concept provide a different approach to assessing the environmental sustainability of a structure. It is one of the very few currently available methodologies that can be applied to the complete range of projects that can be constructed as steel or timber structures.

The concept of the life cycle is directly applied to a construction project, thus creating a space for the inclusion of any product or process associated with the project. The first stage (raw material acquisition) can incorporate environmental data concerning the manufacturing processes of steel and timber structures, taking into account the fact that they may have been acquired from recycling or reuse. During the construction stage every construction process, activity or resource can be documented and quantified into environmental burden of benefit. The ease, speed and accuracy of steel and timber construction can be fully quantified, thus presenting their full potential in this stage. At the end of the life cycle it is also possible to include environmental data referring to the recycling or reuse of steel and timber elements and calculate the amount of environmental benefit that can be achieved.

The results obtained from an LCA analysis provide a detailed account of environmental inputs (raw materials) and output to the environment (emissions to air, water and soil), while also calculating the environmental impact caused throughout the life cycle of the project. This type of results provides the necessary depth that is required to analyze the environmental sustainability of a steel or timber structure, while also allowing for more precise comparisons between alternative designs or construction technologies.

4.4 Rating and certification systems

Each type of assessment methodologies can be used in different occasions, with LCA providing a very detailed and adjustable methodology to steel and timber structures. Performance management and certification systems also constitute efficient solutions for the assessment of the environmental sustainability of buildings; especially in cases where issues related to the building's function and use are included. In cases where the goal is the optimization of the construction stage of a project in terms of environmental impact, LCA systems provide a wide

ISBN: 978-1-61804-167-8

range of options concerning the inclusion of any construction process or product and the quantification of the environmental impact associated with it.

5 Conclusions

The presented research examined the main types of methodologies that are currently available for the assessment of the environmental sustainability of construction projects. Performance management, rating, certification and life cycle assessment (LCA) systems were briefly described and examined in regard to their main functions, content and scope of application in order to eventually determine their potential to efficiently assess the environmental sustainability of steel and timber structures. The characteristics of each assessment were cross-checked with a series of key issues related to the environmental sustainability of steel and timber structures which were also identified. Recycling and reuse of steel and timber structural elements, waste streams, ease, speed and accuracy of construction and the wide variety of projects that can be constructed as steel or timber structures were used as the basis for the description of the potential of each assessment type.

It was found that the key sustainability issues identified for steel and timber structures can be taken account of in all assessment types, yet it varying manners. Performance management systems do not usually include such indicators so it is only possible to incorporate these issues indirectly through other related indicators. Most rating and certification systems were found to include the indicators thus allowing for the direct inclusion of the key issues, while LCA systems were found to provide the most options, since they allow for the direct inclusion of any process or product directly.

Overall, it was found that performance management and rating systems can be used in studies of steel or timber buildings where specific focus on user requirements or certification is required. On the other hand, LCA can be used for any type of steel or timber project for the optimization of the environmental impact caused or the comparison of alternative designs.

Acknowledgments

This research work is implemented through the Operational Program "Education and Lifelong Learning" and is co-financed by the European Union (European Social Fund) and Greek national funds – **ARCHIMEDES III.**

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