QATAR UNIVERSITY

COLLEGE OF ENGINEERING

TOWARDS SUSTAINABLE FIFA WORLD CUP™ 2022: A CRADLE-TO-CRADLE SOCIAL LIFE CYCLE IMPACT ASSESSMENT FOR REUSABLE CONTAINER STADIUM IN THE STATE OF QATAR

BY

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ABSTRACT

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Title: Towards Sustainable FIFA World Cup 2022: A Cradle-to-Cradle Social Life Cycle Impact Assessment for Reusable Container Stadium in the State of Qatar

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Restorative circular economy practices in green stadium construction act as a shrewd economic move in reaching net-zero carbon emission goals for Qatar, the 2022 FIFA World Cup™ host. This research intends to conduct the first social life cycle impact assessment for Ras Abu Aboud stadium, a reusable shipping container stadium in Qatar, that will be the host to 40,000 spectators from around the world, which will then be dismantled after the world cup tournament. In this regard, this research effectively utilized the Ecoinvent version 3.7.1 and real construction data of Ras Abu Aboud stadium to quantify the human health impacts by applying the ReCiPe 2008 End point impact model under the Egalitarian perspective. The findings of this research presented the contributions of various life cycle phases such as the production of materials and resources, construction, operations, and end-of-life management. The results revealed that the majority of social impacts came from the production phase. The damage to human health from the construction and the operation phases were found to be significantly lower than that of the production phase by 85% and 98.6%. The end-of-life management under a circular economy strategy was assessed to reveal the benefits of circular economy applications in sustainable construction from a pessimistic, and optimistic approach. Finally, a sensitivity analysis was conducted that identified human toxicity as the most sensitive impact category across the production and construction phase of the life cycle. While, climate change was the most sensitive among all the other impact groups in the operations phase. Later, the legacy aspect of reusable stadium design and construction fostered by Qatar's FIFA world cup organizing committee is presented and its potential benefits for the society are discussed. This research thus promotes professional growth in the area of sustainable building practices, supporting United Nations “Urban Development program” to promote environmental-related research in Qatar and future FIFA host countries.

DEDICATION

I dedicate this thesis to my beloved husband who has offered unconditional encouragement and support during the past years of my master's degree journey. A very special thank you for your emotional support as I shared the roles of wife and mother, to the competing demands of my work, study, and personal growth.

To my son, for the time taken for this research and for granting me unconditional love and happiness.

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ABBREVIATIONS

CC	Climate Change
CE	Circular Economy
CF	Characterization Factors
CO_2	Carbon Dioxide
DALY	Disability Adjusted Life Years
DEA	Data Envelopment Analysis
ELCA	Environmental Life Cycle Assessment
FIFA	Federation Internationale de Football Association
GHG	Greenhouse Gas
GWP	Global Warming Potential
HT	Human Toxicity
IR	Ionizing Radiation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compounds
OD	Ozone Depletion
PMF	Particulate Matter Formation
POF	Photochemical Oxidant Formation
RAA	Ras Abu Aboud
RoW	Rest-of-the-World

SCDL	Supreme Committee for Delivery and Legacy
SETAC	Society of Environmental Toxicology and Chemistry
SLCA	Social Life Cycle Assessment
S-LCIA	Social Life Cycle Impact Assessment
SMoC	Social-impact Model of Construction
UNEP	United Nations Environment Program

CHAPTER 1: INTRODUCTION

The 2022 FIFA World Cup is a vital mega-event that represents an important milestone in Qatar’s development, and sets a unique opportunity in delivering legacy and sustainable prosperity to the state with respect to Qatar National Vision 2030 aspirations. Preparations are set under process mainly in construction sector to deliver 2022 World Cup on time according to FIFA requirements. Large-scale construction projects like stadiums are responsible for massive carbon emissions globally. Academics, governments, and businesses around the world are actively researching potential methods to reduce this negative environmental effect by using green construction strategies. However, sustainable construction goes far beyond environmental and economic concerns and has other tangible outcomes namely in social sphere. Vast breadth of thinking is necessary to understand the social aspects of design and quantify the possible outcomes, leading to improved quality of life for the local community.

The subsequent sections will provide a background overview for sustainability practices and impacts of past World Cups, then present significance of circular economy strategy used in green stadium construction. At the end of this chapter, the research objectives and thesis outline are demonstrated.

1.1 Sustainability Aspects of Past World Cups

The concept of sustainability has become a major concern in societies and governments in recent years. According to Talavera et al. (2019), sustainability can be identified as an achievement not only on people and planet but also a tool to meet the economic, social, and cultural needs of all involved stakeholders and the hosting country. Sports mega-events such as “*Federation Internationale de Football Association*” (FIFA) World Cup tournaments have been actively embracing this sustainability trend (Death, 2011). World cup mega events utilize substantial amount of resources leaving a prolonged impact on the host state and neighbors. While organizers of the event are mainly focusing on the event itself, it is the government that is left with the task of employing sustainability (Preuss, 2013).

First recognized FIFA World Cup to apply sustainable greening agenda was Germany 2006, where the “Green Goal” initiative was created with goal to reduce the environmental impacts related to World Cup organization (Ackermann, 2011). It focused on four main areas namely energy, sustainable transport, water and waste management. According to report results Germany 2006 achieved carbon-neutrality, however they did not take account of the international travel carbon emissions for spectators and other related parties in their calculations ,which is a major part of total carbon emissions (FIFA, 2006).

After Germany 2006 set the new standard, it was difficult for a developing country burdened by poverty and social inequality like South Africa to surpass. A different priority was set in South African 2010 World Cup which focused on social and economic development rather than environmental mitigation. As a result, the tournament showed good performance although it never reached the anticipated potential. Most significant impacts of the tournament included development of public transport systems and infrastructure, jobs creation, and tourism boost. However, it lacked organization and it raised questions due to spending public money on expensive “white elephant” stadiums in a country which is in desperate need of adequate and safe housing (Death, 2011).

The 2014 World Cup in Brazil had similar impacts as South Africa. Again, an emerging country seized the opportunity to host the tournament in hopes of leaving a positive impact on the national economy by creating sustainable job opportunities, improving hotel and tourist industry, and accomplishing projects in construction by upgrading rail and road transport infrastructure. Instead, there was a slowdown in national economy and criticism of human rights violation was raised. In the midst of angry protests and financial concerns the environmental aspect was mostly neglected (Paula, 2014).

The most recent World Cup held in Russia 2018 has a quite modest amount of research addressing the sustainability results and various issues of the tournament, but according to the official FIFA report the residents of host cities have observed a positive impact the tournament left on urban infrastructure development and raised awareness on recycling, climate change, and biodiversity through the held campaigns (FIFA, 2019). The event gave Russia the opportunity to revive the cities away from Moscow urbanistically and participate in green building projects both domestically and in other countries as part of carbon footprint offsetting strategies (Talavera et al., 2019).

As Qatar is set to be the next host of World Cup 2022 tournament, key sustainability issues associated with “triple bottom line” concept namely economic, social and environmental spheres must be given an equal priority to ensure that the event leaves a positive legacy on the host country and its residents.

