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A Discussion on the Advantages of Steel Structures in the Context of Sustainable Construction

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Abstract

The various studies were revealed that the environmental impacts such as global warming, the depletion of natural resources, waste generation and pollution etc. increase day by day due to rapidly increasing population of the world which creates a large number of building and construction demand. As a resource-intensive industry, construction industry puts enormous pressure on natural resources and constitutes an important part in all these environmental effects which have badly influences on natural balance, human health and survival. There occur various environmental impacts in construction, operation, maintenance and even at the end of life cycle of buildings. From this point of view, to reduce the environmental impacts of buildings, "sustainability" and "sustainable construction" concepts get importance. It is important to select environmentally friendly building material to implement principles and methodologies of "sustainable construction". Steel is the unique structural component which has almost a closed-loop material cycling and can be reprocessed without quality losses. This study discusses the advantages of steel structures in the context of sustainable construction. This paper provides an overview on "sustainable construction term" and its common criteria and focuses on the advantages of steel structures and examines steel structures through the life cycle stages according to the sustainability criteria.

Keywords:	Sustainability, Sustainable construction, Steel, Life cycle
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1. Introduction

It is required natural resources (energy, water etc. to construct human-made structures such as building, bridges, roads etc. [1]. These human activities which requires material and energy to develop have irreversible effects on ecological systems and environment and most of these impacts have long term results and hazardous consequences for human health and survival [1, 2]. Due to the world population growth there occurred a large number of building construction demand [3]. In parallel with ever-expanding economies and populations of the world, the demand for many construction materials which puts enormous pressure on natural resources increased [4]. It is a fact that, during construction, operation and maintenance and eventually at the end of life cycle of buildings there occur a wide range of environmental impacts such as global warming, waste production, depletion of natural resources, pollution to air, land and water and also human health impacts etc. [1]. According to OECD 2003 data, the construction industry is responsible 44% of the total material consumption; 40% percent of greenhouse gas emissions which results global warming the human race's greatest environmental impact ever challenged on the Earth [3]. It is also estimated that, operation of buildings constitutes 40% percent of total global energy demand and resource consumption on the earth [1]. According to Kibert (2005), buildings are also responsible for over 10% of the world's freshwater withdrawals, 25% of wood harvest, and 40% of material and energy flows in global scale [5]. According to Sayal et. Al, it is estimated that environmental impacts of buildings will increase to 60% by the year 2030 due to the increasing population of the world [6]. Since there occurred different concerns and have been made various scientific researches about environmental impacts of human-made structures which created awareness in different scientific groups and also in society. The integration of built environment with natural environment; efficient use of energy, materials,

water and other biological resources and reducing the impact on ecological systems got importance [3, 7, 8, 9]. According to these raising awareness various approaches and concepts have taken place in the construction sector such as; sustainable construction; energy efficient design; ecological design etc. [3, 7, 8, 9].

This paper discusses the advantages of steel structures in the context of sustainable construction. This study provides an overview on sustainable construction and its common criteria and focuses on the advantages of steel structures and examines steel structures through the life cycle stages according to the sustainability criteria. As the conclusions this paper highlights the key points.

2. What is sustainable construction?

The sustainable development movement has been evolving for almost 25 years all over the world [12]. The United Nation World Commission on Environment and Development (WCED-1987) defines Sustainable development as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" in the report "Our Common Future" which is also known Brundtland Report [13]. After Brutland report, an environmental movement of sustainability began to affect all segments of society including construction industry and the concept of sustainability became a part of the environmental vernacular [14].

The construction industry, in which large number of actors occupied in the process of activities from the design and development phase to the end of life deconstruction or demolition is defined as "all parties that design, build, alter, or maintain the built environment over its life cycle: developers, planners, architects, engineers, builders, and operators" by Kibert [14, 15].

The requirement for sustainable development in the construction industry has got importance in the last decade due to the major resource consumption and contamination buildings generate and other damages such as large quantities of waste, energy consumption, noise caused by construction operations etc. (see Table 1, "Impacts of the built environment") [5,14].

The first definition of sustainable construction was declared during the First International Conference on Sustainable Construction which were held in Tampa, Florida, in November 1994, by Kibert [17]. According to Kibert, Sustainable construction is one component to create an sustainable environment and means "insuring that we leave the world in a condition that will allow future inhabitants to enjoy at least the quality of life we have experienced" [14]. At first International Conference on Sustainable Construction six principles of sustainable construction, which later amended to seven principles by CIB also defined [12].

