Sustainability and application of life cycle assessment in welded structures

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Abstract: *As global environmental impacts have increased, modern societies have expressed a strong interest in implementing sustainable solutions to reduce emissions and use operational energy and natural resources. The construction industry is a leading promoter of significant environmental impacts because it consumes a significant amount of water, energy, and materials. Steel and welding are critical in all three major sectors of the industry: construction, infrastructure, and industry. This paper discusses the significance of meeting sustainable development goals in welded structures and identifies ways that this industry can help to reduce environmental impact and improve employment conditions while achieving economic growth, saving time, and maintaining structural quality. The paper discusses how to optimize various aspects ranging from raw material extraction to construction waste disposal using the life cycle assessment (LCA) methodology. It provides a starting point and demonstrates how these tools can contribute to more sustainable welded structures.*
Keywords: LIFE CYCLE, SUSTAINABILITY, STEEL STRUCTURES, MATERIALS, WELDING

1. Introduction

Over the last few years, national and global interests have shifted towards sustainable, efficient, and environmentally friendly production. It's understandable given that high levels of air pollution, greenhouse gas emissions, dangerous substances, and waste pose a serious threat to the environment and humanity, as well as widespread concern about energy consumption and limited resources. The construction industry has a significant environmental impact. According to recent data, buildings account for approximately 40% of CO_2 emissions [1-2]. Buildings account for up to 40% of total energy consumption and 30% of greenhouse gas emissions, according to data from the United Nations Environment Programme (UNEP), and in some countries, these percentages can reach nearly 70% [5]. To address the significant impact of the construction and building industries on planetary and human health, The World Green Building Council (WorldGBC) has established the ultimate goal of reducing emissions to zero by the end of 2050, and many countries, including Canada and the United States, have developed new standards to meet these targets [1-4]. According to the most recent data on the construction industry's environmental impact, construction is responsible for 23% of air pollution, 50% of climate change, 40% of drinking water pollution, 50% of landfill waste, and 40% of global energy usage [5].

A construction is considered environmentally acceptable if it meets the prescribed green standards throughout its lifetime. These so-called eco-friendly or green buildings combine techniques, materials, and technologies to improve environmental and social performance. Certain practices, materials, and processes are expected to significantly reduce environmental impacts and efficient resource consumption throughout the lifecycle of a building [6]. LEED (Leadership in Energy and Environmental Design) is the most commonly used rating system (standard) for eco-buildings when designing for sustainability. Despite progress in implementation, there are still some challenges that remain. LEED is a good starting point but there are other paths to sustainable design that go beyond LEED by implementing alternative sustainable design methods and standards. Beyond eco-standards, sustainability refers to the environmental, social, and economic impact. It considers the planet, people, and profit and it promises long-term growth and increased competitiveness.

In production, steel is considered an excellent sustainable building material because of its durability, adaptability, and recycling capabilities, all of which are important principles for sustainable development [7-8]. It is widely used for fabricating steel structures such as ships, bridges, buildings, and pipelines. However, according to Kleiwerks' most recent research, building materials such as concrete, aluminum, and steel are directly responsible for large amounts of carbon dioxide (CO_2) emissions [5]. When these materials were compared, the steel industry produced the most harmful emissions and pollution, which is significant because steel is widely used in construction and is expected to grow significantly in the future [5]. However, this is not the only factor to consider when evaluating the sustainability of welded structures; the joining process should also be considered. Welding is a common joining process that has a direct impact on the overall value of the structure. On-site welding techniques can be used in construction or manufacturing. Depending on the technology and process parameters, the time of joining and the use of energy and resources can vary; some require a large amount of energy and resources, which is critical from an environmental standpoint. Socially, welding entails working in a hazardous environment, which has a negative impact on workers' health.