1.2 Environmental Impacts of World Cups

In the last decade, global climate change and environmental concerns gained an increased interest particularly in terms of their impact on host cities, residents, and audiences. Consequently, sustainable approaches associated with mega-events are starting to get more recognition and are primarily presented in the biding process (Homes et al., 2015). Since 2006, greening programs are actively concentrating on environmental projects including health enhancement, pollution reduction, management of waste and water recycling, and application of environmental standards.

Although in some cases like in South Africa 2010, the environmental proposal to use waste management, energy efficient projects, biodiversity preservation ,and city beautification among others was not fulfilled due to shortage of funding (Baroghi et al., 2021).

By their nature, mega-events result in variety of positive and negative impacts both locally and worldwide. A great deal of literature supports the idea that mega-events can cause essential positive environmental outcomes. Most frequently the positive aspects are associated with the sustainable construction of new infrastructure and buildings such as stadiums, airports, transport development, and upgrades in water and sewage. In many cases, these developments might have not been considered feasible or necessary if it was not for the event (Ahmed and Pretorius, 2010). However, finding a balance between construction regulations and environmental performance can be challenging. When new structures are constructed for the event, they must comply to design guidelines of architectural design, safety regulations, execution time, thermal, acoustic and other performance metrics. Despite these regulations, vital planning is required to support sustainable practices that would guarantee good environmental performance like waste management, air pollution and other substantial issues (Gallo et al., 2020).

It is worth pointing out that one of the greatest environmental threats that can be triggered by construction development and mass tourism in mega-events is the associated carbon and ecological footprints, which emanate into irreversible environmental and social impacts (Ahmed and Pretorius, 2010). This attention to carbon emissions has led Qatar to take on the commitment of delivering a carbon-neutral 2022 FIFA World Cup which in return would leave a sustainable legacy for the country (FIFA, 2019). Although this may involve multiple challenges for Qatar due to its arid climate, high economic dependance on fossil fuels, and limited resources of water and others (Talavera et.al, 2019).

There is abundant literature that focuses on environmental impacts in mega-events including carbon footprint that has been explored in case studies of Beijing 2008 Olympics (Wu et al., 2011) FIFA World Cups (Pereira et al., 2017), environmental consequences in 2003/2004 Football Association Cup (Collins et al., 2007), and quantitative impact assessments for environmental impacts (Collins et al., 2009), etc.

Surprisingly, other sustainability pillars namely social and economic sustainability, are not given the same particular attention at present, even though they have as equally vital significance as environmental impacts and are all interrelated (Talavera et al., 2019).

1.3 Socio-Economic Impacts and Benefits of World Cups

It is frequently argued that the prime motive for the decision of a country to host a mega-sporting event is the economic benefits of the event on the local market. FIFA World Cup events are not only attracting global interest and media attention for the host countries, but also are a leading cause behind shaping tourism patterns and introducing new tourism destinations, promoting investments and business alliances, and creating a positive socio-economic impacts. The beneficiaries of these impacts involve several stakeholders namely residents, local businesses, community organizations, and any other educational or financial organization contributing to the delivery of the event. Different stakeholders can have different perspectives of impacts; thus, they are not a standard set, they differ from one host country to another depending on the economical, social, and cultural backgrounds. These impacts can be both positive and negative (Hermann et al., 2012). An indication of the potential economic positive and negative impacts for the hosting country are illustrated in Table 1.

Table 1. Positive and negative economic impacts of tournaments on host countries

Positive Impacts	Negative Impacts
• Public wellbeing improvement through the provided employment opportunities	• High construction costs
• Local business opportunities and corporate relocation	• Investments in unnecessary structures
• Attraction of business development	• Increase in property rental
• The event provides long term promotional benefits for the area	• Non-permanent increase in employment and business opportunities
• Event fosters public spending on sports venues and activities	• Public money spent on the event rather than community needs
• Increase in property value	• Under-utilized infrastructure
• Local suppliers of goods and services for the event gain economic benefits	• Increase in living costs, transport, and other goods during the event period
• Promotion of local tourism	• Inflation and tax burdens

Sources: (Preuss, 2006); (Ntloko and Swart, 2008); (Hermann et al., 2012)

Hermann et al. (2012) stated that potential host countries focus on delivering a successful event and that the hope of creating economic opportunities lead to ignorance of the possible negative economic impacts that might arise. The value of wedges that is generated by the event has a critical advantage for the country government and is frequently set as the main object when planning for hosting events. Consequently, the governments aim to reap the substantial advantages including the prospect of undertaking infrastructure development projects, creation of jobs, and the attraction of business investments and potential income generation. In the effort to achieve valuable economic impacts, social issues are often neglected. However, exploring social impacts in particular the residents' perception of event hosting is even more significant for the community than economic growth. A brief overview of the possible social impacts is provided below in Table 2.

Table 2. Positive and negative social impacts of tournaments on host countries

Positive Impacts	Negative Impacts
• Increase in sports activities participation by the community	• Poor behavior of the event viewers and fans
• Building civic pride and social cohesion	• Vandalism and possible property damage
• Increased community involvement	• Substance abuse
• Recognition of host country internationally	• Negative publicity
• Demonstration effect on fitness and health	• Noise
• Providing the chance to expose cultural identity and showcase local traditions	• Traffic congestion and social pollution which drives locals to leave host city during the event
• Volunteering opportunities	

Sources: (Preuss, 2006); (Ntloko and Swart, 2008); (Schofield, 2017) (Hermann et al., 2012)

Social and cultural impacts are often an under-researched in mega-events. These shortcomings can clearly be understood since both the impacts are considered intangible and hard to measure and manage; hence they are often called “soft” impacts (Perić and Vitezić, 2019). Among these intangible social impacts is residents’ perceived quality of life, social pride and cohesion, and increased participation potential in sports activities (Kersulić et al., 2020). Recently, there has been a growing attention for attaining community-wide support in mega-events. Past experiences have showed that in some cases namely in South Africa 2010 and Brazil 2014, the privileged were gaining benefits at the expense of the poor which lead to socio-economic inequalities. Major negative consequences were evident throughout the tournaments which included: forced evictions of residents to city outskirts with very limited compensations and expected risk of homelessness, labor human rights violations with high level of exploitation, the loss of informal traders livelihoods, and questionable legacies (Maharaj, 2015).

For Qatar, social and human issues may represent a great challenge because it can drastically affect the branding of the sports event, and the image attractiveness of the country and region. The accusations of human rights and abusive migrant workers practices by several reports, is alarmingly showing a negative perception of the country with lack of respect for labor rights and may tarnish its reputation of an appealing country as a business destination. Although these practices have not been specifically linked to World Cup construction works; social impacts provide a plethora of content to investigate at the research level on the healthy promotion of positive legacy to the state (Talavera et al,, 2019).

1.4 Circular Economy and Green Design in Construction

With the rapid growth in construction industry in the last decades, the negative impacts that the construction sector is leaving on our natural environment is becoming alarmingly evident. In many countries, approximately half of the existing resources are consumed during the design, construction, and maintenance of the built environment (Finch et al., 2020). According to Ürge-Vorsatz and Novikova (2008) the building sector is contributing to nearly 33% of the total global carbon dioxide (CO_2) emissions, making it the second largest carbon emitting sector after industry in both developed and developing countries. Consequently, this dilemma suggests that environmentally friendly strategies must be implemented to maintain societal health and welfare and provide opportunity for current and future generations to flourish (Al-Hamrani et al., 2021; Kucukvar et al., 2014b; Kucukvar et al., 2014c).