The sustainable construction was defined as "...creating and operating a healthy built environment based on resource efficiency and ecological design.". Seven Principles of Sustainable Construction, which would be a guide for decision making during each stages of the design and construction process throughout the building's entire life cycle were also articulated by the Conseil International du Bâtiment (CIB) In 1994 [12]. Principles of Sustainable Construction which can be applied in whole life cycle of building, from planning to end of life (refers deconstruction rather than demolition) follows [12];

1. Reduce resource consumption (reduce);
2. Reuse resources (reuse);
3. Use recyclable resources (recycle);
4. Protect nature (nature);
5. Eliminate toxics (toxics);
6. Apply life-cycle costing (economics);
7. Focus on quality (quality).

In Agenda 21, Sustainable construction is referred as a holistic process aiming to restore and maintain harmony between the natural and built environments and defined as "means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation

Table 1: Impacts of the Built Environment [Adopted from 16]

Aspects of Built Environment:	Consumption:	Environmental Effects:	Ultimate Effects:
• Siting • Design • Construction • Operation • Maintenance • Renovation • Deconstruction	• Energy • Water • Materials • Natural Resources	• Waste • Air pollution • Water pollution • Indoor pollution • Heat islands • Storm water runoff • Noise	• Harm to Human Health • Environment Degradation • Loss of Resources

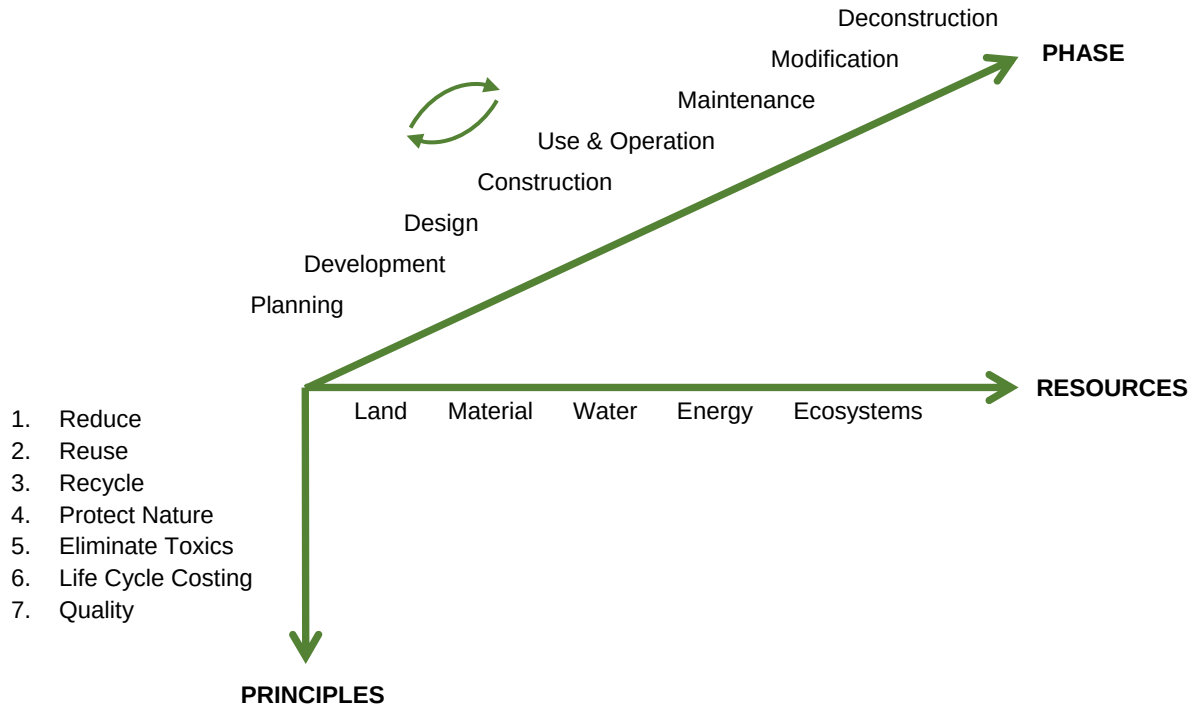

Figure 1: Framework For Sustainable Construction [Adopted from 12]

of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste" [18]. (See Figure 1 for the framework for sustainable construction) The Sustainable construction which should balance human needs with the natural and cultural environments is a vital agent to preserve the resources on the earth and promote quality life across the globe [5, 19]. Achieving the goal of sustainable construction doesn't mean restricting the total amount of construction, it is about paying more attention to the design and selection of sustainable building materials which also improves living quality, user health and comfort [24, 25].