It is clear that many factors contribute to the overall assessment of the sustainability of welded structures, and a suitable assessment tool should be used to obtain relevant results. The life cycle assessment (LCA) tool is a well-known methodology that can account for a variety of environmental impacts such as ozone layer depletion, global warming, eutrophication, and pollution, among others. LCA considers all or some of the following product or process phases: extraction, production, application, disposal, and recycling. If steel structures are made of raw material, LCA can be used to examine the environmental impact in terms of resources and energy that are required to extract the raw material from the ground. The impact of steel production will be followed by the impact of steel application (maintenance, etc.), and finally, the impact of steel rejection and recycling will be considered. If the steel is transported to a landfill, the amount of land used, the potential for environmental leakage, and other factors can be taken. Then there are the joining processes, which also have an impact on the environment and must be evaluated in terms of energy and water consumption, waste, emissions, ease, economy, and time of production. All of these factors should be considered, and a decision on the best joining technique should be made accordingly.

This paper aims to improve understanding of welded structure sustainability while also evaluating and proposing potential solutions to the remaining challenges. It introduces LCA methodology and examines the sustainability of welded structures, as well as provides a basic framework. Furthermore, critically reviewing the progress made in the sustainability of welded structures to date will help current and future engineers understand the problems that need to be solved.

2. Sustainability and sustainable welded structures

Sustainability and sustainable development focus on three major areas: the environment, the economy, and society. The Bruntland definition of sustainable development from 1987 does not explicitly mention the environment, suggesting that it can entail more than just reducing negative environmental effects [7]. The connection between sustainable development and construction is evident, given that the construction industry is Europe's largest industrial employer and thus has significant environmental and social impacts [9]. Sustainable structures, in general, seek to achieve optimal operating conditions with minimal environmental impact, reduce material consumption, improve people's lives, provide more efficient and cost-effective work, and protect natural resources for future generations while maintaining high productivity and quality to satisfy customers without increasing costs. The term “ green building” is referring to a structure that meets the environmental standards through its life cycle [8], but that doesn’t make the structure sustainable because sustainability cannot be achieved by focusing solely on environmental issues, these must be balanced against economic and social concerns [9]. The life cycle of a structure includes its construction, use, and deconstruction, as well as the underlying activities and material and energy flows that have an unavoidable positive and negative impact on the environment [10]. In this paper, the term "sustainability of structures" refers to the major health and environmental aspects associated with the life cycles of welded steel structures. Social issues are not the primary focus and are not addressed in depth.

In welded structures, steel is the most commonly used material. It is an excellent choice for structural applications due to its high strength-to-weight ratio, low cost, and ease of design and construction [7, 11]. One of the most appealing characteristics is that it can be fully recycled multiple times without losing quality. There are two billion tons of steel waiting to be recycled, and the recovery rate of structural steel products is currently around 95% and rising, which may be the most compelling sustainability argument for using steel in construction[10]. The high rate of recyclability and prefabrications is directly linked to benefits like less waste generation, the off-site production of steel means small construction sites, the structures are light with high strength and the time for production is short making it flexible and applicable for possible extensions of existing buildings [7,10,11]. Steel structures have an increased lifecycle, long design life, and high-quality remains over time. Also, there are flexible solutions for low maintenance and effective anti-corrosion measures that can be undertaken. There are many other possibilities that steel offers like use for the construction of modular buildings on temporary locations, buildings with long spans that provide open spaces that can be adapted for all sorts of use, and large, prefabricated units from modular buildings that can be reused in other structures. The high rate of recyclability and prefabrication is directly related to benefits such as reduced waste generation, small construction sites, light structures with excellent strength, and a short production time, which makes it flexible and applicable for possible extensions of existing buildings [7,10,11]. Steel structures have a long design life and lifecycle while maintaining their high quality over time. There are also adaptable solutions available for low-maintenance and effective anti-corrosion measures. Steel can also be used to build modular buildings on temporary sites, buildings with long spans that provide open spaces that can be adapted for a variety of uses, and large prefabricated units from modular buildings that can be reused in other structures. Furthermore, steel is an excellent material for high-rise buildings. All these characteristics show that steel is a desirable construction material for reasons other than its low cost and ease of design and construction. There are, however, other aspects to consider that correspond to critical concerns in the field of sustainability. The production of steel generates more CO_2 than other materials and the energy required to produce makes us question if this material meets the overall sustainability goals. According to World Steel Association data, the steel industry in the United States consumes about 2% of all domestic energy each year [7]. Sustainable structural components have low energy costs, high durability, low maintenance requirements, and contain high proportions of recycled materials. The extraction, processing, transport, construction, operation, disposal, reuse, recycling, and off-gassing and volatile organic compounds associated with the material should all be considered. In Fig. 1, the sustainability and potential benefits of steel structure construction can be investigated in different phases [10].