Recent trends in construction industries and architecture are moving towards the application of sustainable green design that aims to reduce the possible negative impacts (Kutty et al., 2020a; Park et al., 2015; Shaikh et al. 2017). At present, there are various eco-friendly solutions applied in buildings that are environmentally, economically, and socially considerate. These applications include: intelligent façades, passive solar systems, vertical planting, energy efficient designs, and use of recycled materials, just to name a few (Pons-Valladares and Nikolic, 2020). In the case of the World Cup tournaments, FIFA has detailed the green building principles and certification requirements in their ‘Technical Recommendation and Requirements’ book. According to FIFA (2011), the newly constructed stadiums must be eligible for LEED certification incorporating sustainable and green building design measures that include: use of energy efficient strategies for lighting and air-conditioning, passive design that reduces heat and improves air circulation, use of non-toxic and recycled materials, and aim to reduce total waste. Thus, with proper analysis, design, and operational strategies the prospect of stadium construction can become a positive experience during construction and throughout the stadium’s lifespan.

Ever since the revolution of industry, the conventional linear economy model has been extensively applied in society, however due to its limitations this production and consumption model is becoming incredibly unsustainable. Most recently, businesses and governments around the globe have come to notice that resources are not infinite and are actively reaching planetary boundaries. The continuous exhaustion of natural resources into waste via production activities is contaminating our ecosystem (Nandi et al., 2020). Figure 1, seen below, demonstrates the flow of resources in a linear economy model where waste is discarded and dumped in landfills.

Figure 1. Materials flow in linear economy model

In the light of the challenges and the underlying limitations imposed by the linear economy model, the scientific and global policy communities are gradually attracted by the concept of circular economy (CE). Since the built environment is causing a carbon stock in cities, the use of recycled and bio-based building material generated from waste can play an essential role in climate change mitigation (Caldas et al., 2021). Circular economy can be defined in numerous possible ways, though in line with construction sector it can be described as a restorative design model that uses circular flow of materials to guarantee high utility and value of resources at all times (Geissdoerfer et al., 2017). Figure 2 illustrates the circularity of resources in circular economy model.

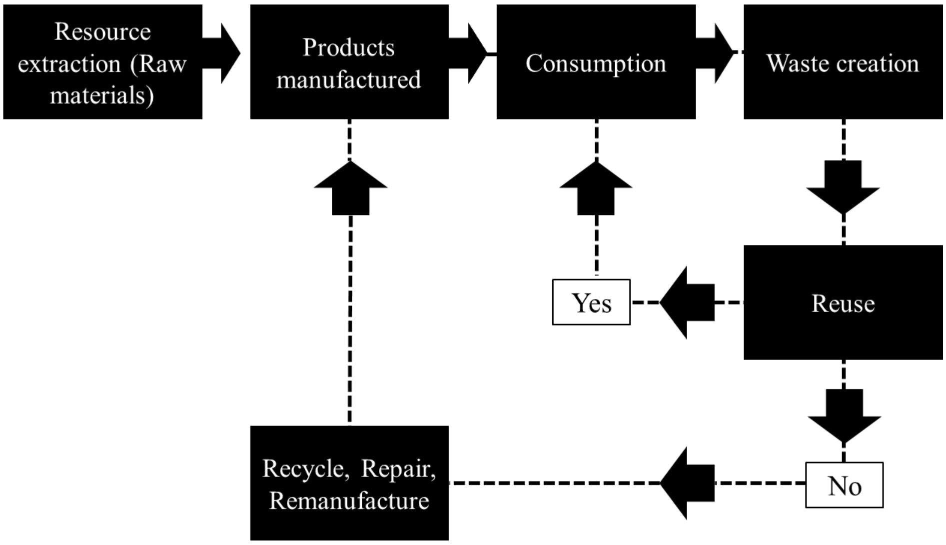

Figure 2. Materials flow in circular economy model

1.5 Research Objectives

The current research is set out to investigate and quantify the social impacts of reusable stadium construction by exploring a novel hybrid social life cycle assessment approach. The research relies on data collected for Ras Abu Aboud reusable container stadium. Human health impact was selected as the main end point inventory indicator. This data was then processed using ReciPe 2008 model to illustrate the social benefits induced by the innovative construction of container stadium and reveal the potential damages in each life cycle phase. Thus, the finding of this research will support decision-making for policymakers aiming to better understand the sustainability of the project considering the social aspects. The objectives of the thesis are as follows:

a) Identify possible knowledge gaps in the area of sustainable construction designs for world cup stadiums across the globe through a systematic literature review.

b) Conduct a Social life cycle impact assessment (S-LCIA) using ReciPe 2008 model/End-point impact method to quantify the human health related damages associated with the Ras Abu Aboud stadium construction case study.

c) Identify the significant contributors across each mid-point impact categories and the potential impact categories that inflict damage to human health across each phases of the life cycle.

d) Conduct a sensitivity analysis to identify the most sensitive impact categories using volumetric changes to the most significant contributors across each life cycle phases.

e) Propose End-of-Life scenarios to apply a cradle-to-cradle perspective backed with policy recommendations for Ras Abu Aboud stadium and similar demountable stadiums.

1.6 Thesis Structure

This thesis is wrapped around five chapters. *Chapter 1* starts with a general introduction about sustainability in past world cups and a brief about circular economy.

Additionally, it presents the research objectives, and thesis organization.

Chapter 2 represents the literature review which explains the applications of circular economy in construction and discusses the subsequent environmental benefits. Further, the literature review explores the adaptation of environmental and social life cycle assessment methods used in estimating the potential environmental and social impacts through the project's life cycle. The last section of this chapter provides an emphasis on social life cycle methodology framework and application to show the core approach for the research.

Chapter 3 presents the detailed methodology adopted in the research, which includes: the goal and scope definition, structuring the system boundaries of S-LCIA, life cycle inventory and mid-point impact categories used in understanding the damage inflicted on human health and, detailed method and outline for quantifying the human health related damages using the ReciPe 2008 impact assessment model.

Chapter 4 includes the results and brings out the significant contributors across each mid-point impact categories and the potential impact categories that has inflicted damage to human health across each phases of the life cycle and to what extend for the Ras Abu Aboud stadium case study. This section uses graphical representations to visually interpret the results. The results of the sensitivity analysis are also detailed in this section.

Finally, *Chapter 5* summarizes the research, proposes the end-of life scenarios, and recommends policies for circular stadium construction design from a future perspective point of view.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Stadium construction is gaining more and more attention in academic research and studies, whether from political, economic, environmental, and even social aspects, aligning with the current trends of shifting efforts towards sustainable approaches of development (Alegi, 2008; Al-Hamrani et al., 2021; Jones, 2002; Kellison et al., 2015; Miller, 2002; Safir, 1997; Onat et al., 2017; Kucukvar and Tatari 2013). Construction is considered one of major sectors that have impact on sustainability; economically, socially and the environmentally (Dong and Ng, 2016; Medineckiene et al., 2010; Stasiak-Betlejewska and Potkány, 2015; Kucukvar et al., 2016b; Kucukvar et al., 2017). Recent statistics revealed that construction contribute to 50% of climate change happening, 23% of air pollution and 50% of landfill wastes. Thus, affecting the overall natural resources in general (Gocontractor, 2020).