It is stated that for implementation of energy efficient design not only to the operating energy of a building but also to the material choice in other words embodied energy is very important by Thormark (2006) [24]. The materials used for the structure represent generally, more than 50% of the total embodied energy of the building [24, 25] There occur various environmental impacts during the whole life cycle of building and the choice of materials that is used in building will impact the overall performance. According to Franzoni (2011), the building material selection plays an important role for sustainable development in construction industry [24].

Environmentally Friendly Building Material and product Selection for sustainable building projects is used to be a major challenge for project teams. Usually the characteristics of Environmentally Friendly Building Material and products for sustainable building are the ones such as locally and regionally available, including high recycled content and reused building materials. However, to prioritize and combine these attributes into a project for product selection were a problem which should be deal with [12].

Although there are various studies managing sustainable materials selection in construction industry, there is no globally accepted definition of "sustainable building materials" which makes it very difficult to establish principles and guidelines to implement the principles and goals of sustainable development for building components and materials [24, 28, 29].

In order to make appropriate decisions that will improve the creation of the built environment, there is used technical criteria for material selection process of buildings (See Table 2. For "Sustainable Construction Strategy").

According to Kibert these criteria are [14]:

- Embodied energy content;
- Greenhouse warming gases;
- Toxics generated/content.

Although there is no clear consensus about criteria for the environmentally preferable building materials and products. There are several tools to assist environmentally building material selection process, the most familiar of these tools is LCA which is also used in

Table 2: Sustainable Construction Strategy [Adopted from 12 and 27]

Sustainable Construction Strategy	Descriptive Information
Maximize Durability	Minimizes use of new materials in connection with minimize resource depletion; transportation; and processing energy, waste, and other environmental effects.
Minimize quantity of materials	Using the minimal amount of materials also reduces the environmental impact of products that is manufactured from raw materials.
Maximize The Energy Efficiency and Renewable Resources	Using the materials and components which is created from renewable resources that enable the opportunity to close materials loops.
Maximize Future Recyclability	Mechanical fastening should be preferred to adhesive/solvent welding and connections should be easily disassembled.
Maximize Future Reusability	Design for deconstruction (DfD). Deconstruction and reuse of building materials and components reduces the environmental impacts due to the requirement minimal resources for production and reprocessing.
Maximize the maintainability	
Maximize the recycled content	Maximizing the recycled content of building material and products the closes materials loop in construction
Maximize the use of local materials/regional material	Locally manufactured products reduce the transport and the overall environmental impacts of materials.
Minimize embodied energy	Efficient use of a material avoid wasting the embodied energy.
Minimize the use of hazardous natural and of synthetic chemicals	Minimize the use of noxious chemicals (asbestos, lead, etc.)

crafting EPDs which is a verified document which include environmental data of products based on life cycle assessment (LCA) and other relevant information, the commonly accepted approach for comparing products in the decision-making stage [12, 30].

3. Steel structures and sustainable construction

Today, the steel is a widely-used material in buildings such as multi-storey residential buildings, skyscrapers, bridges, commercial buildings etc. due to the strength, durability, usability, low cost, flexibility, aesthetics, low weight and performance characteristics. Therefore, the widespread usage of steel makes it an important issue to evaluate steel structures in life cycle on environmental aspects. Structural system constitutes often more than 50% of a building's embodied energy which is a standardized quantity and an important indicator allows you to make a comparison in terms of environmental impact [3, 26, 39, 40, 41]. In this context, it can be also said that for sustainable buildings and to reduce environmental impacts, reducing the embodied energy of the system plays an important role [3]. There also occur considerably energy consumption and carbon dioxide (CO_2) emissions during the production process of steel. On average, it is known that during the production of 1.8 tons of steel, there occur one ton of CO_2. According to International Energy Agency's 2010 data, iron and steel industry constitute 6.7% rate in total carbon dioxide (CO_2) emissions on the earth. Steel industry is also responsible for a significant amount of resource consumption on the earth. According to US Geological Survey (held in 2009), 2.2 billion tons of iron ore is extracted from the ground on an annual to produce steel used in buildings, bridges and other infrastructure and also It is estimated that current accessible iron ore reserves are 150 billion tons on the earth. According to Brown's estimates, accessible iron ore reserves equates to 64 years based on an annual steel demand rate in extraction. As well as depletion of iron reserves, in literature survey, it has been found that the production phase of structural steel plays an important role in energy consumption and environmental impacts. For this reason, evaluation the recovery facilities of structural steel is thought to be so significant in environmental burden [1, 3, 42]. The advantage of structural steel is can be grouped as: Architectural Advantages, Structural Advantages, Constructional Advantages and Sustainable Advantages [3, 43]. In this study it is found adequate to mention the sustainable advantages of steel in the context of study.