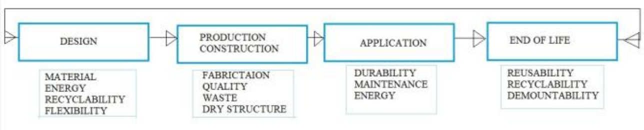

Fig. 1 *Considerations on the sustainability of a steel structure in different phases [10]*

In steel structures, welding is a very important joining technology in modern manufacturing, it accounts for a major part of the cost and directly affects the value of the structure and the product. Structures such as ships, bridges, buildings, and coastal foundations are made of structural steel. Depending on the material’s dimensions welding can be performed in one or several passes and layers depending on the technology and process parameters. In order to reduce the time of the process, it is recommended to use high-energy processes, which require a large amount of energy and resources, which is critical from an environmental perspective. From a social point of view, welding involves working in a dangerous environment, and has a harmful effect on the health of workers, resulting from welding gases, radiation, sound, etc. This aspect has been neglected in the selection of the welding process, due to the predominant focus on economics combined with a lack of adequate methods to assess these hazards. The majority of welding research and studies are aimed at developing new processes and technologies. There are few research papers on sustainability that cover all three critical aspects of welded products or structure development.

In construction, submerged metal arc welding (SMAW) is used for welding large profiles and beams, flux cored arc welding (FCAW) is more convenient for the fabrication of steel structures as well as heavy machinery repair, gas tungsten welding (GTAW) is used for joining various metals such as stainless steel, aluminum, bronze, and copper, and gas metal arc welding (GMAW) is used for structural and non-structural purposes. Compared to a separate analysis, these technologies are all different and have different effects on the environment, with some being more hazardous or economical. Fusion welding techniques and their environmental impacts are becoming more important for larger components and thicknesses as production time, material, and energy needs increase. According to a recent study on the environmental impact of manual metal arc welding (MMAW), when compared to laser arc-hybrid welding (LAHW) and gas metal arc welding (GMAW), MMAW has the greatest environmental impact in terms of global warming, acidification, eutrophication, and photochemical ozone creation [12]. MMAW is widely used in construction and uses coated electrodes; however, its productivity is low, and reducing energy consumption in the process is one of the most important ways to improve the environmental performance of the process. [13]. Also, the use of titanium dioxide for electrode coating in MMAW plays an important role in contributing to the overall burden of acidification and eutrophication [13].

The manufacturing or construction phase is one chain in the overall assessment of the welded structure's sustainability. There are separate research papers on each phase's sustainability, but the results are limited to the defined framework conditions. The most significant constraints stem from the exclusive focus on each phase of construction. There are numerous factors to consider when selecting environmentally friendly processes. The very first step in assessing sustainability is to establish a clear goal and understand the steel structure that is under consideration. This is also important for the next step, which involves selecting and evaluating indicators and gathering primary data for the assessment. Fig.2 depicts the general steps for sustainability assessments that can be adapted to a particular case. It also, shows the criteria for selecting indicators for collecting primary data [13].