There is a noticeable imbalance of resources that is expected to get worse if no actions were taken. Challenges such as demographic trends worldwide, infrastructure needs associated with the increase in population, climate change and many other are only indicators of the potential risks associated with ongoing resources consumption. Thus, the reliance on large quantities consumption of resources does not seem to be functioning anymore (MacArthur, 2013). The standard model of production, which is based on the three aspects of; take, make and dispose is not effective anymore (McDowall et al., 2017). In other words, the linear way of resource consumption where more production requires more resources and produces more waste should be replaced with a circular method where resources are initially obtained from the environment but later on waste produced becomes the resource itself (Bonviu, 2014).

Accordingly, circular economy concept is highly adopted and considered at a global level, where both private sector and governments are focusing efforts on resource related sustainable innovations (Preston, 2012). Also, many sustainability assessments are being conducted to analyze various impacts, with the Life Cycle Assessment (LCA) method being mostly used to evaluate the environmental, as well as social and economic impacts (Corona et al., 2017).

This chapter covers an overview of previous literature and existing knowledge on research topics, introducing the concept of CE and its historical development, as well as various applications in construction. LCA as a tool for assessing CE, relative phases, guidelines, and standards. Environment and Social LCAs, their implementations, and limitations, as well as applications within the construction sector.

2.2 Circular Economy Through the Lens of Construction

According to Ruiz et al. (2020), construction and demolition waste is a high focus for many strategies all over the world. Waste management is one of the challenges related to the environment in the sector, as around 30 to 40% of worldwide solid waste results from construction and demolition waste (Jin et al., 2019). Such huge ratio can leave a great impact on the environment, resulting in huge energy consumption, land degradation, water pollution, carbon and greenhouse gas emissions and reduction of resource availability (Akanbi et al., 2018). Therefore, the tendency has turned to implementing CE, which is one of the initial requirements for sustainability (Geissdoerfer et al., 2017). CE is an approach based on principles that are considered scientific or even semi-scientific, including industrial symbioses, cleaner production and the concept of zero emissions (Korhonen et al., 2018). One of these basic principles is the 3R principle that include Reduction, Reuse and Recycle (Ghisellini et al., 2016). Thus, implementation of CE is important to overcome the environmental challenges but at the same time to have a positive impact on economy (Ruiz et al., 2020), by simply optimizing material usage and value during the various stages of material life cycle, resulting in minimizing waste produced (Bocken et al., 2016). According to Deselnicu et al. (2018), CE leading to better allocation and use of resources is beneficial for businesses, and valuable for maintaining resources' preservation for many generations to come.

Geissdoerfer et al. (2017) defined CE as "A regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling". Ellen MacArthur Foundation (2017) in defining CE simplified the concept by stating that it is "based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems". Ellen MacArthur Foundation was established in 2009 aiming to speed up the transition to CE by promoting its idea and applications and collaborating with businesses, academics, policymakers, etc… to spread the concept globally.

The foundation set three main principles for implementing CE. The first one is to "design out waste and pollution", the second is to "keep products and materials in use" and finally the third is to "regenerate natural resources". So far, the foundation was able to build partnerships with worldwide recognized organizations and businesses in various industries such as Google, Ikea, Groupe Renault and many other. Collaborating in the five areas of; "Business", "Institutions", "Governments and cities", "Insight and analysis" as well as "Learning" and "System initiatives". The foundation has various publications on the subject as well with the aim of increasing awareness and application (Ellen Macarthur Foundation, 2017).

One of the most important needs for CE is to reverse the negative impact of economic growth on the environment through the implementation of new practices and technological solutions, leading to satisfying consumers needs more efficiently (Brown et al., 2019). Another objective is to innovate the full chain of producing, consuming, distributing and recovering or products, resulting in better efficient and effectiveness of resources use (Ghisellini et al., 2018). Due to its positive impact, CE is being taken into consideration as a major aspect in developing strategies and policies (European Commission, 2020).

The principles of CE are quite simple, one is to reach a point where there is no waste produced, and it starts with the design phase of the products, considering the use of components that are biological and technical and can be composed or refurbished and reused afterwards. Other principles include: the use of green energy sources, understanding the relationships between various elements so that comprehensive systems are developed (MacArthur, 2013). Most importantly, CE does not consider the impact on the environment alone, but also takes into consideration other aspects including the social and economic during the full lifetime of a resource (Szita, 2017).

Figure 3 represents the life cycle of product’s evolution, the smaller loops such as “Reuse” and “Remanufacturing” consume less resources than the “Disposal”, which consumes more energy, time and cost, and produces more waste and pollution (Mihelcic et al., 2003).

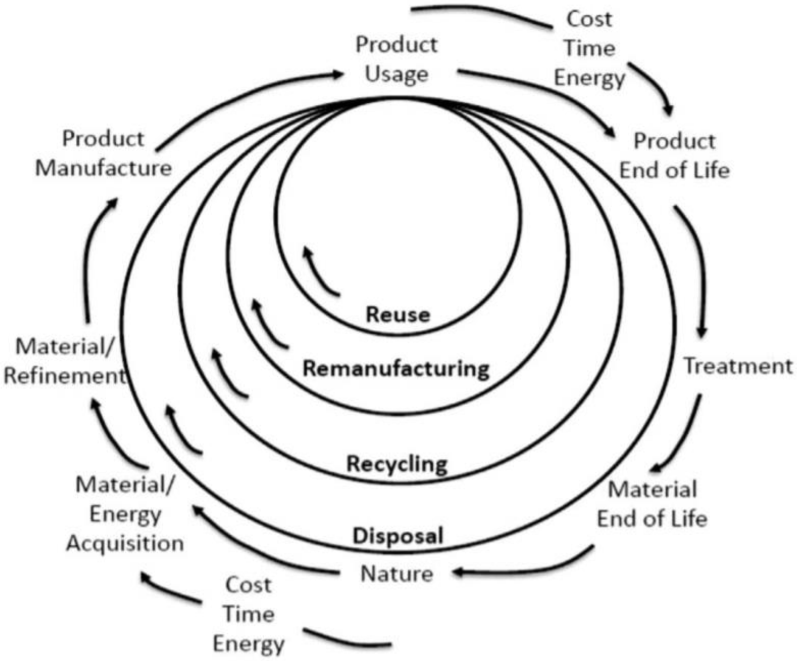

Figure 3. Product life cycle stages (Mihelcic et al., 2003)

2.2.1 Circular Economy: Past, Present and Future

The concept of CE was presented in literature in the mid-eighteenth century (Cardoso, 2018). With the current trends oriented towards enhancing resources efficiency, both European and Chinese policies are actively implementing CE applications and were the first to lead the adoption of CE concept (Merli et al., 2018). The European action plan developed in 2015 covered areas of; production, consumption, management of waste and boosting markets for secondary materials (McDowall et al., 2017).