For sustainable development, it is declared that cyclic processes must replace linear ones in UNESCO Conference (1992-Rio). Steel is the unique structural component which can be reprocessed [44]. Steel is a material which has almost a closed-loop material cycling [2, 45]. Closed loop refers a process of keeping materials in life cycle by reuse and recycling rather than disposing

them at the end of the product or building life cycle [12]. For sustainable buildings, material should be kept as long as possible in their own cycle. This can be implemented in two phases which are; during "the design stage" and "demolition stage" [2, 46]. For this reason, increasing the of structural steel reuse and recycling possibilities become more of an issue.

The sustainable advantage of steel can be summarized as [2, 47]; Material efficiency which means less natural recourse consumption, less transports, less energy consumption and less emissions; Durability; Recyclability which means less natural recourse and energy consumption, less waste production and less emissions and Dry and lean construction which means less energy consumption, less emissions, less waste, less health hazards and better construction conditions (See Table 3 . Attributes of Steel in Sustainable Construction).

3.1. The sustainability of steel structures through the life cycle

The sustainability of steel structures will be evaluated in four phases in life cycle as (See Fig. 2 For the Sustainability Criteria in Life Cycle Of Steel) [47]: Design Phase; Construction Phase; Operation and Maintenance; End of Life Phase.

Design Phase: The proper design is fundamental for sustainable construction. The decisions made at initial design are directly related to impacts of buildings and have effects on overall sustainability [47]. In this phase creating flexible architectural plans, efficient and environmental building friendly material selection should be aimed and efficient use of natural resources and energy consumption should be also taken into consideration [48]. It is widely known that generally operational energy of buildings is higher than embodied energy. For instance a 60 year design life air conditioned office buildings the operational energy is 10 times higher than it embodied energy. It is possible to decrease the operational energy in design phase by creating optimum shape and orientation [49]. There are also two main approaches for sustainability of building materials and components in design Stage These are "Design for Deconstruction" (DFD) and "Design for Recycling" (DFR). DFD is an approach which aims to reuse building component and materials by choosing a dismountable building system in which component can easily be separated and directly reused. DFR is an approach which takes in consider what to do with the building materials after demolition in design phase. Demolition stage covers all the precautions which is taken in demolition site to improve recycling opportunity [2, 46].

Construction Phase: In construction phase There occur various environmental impacts such as waste production, noise, dust, pollution and traffic congestion. One of the most effective ways to reduce these site impacts is to maximizing offsite prefabrication. All steel components are manufactured offsite and brought to site as ready for assembly. Steel prefabrication not only reduce environmental impact but also provides safe, efficient, high quality and fast construction. Prefabrication and factory based production also enables waste reduction on site and during the manufacturing process depending on the computer aided design and semi or fully automated production lines [3, 49].

Operation and Maintenance: Operational energy of a building is the key issue of environmental effects in life cycle sustainability in construction and also sustainability. Thermal efficiency should also supplied for sustainable buildings by reducing the heat loses in building envelope; reducing cooling loads, using energy creation system etc. Steel structures can supply well-insulated details and solutions. Durability is another important factor for sustainability in operation and maintenance phase of building. Durability supplies long

Table 3. Attributes of Steel in Sustainable Construction [47]

Attribute	Comment on Steel Construction
Usability	Steel Construction is prefabricated in efficient factory processes with minimum use of resources and enables long-span, high-rise and flexible buildings.
Speed	Steel structures are installed rapidly on site which reduces local disruption.
Weight	Steel structures are light and therefore efficient on materials, energy, transports and emissions. The low weight also enables vertical extension and optional location.
Waste	Steel structures is very material efficient, generation low amounts of waste and most of waste is recycled.
Performance	Steel is high performance, dimensionally accurate material produced with modern computerized technology.
Logistics	Steel structures are delivered to site just in time for installation and can be produced locally.
Durability	Steel structures are high qualified and long lived.
Health	Steel construction is dry constructions, low emitting materials, controlled and safe process and leeds to high quality architecture.
Recyclability	Steel can be recycled without quality lose
Reusability	Steel building component can be dismantled and reused.