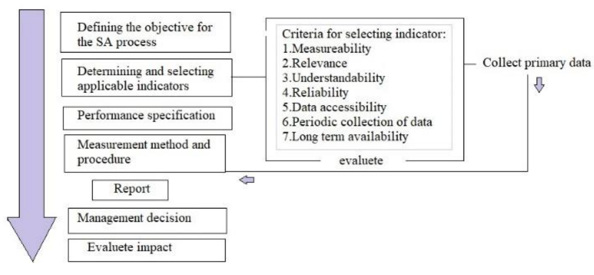

Fig. 2 *Sustainability assessment steps and evaluation of indicators [13]*

3. LCA methodology

An LCA methodology is a standardized approach for assessing the environmental impacts of a product, process, or even an entire industry. It examines the entire life cycle of a product or process, from raw material extraction and energy production to application, and takes into account numerous environmental impacts at each stage [12]. It is one of the tools developed by the European Commission to improve policy development strategy in 2015 [1]. It evaluates energy and raw material consumption, emissions, and other wastes associated with a product's or system's entire life cycle [1]. Among the effects that can be studied are climate change, resource depletion, and ecotoxicity. It can be used to assess the environmental impacts of building materials throughout their entire life cycle, from extraction to manufacturing, transportation, operation, maintenance, and disposal [1]. Allows stakeholders to compare different material options during the design phase. Many LCA software tools, such as GaBi, Athena, Building for Environmental and Economic Sustainability (BEES), and SimaPro, are used to calculate CO_2 emissions [1]. The obtainable programs contain environmental data on the most common materials used and can save a significant amount of time by presenting it in a simple and user-friendly format. Tools and databases have evolved in response to geographical location and application. In Fig. 3 a basic LCA framework is presented [14]. The objective and scope entail determining the system's purpose and limits, whereas the life cycle inventory (LCI) entails collecting data for each segment in relation to all its inputs and outputs [14]. LCA applications in construction are classified into four types: construction material selection, system evaluation and construction processes, construction industry tools and databases, and construction industry methodological developments [1]. An LCA can be useful because environmental impacts can be linked to specific decisions and can aid in making environmentally sound decisions about where to obtain steel, what joining technique to use, and maintenance coating, among other things, to minimize environmental impacts.

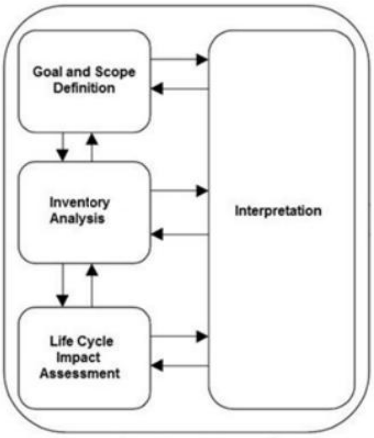

Fig. 3 *Basic LCA framework is presented [14]*

4. Conclusions

Sustainability decisions and making the right choices in the construction of economically and socially acceptable welded structures are difficult and complex. There are various stages that must be addressed, from design to end-of-life, and it has been demonstrated that the LCA methodology tool for sustainability assessment is applicable to each of them and offers acceptable solutions. When analyzing steel structures in the construction industry, the question of what kind of design, material, or manufacturing process can make a steel structure more sustainable arises. When compared to other building materials, steel has been identified as a sustainable building material. Furthermore, because there are various joining techniques that can be used for assembling structures with varying environmental impacts, choosing the right welding technology can play an important role in the overall structure's sustainability. Besides that, recent studies [13] show that the greatest environmental loads generated throughout the life of a specific structure occur during the operation and maintenance phase. This is primarily due to high energy consumption and significant atmospheric emissions. There are also social and economic indicators that should be considered throughout the entire process of implementing sustainability in steel structures. At the end of this study, it can be concluded that there is a strong need to push the boundaries of traditional structural analysis and provide new design and manufacturing knowledge to achieve sustainability of steel structures. The environmental and social impact of modern structural design should be considered, and each decision should be followed by a separate analysis at each stage of manufacturing and construction.

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