CE emerged in China in 1990's. However, the concept was officially implemented in 2002 as a new development strategy for China. In 2009 the "Circular Economy Promotion Law" came into effect. In China, current practices are implemented at the various levels covering areas of; waste management, consumption and production. On the other hand, China is also facing some challenges in the implementation of CE such as; need for more advanced technologies and reliable information, need for more law enforcement, weak economic incentives and public awareness (Su et al., 2013). However, there is a slight difference in approaches towards CE adopted by China and Europe, where China considered CE as a part of greater response to environmental challenges focusing on scale and place, Europe is mainly focused on waste and resources, considering the economic impact CE will have (McDowall et al., 2017).

There are global efforts as well in regards to promoting and implementing CE, among them is the “Circular Economy 100” initiative, a platform established with the aim of unifying global efforts of companies, inventors, universities, etc.. to accelerate CE application (Bonviu, 2014).

2.2.2 Circular Economy Applications in Construction

When it comes to construction, it is proven that such sector has a great impact on sustainability (Smol et al., 2015; Tatari and Kucuckvar, 2012; Kutty et al., 2020b), and when compared with other sectors it has a high potential of successfully adopting CE (Brambilla et al., 2019).

The vision for applying CE in the construction sector is to adopt methods that will allow buildings to become banks for material and products. Accordingly, when buildings reach their end of service stage, they will be able to be deconstructed increasing their bulk/ value ratio, and will be a rich source for material to be remanufactured and reused in new buildings, leading to huge cost reduction (Hopkinson et al., 2018).

The key principles of applying CE specifically to buildings are very similar to the general principles of CE; reducing waste by focusing on materials that are either technical or biological nutrients so they can be part of the closed loops of “waste as food”, increasing material productivity by doing more with use of less material, increasing material value environmentally and economically, and finally developing systems where waste can become an input through understanding the flow of material and energy, and how they link to each other (Adams et al., 2017).

Simple application idea of CE designs that can be implemented in construction is the use of standards or modules, producing components that can be easy dissembled and reused (MacArthur, 2013). However, the application of CE can face challenges of changes associated with the industry itself, the society and various business operations (Lieder and Rashid, 2016). Also, it is hard to implement CE immediately in an effective way, due to the fact that most current buildings are not constructed to be reused or their material to be recovered, and most current market mechanism do not support recovery as well (Adams et al., 2017; Akanbi et al., 2018). Examples of recovery practices being implemented to solve the issue are recycle and reuse. However, these practices are able to recover only 20% to 30% of the demolition waste as well as construction waste worldwide (The World Economic Forum, 2016). Ending up with large amount of waste being dumped in an illegal way causing many environmental problems (Esa et al., 2017).

With the understanding of the high importance of applying CE and the great positive impact it can have, the practical implementation should be considered as well. Accordingly, a comprehensive tool is required to assess the circular designs of products in terms of performance and impact (Haupt and Zschokke, 2017), and considering the whole system in the process of analysis (Curran, 2014). LCA is considered a great tool to support in the decision-making process of implementing CE approach since it considers all phases of product’s life to have full identification of potential issues associated with these phases (Finnveden, 2000).

2.3 Life Cycle Assessment

Life Cycle Assessment is a comprehensive method that aims to integrate the analysis of the three pillars of sustainability; the environment, the economy and the society (Corona et al., 2017). One of the key aspects of LCA is that it takes into consideration the entire life cycle duration of any product whether goods or services, following the "cradle-to-grave" approach (Pryshlakivsky and Searcy, 2013). This basically means that the respective product's systems are being analyzed instead of the product itself, and by systems it means the "production-consumption-waste treatment" systems of any product, but keeping the product as the point of reference when considering the impacts (Guinée et al., 1993). Following such approach is the reason why it is considered sustainable (Shaked et al., 2015; Egilmez et al., 2013; Egilmez et al., 2016). The full life cycle simply means that all life stages of the product or service are considered in the analysis, starting with raw material extraction for example, the production of final products, the usage and waste removal or recycling, also any transportation used during these processes is taken into consideration in the analysis. Also, LCA is differentiated from other assessment methods for its other unique feature that is the use of functional units, which is the standard way of comparing the various products when they provide the same or similar function, providing quantitative description of the function being compared among those products (Klöpffer, 2014).

As presented in Figure 4 below, LCA can be considered as a tool for system analysis, including all requirements, inputs and outputs in the stages of life cycle (Guinée and Heijungs, 2000).

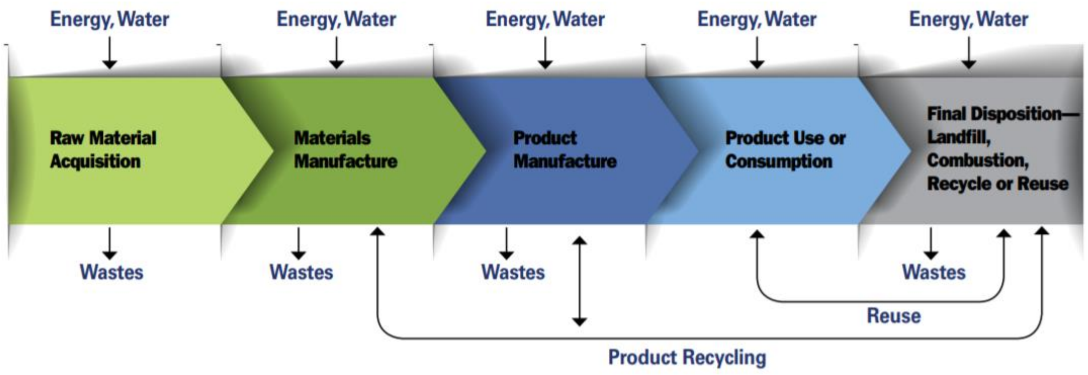

Figure 4. LCA systems approach (Guinée & Heijungs, 2000)

Accordingly, the overall purpose from LCA is to follow a system view in the process of goods and services evaluation. And the full assessment is being implemented through the three complimentary components that are: inventory, impact and improvement analysis. However, it is not necessary for LCA to be a linear or stepwise process, meaning that the three components can feed into each other, where one component can complete the information from the other two components. Some practitioners include a fourth component as the initiating step of describing the scope and goals of the assessment (Vigon and Harrison, 1993).

The need for having a measurable approach is one of the reasons for developing LCA methods and guidelines (Corona et al., 2017). It allows for product comparison, decision making that is based on systematic inputs and outputs, the development of end life design strategies (Pryshlakivsky and Searcy, 2013).

LCAs have become more important with the increased level of awareness among societies about the impact of continuous consumption of manufactured products and marketed services on the supplies of the environment and resources within nature (Vigon and Harrison, 1993). LCA is considered a successful tool due to the fact that it can be applied to all product systems (Klöpffer, 2014). The method has been used in different sectors to assess the sustainability impacts, whether it is the impact of buildings (Hollberg et al., 2020; Meex et al., 2018), electric vehicle technologies (Onat et al., 2019; Onat et al., 2020), food manufacturing and security (Egilmez et al., 2014; Kutty et al., 2020; Park et al., 2016; Kutty and Abdella, 2020), or even pharmaceutical chemicals (Cespi et al., 2015).

However, one of the limitations for applying LCA is that they are time and data intensive, although the issue can be resolved by using tools and software packages such as the Ecosolvent, EcoChain, SimaPro, Mobius and OpenLCA (Capello et al., 2008).