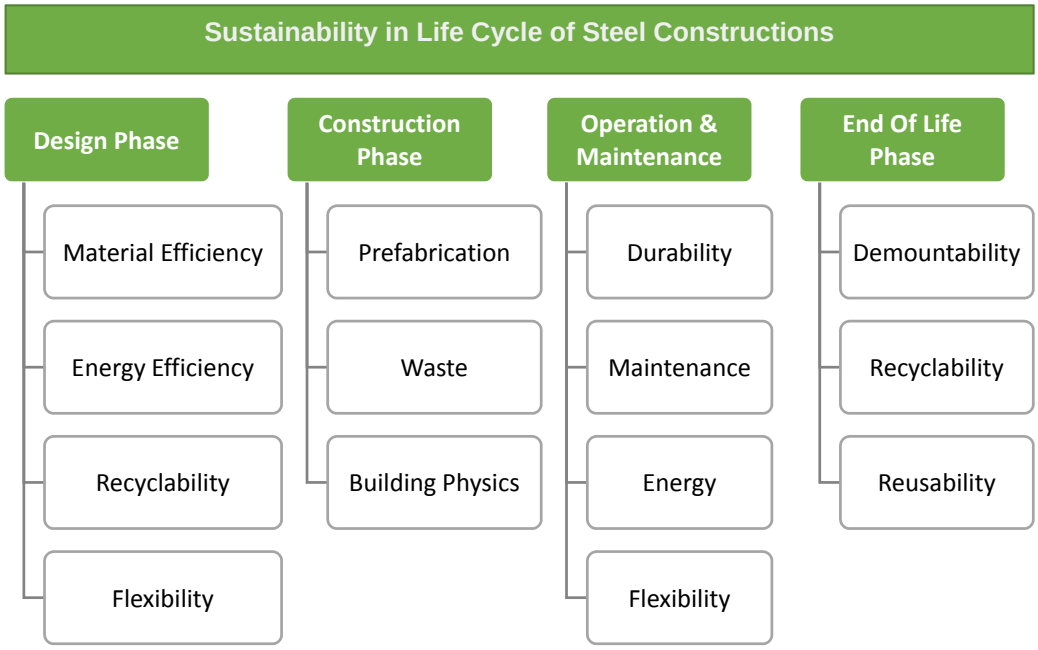

Figure 2. Sustainability criteria in Life Cycle Of Steel [Adopted from 47]

lasting functionality and safety for building users. The steel construction offer easy maintenance and long-term production [47, 49].

End of Life Phase: As a part of the building, steel lives longer than the construction itself. Due to the this specialty, after the deconstruction, steel can be reuse as a new product in another building or recycled. [47]. There are three forms of reuse in building.

These are [2, 4]:

- Reuse an existing structure (adaptive reuse);
- Reuse existing building in a new location by moving whole building or part of the building;
- Reuse building components.

Building material and component reuse is an effective way for reducing the embodied energy of buildings. It is estimated that reuse saves about 95% of the embodied energy in buildings. Recycling also saves embodied energy and environmental damage of mining of material and transportation impacts [2, 50]. To recycle the scrap steel it is required energy for melting which means considerable CO_2 emissions. However it is required energy for deconstruction, transportation and adjustments recovering the structural steel for reuse. Both of "Recycle" and "Reuse" reduce the amount of primary resources which is required to produce per unit of component; waste generation per unit of component; total non-renewable energy used per unit component.; emissions such as greenhouse gas but beside these, although the energy requirement for deconstruction and related activities, reuse of structural steel components cause less hazardous environmental impacts. [2, 44, 51].

4. Conclusion

As an resource-intensive industry, the construction industry constitutes an important part in environmental impacts which have badly influences on human health and natural balance. To reduce the environmental impacts caused by building industry "sustainable construction" concept gets importance. As the key points of this study, it can be summarized as;

- It is important to implement principles and methodologies of sustainable construction by using sustainable and environmentally friendly building materials components, structures and systems.
- It is also important to increase recovery potentially of the building materials and components at the end of their life cycle to increase overall sustainability.
- It is important to have an holistic approach on evaluation of building through all life cycle for overall sustainability.

It can be concluded that, Structural steel is an environmentally friendly building material due to the durable, recyclable and reusable characteristics which mean less environmental impacts compared with the other modern structural components. The usage of structural steel to implement the sustainability criteria

from the extraction and beneficiation of raw materials, through the design and construction of buildings to the end of life is very important for overall sustainability.

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