2.3.1 Guidelines and Standards

The development of the first structured LCA was during the workshop held by the "Society of Environmental Toxicology and Chemistry" (SETAC) titled "A Technical Framework for LCAs" in 1990, developing the well-known "SETAC triangle" that consists of the three elements; "Inventory", "Impact Analysis" and "Improvement Analysis" (Klöpffer, 2014).

Later on, the first code of practice for LCA was published by SETAC in 1993 (Benoît et al., 2010), developing the triangle into the four components that are; Goal Definition and Scoping, Inventory Analysis, Impact Assessment and Improvement Assessment, that were used later on by ISO to develop its relative standards such as: "ISO 14040 (2006)" and "ISO 14044 (2006)", with minor modification on Improvement Assessment changed to Interpretation (Klöpffer, 2014).

Many reasons were behind the need for developing such ISO standards; it was important to organize and unify the procedures of LCA, but also to convince stakeholders and international community with the need for implementing such kind of assessments by referring to an internationally recognized standard (Finkbeiner et al., 2006), as a response to the growing recognitions of the usefulness of LCA in defining areas of environmental development, and to cover the need for scientific methods focusing not only on physical products (goods) but also services as well (Ryding, 1999).

These standards define the overall framework for conducting LCA, but leaving it to the practitioners to take lead on the methods and mechanics of detailed aspects such as; data collection, calculation and interpretation (Pryshlakivsky and Searcy, 2013; Sen et al., 2020).

2.3.2 Phases of Life Cycle Assessment

According to "ISO standard 14040 (2006)" and "ISO standard 14044 (2006)", there are four phases or components for implementing LCA in general, these phases can be summarized as follows:

- "Goal and Scope Definition": defining the needs for conducting the study (Benoît et al., 2010). More in specific, goals can include reasons for conducting the study, targeted audience and intended applications, while scope of the study describes the system, its boundaries, functional units, procedures of allocation, impact categories, data requirements and assumptions, limitations and type of reporting (Klöpffer, 2014). This phase can be done internally and informally within project staff in organizations, but for external studies a formal procedure may be required for revision of study boundaries and methodology (Vigon and Harrison, 1993).
- "Life Cycle Inventory" (LCI): it is a technical process based on data (Vigon and Harrison, 1993), defining the system or systems of the product and its unit processes, then setting the exchanges of the product system/s with the environments, these exchanges are categorized into inputs and outputs. Inputs such as; land used and extracted raw material, while outputs can be; emission to air and water. These exchanges should be based on one functional unit that is

already set in the “Goal and Scope” phase (Benoît et al., 2010). LCI can be carried out for process analysis, material election, product evaluation and comparison, as well as decision making (Vigon and Harrison, 1993). This phase is considered as the core of any LCA (Klöpffer, 2014), and it is the most developed component as its methodology has been evolving for more than 20 years (Vigon and Harrison, 1993).

- “Life Cycle Impact Assessment” (LCIA): evaluating the significant of environmental impacts related to the defined input and output exchanges (Benoît et al., 2010). In other words, assessing the impact of resource requirements identified in the inventory stage or component, and this component is usually focused on the qualitative aspects of analysis, but it can be quantitative as well (Vigon and Harrison, 1993). The mandatory elements of this phase of component are; “Selection of Impact Categories”, “Category Indicators”, “Characterization Models”, “Assignment of the LCI Results to Impact Categories” (classification) and “Calculation of Category Indicator Results” (characterization). This phase can include also optional elements such as “Normalization”, “Grouping” and “Weighting” (Benoît et al., 2010).

Additionally, there are two methods to derive characterization factors, these methods are known as midpoint and endpoint levels. Midpoint level factors are considered in the cause-impact phase, endpoint level factors show the damage at one of the three following areas of protection; “Human Health”, “Ecosystem Quality” and “Resource Scarcity” (Huijbregts et al., 2017). Also, midpoint level factors focus on one environmental problem such as climate change, while endpoint level factors show impact on the three areas mentioned above (The National Institute for Public Health and the Environment, 2018).

The two methods complete each other, as the midpoint characterization has less uncertainty than endpoint characterization, but it is more related to the environmental flows. However, endpoint characterization provides more information on the relevance of the environmental flows (Hauschild and Huijbregts, 2015).

This approach of integrating midpoint and endpoint levels is known as the ReCiPe method (Gonçalves et al.). This method was developed by Goedkoop et al. in 2009, and continuously updated to be implemented at a global scale. Figure 5 represents ReCiPe2016 midpoint impact categories and endpoint areas of protection (Huijbregts et al., 2017).

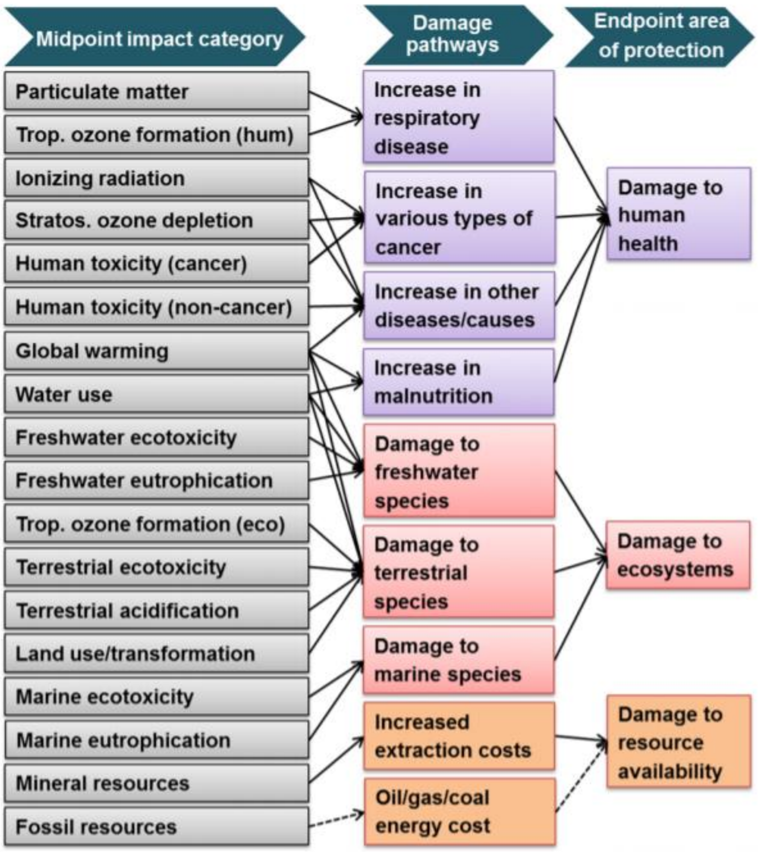

Figure 5. Impact categories according to ReCiPe2016 (Huijbregts et al., 2017)

One of the major differences between LCIA and other impact assessments is that it does not aim to quantify specific actual impacts relative to the product or process. But instead linking between the life cycle of the product or process and potential impacts (Vigon and Harrison, 1993).

- “Life Cycle Interpretation”: combing the outcomes of the two last phases and aligning them with Goal and Scope to come up with the conclusions and recommendations (Benoît et al., 2010). Defining the possible opportunities and needs to reduce the undesired impact (Vigon and Harrison, 1993).

Figure 6 illustrates the four stages of implementing LCA as defined earlier, showing the interrelations between them.

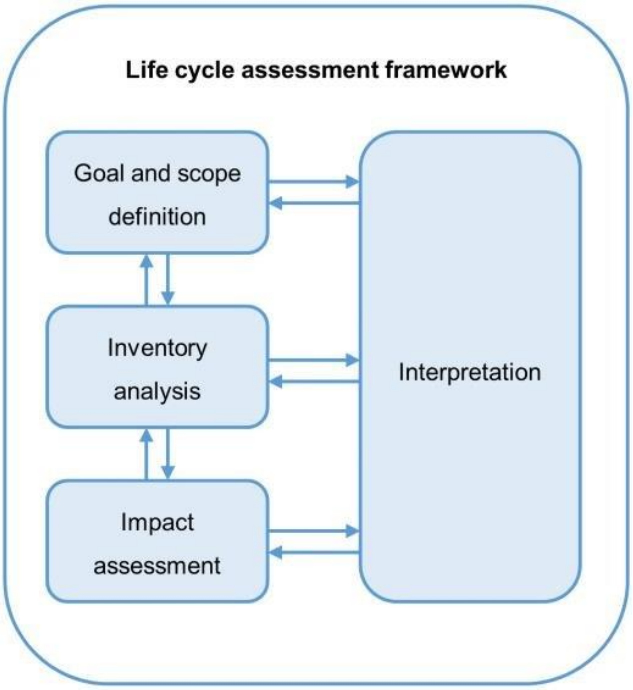

Figure 6. The framework for LCA stages (Syedaridazahra, 2020)

2.4 Environmental Life Cycle Assessment

Issues and concerns related to the environment are increasingly being taken into consideration while making decisions on the various political, industrial and economic aspects (Shaked et al., 2015). “Environmental Life Cycle Assessment” (ELCA) is basically addressing all aspects related to products (whether goods or services) and their impacts specifically on the environment throughout their full life cycle, including all stages of the products in general starting with the acquisition of raw material or the production of a natural resource, moving to processing and manufacturing, distribution, use and re-use, recycling to eventually reaching final disposal (Benoît et al., 2010; Joshi, 1999).

The concept and method of ELCA was first developed in the late 1960's, most environmental areas considered were the consumption of energy and production of solid waste, later on other aspects like air and water pollutants were considered (Benoît et al., 2010). Also, various set of impacts were suggested to be included in ELCAs including impact on resources, impact on nature and landscape, air and soil pollution, surface water, noise, electromagnetic radiation and ionizing radiation (Hendrickson et al., 2006).

In ELCA, energy and material balances are required for all stages (Hendrickson et al., 2006). When implementing ELCA, the inventory component is focused on areas such as quantifying energy and raw material requirements, atmosphere, waterborne emissions, as well as solid waste (Vigon and Harrison, 1993). ELCA is different from other environmental methods because it links environment performance with functionality of the product or system (Shaked et al., 2015).

A broad range of literature used ELCA to assess the impact of construction sector on the environment (Jain et al., 2020; Sharma et al., 2011; Ramesh et al., 2010). For example, results revealed that recycling can reduce the impact construction has on the environment in India, where lower greenhouse gas emissions will be achieved, in addition to lower energy consumption, as well as water and land use (Jain et al., 2020). Also, the recycling of ferrous as well as non-ferrous metals can effectively reduce carbon footprint of waste management (Kucukvar et al., 2016a). Moreover, the recycling of construction materials will have a positive impact not only on carbon, but also energy and water footprints (Kucukvar et al., 2014a). According to Ramesh et al. (2010), energy consumption of a building during the full life cycle can be minimized by reducing energy consumption in the operation stage, using passive energy solutions. Therefore, low energy buildings are observed to have better energy performance than self-sufficient building when considering the whole cycle of life of both buildings. Apart from that, Sharma et al. (2011) conducted a study on buildings showing that during all of building's life cycle stages significant impact on the environment is generated, however the operational stage has the highest consumption rate of energy. Also, the results showed that commercial buildings have more environmental impact than residential buildings in general. Onat et al. (2014) in their study conducted on residential and commercial building in the U.S. revealed that the construction phase affects sustainability impacts the most. Also, the use of electricity has the greatest impact on the environment. Results of similar study conducted on U.S. building as well revealed that the highest emissions are produced in the usage phase of the buildings (Onat et al., 2014).

Other studies focused on construction materials, such as study conducted by Kucukvar and Tatari (2012), revealed that Continuously Reinforced Concrete is a more convenient pavement design when considering the overall consumption of ecological resources compared with Hot-mix Asphalt. Just recently, Al-Hamrani et al. (2021) showed that 94% of the total CO2-eq emissions from construction are caused by concrete ingredients production, and around 80% of fuel is consumed in transporting concrete from the plants to various constructions sites.

With all these studies, there are several limitations on applying ELCA, most of these limitations are not directly related to the tool itself, but to environmental system analysis tools in general. Most affecting limitations are relative to the availability of data required, and the uncertainty of data as well (Finnveden, 2000). There are other limitations associated with the construction sector itself when it comes to conducting ELCA. For example, most buildings have very long lifespan that can be fifty years on average (Sartori and Hestnes, 2007). Also, using huge variety of materials can be considered a limitation as well (Ramesh et al., 2010).

2.5 Social Life Cycle Assessment

According to Benoît et al. (2010), "Social Life Cycle assessment" (SLCA) aims to evaluate the potential positive and negative impact of social and socio-economic aspects for all life cycle phases of any product life-cycle, including but not limited to extraction, processing, manufacturing, assembly, selling, using, recycling, etc. This kind of assessment is unique and different from other social impacts assessment because of its scope and objects. Where objects in such kind of assessment are; physical products (goods) and services, while the scope include full life cycle. Example of social aspects can be behaviors of enterprises and impacts on social capital.

The benefits of implementing SLCA come in providing data on social and socio-economic aspects to support decision making and performance improvement within organizations and their relative stakeholders. SLCA can provide useful data related to the product or service. However, it cannot be considered as a method to relay on for direct decision making such as taking the decision of proceeding or not proceeding with product manufacturing. Also, SLCA as a tool does not provide direct solutions for sustainable development, but rather helps in defining incremental improvements that can support in achieving sustainable development (Benoît et al., 2010). The method of SLCA was initiated to assess aspects of sustainability other than the environmental aspect, resulting in more comprehensive assessment of products and services, understanding the impact on various social entities. The methodical phases followed in conducted SLCA are the same phases followed in conducted LCAs in general including ELCA, starting with “Goal and Scope Definition”, then the conducting of “Inventory”, “Impact” and “Interpretation” analyses (Hauschild et al., 2018).

Many researchers referenced the United Nations Environment Program/Society for Environmental Toxicology and Chemistry (UNEP/SETAC) Guidelines when conducting SLCA (Corona et al., 2017; Dong and Ng, 2015; Hosseinijou et al., 2014; Navarro et al., 2018).

When considering the social impact, it is meant to assess the impact on well-being stakeholders affected by the product or service through its life cycle (Hauschild et al., 2018). Impacts are not necessary to be negative but can be positive as well. Examples of positive impacts are contribution to local income and employment opportunities, while negative impacts can be; child labor and population displacement. Also, conducting social assessments with the aim of increasing positive impacts can be more beneficial than attempting to reduce negative ones (Sala et al., 2015). Impacts can be physical, psychological and many other as well, these areas of which well-beings maybe affected are identified and categorized into more than 30 categories. Table 3 below represents some of these areas that are grouped based on stakeholder type (Hauschild et al., 2018). According to Sala et al. (2015), Workers stakeholder category is the most considered category within previous research.

Table 3. Examples of identified areas of social impacts

Stakeholder	Relative Social Impacts
Workers	• Equal opportunity without discrimination • Associations freedom • Child labor • Level and regularity of wages and benefits • Working conditions- physical • Working conditions- psychological
Societies	• Corruption • Investment in society • Acceptance of company by local community
Product users	• Consideration of costumer health and safety aspects in products development • Availability of relative product information to users • Ethical guidelines for products' advertisements

There are many studies available on conducting LCAs and ELCAs, but there is a lack in literature on SLCA conducted especially in the construction sector, although building projects are constructed with the purpose of enhancing social aspects related to improving the quality of life (Dunmade et al., 2018).

2.5.1 Comparison between Social and Environmental Life Cycle Assessments

SLCA can be applied separately or combined with ELCA. The most recognized similarities between ELCA and SLCA are that; both follow the same framework or phases of implementation as defined in "ISO 14040 (2006)" and "ISO 14044 (2006)", both use huge data, provide useful information to support decision making, conduct hot spots and data quality assessments, and finally both do not reflect impacts by functional unit when qualitative or semi-quantitative data is used (Benoît et al., 2010).

O'Brien et al. (1996) suggested a combined method including both ELCA and SLCA, with the aim of developing a framework that integrates both scientific/technical and social/strategic assessments, bringing together various aspects of sustainability to reach more comprehensive analysis and defined areas of development. Besides the fact that ELCA focus on the environmental aspects and SLCA focus on evaluating socio-economic and social impacts, there are other differences between both approaches as well. One important fact is that ELCA relay on physical quantity data related to the product throughout its lifecycle, while the SLCA collects data and information related to organizational related aspects (Benoît et al., 2010).

2.5.2 Applications of Social LCA in Sustainable Construction

In their study, Dong and Ng (2015) aimed to develop a Social-impact Model of Construction (SMoC) for construction projects in Hong Kong. Their Model of Construction was developed through three stages, the first one consisted of implementing SLCA method. The next stage a survey was conducted in order to collect the weighting factors and also to reveal the social impacts related to construction practices at the site and based on it the SMoC model was developed. The third and final stage case study was conducted following the four-phases as defined by UNEP/SETAC guidelines. Results of the study revealed that workers' health and safety is the most area that is important socially. Also, environmental-friendly activities are useful for the society. One of the interesting findings of the study is that the adoption of precast concrete components has a negative impact on fair salary and local employment, since the precast concrete is usually imported from outside Hong Kong. According to sensitivity analysis results, environmental-friendly construction practices have a positive impact on social performance.

Navarro et al. (2018) studied the social impact of a concrete bridge deck in Spain in order to contribute to the existing knowledge of sustainable design of bridges. To conduct the study, social impacts of alternative designs were estimated taking into consideration the impacts derived from construction and maintenance phases under conditions of uncertainty. Results of the study indicated that the social impacts of structures like bridges during the service life are important to be taken into consideration in sustainability assessments. Also, designs that need less maintenance operations are more socially preferred.

A notable example in material selection in construction projects is the study for Hosseinijou et al. (2014), they stated that selection of materials should not only take into consideration the functionality, but also should consider the environmental, social and economic impacts. Assessment of material's social impacts should address the full life cycle. A case study was analyzed in order to assess the social and socio-economic impacts in the life cycle of concrete and steel in Iran. The proposed method for SLCA as an outcome of this research was specifically focused on materials and products comparison. Regarding the results of the case study, Steel as a material has better social performance than concrete in the north of Iran. Also results revealed the reason behind negative impact of cement industry is due to its effect on safety and the health environment.

Corona et al. (2017) in their research aimed to add suggestions for improvements on the characterization model built by previous methodological developments. Taking the case study of a power generation in a concentrated solar power in Spain, four life cycle phases were defined. Results revealed that "operation and maintenance" is the most phase contributing to social risks, where the most identified social risk were related to; gender inequality and corruption that were both confirmed by site-specific assessment, but injuries and immigrations aspects were not detected.

Dunmade et al. (2018) evaluated the potential social impacts engineering project management process may have on stakeholder categories. Referring to

UNEP/SETAC guidelines for SLCA, an infant food production plant was taken as a case study. Results revealed that the social performance of project managers towards the community is better than towards the project team itself.

The study by Bork et al. (2015) is somehow related to construction, conducted with the aim of assessing the social life cycle of three furniture companies. According to the results, companies should consider training of employees as a way of reducing accidents. One of the three companies should consider reducing the use of overtime and hiring of male gender. Another company may consider choosing a location where employees can have their children safe with them in the work environment.

Singh and Gupta (2018) conducted SLCA for an Indian steel company. Research was conducted by identified social hot spots, defining categories and sub-categories for social indicators referring to UNEP/SETAC methodological sheets. Impact indicators were selected according to their relative importance towards steel industry and geographic context. Stakeholder categories considered were; suppliers, employees, customers, and the community. Results showed that facilities of healthcare, accessibility to clean water, accessibility to education and workplace safety for workers, economic prosperity and infrastructure are the main areas to be improved.

As for green building designs, the study of Fan et al. (2018) analyzed social needs of green building design using LCA method. Different stakeholders were taken into consideration such as; real estate developers and community residents. Results proved that individuals are willing to pay to enjoy better living environment, also, the local authorities are supportive for the development of green housing districts. Green concrete was also the subject of a study conducted by Kono et al. (2018), assessing the social and environmental factors. Hot spot analysis as well as LCAs were conducted. Results showed that the use of green concrete was environmentally beneficial but had negative social impact. A proposed solution is to improve the supply chain management. Essentially, SLCA method has been successfully implemented to analyze the social needs of various construction related projects.

2.6 State-of-the Art Contribution

There are abundant literatures that focus on sustainability concerns in mega-events including studies on carbon footprint accounting for Beijing 2008 Olympics (Wu et al., 2011), environmental foot printing in 2003/2004 Football Association Cups (Collins et al., 2007), and studies on quantitative environmental impact assessments in FIFA World Cups (Collins et al., 2009; Pereira et al., 2017). Surprisingly, the socio-economic dimensions of sustainability were not considered in any of these studies, even though they hold vital significance compared to the environmental impacts and are all interrelated (Talavera et al., 2019). Furthermore, the value of wedges that are generated by an event hold a critical advantage for the host country and are set as the main objectives when planning to host world cup and Olympic events (P.Hermann et al., 2012). Consequently, the governments aim to reap the substantial advantages including the prospect of undertaking infrastructure development projects, creation of jobs, and the attraction of business investments and potential income generation (Schofield, 2017). In the effort to achieve valuable economic impacts, social issues are often neglected. However, exploring social impacts in particular the residents' perception of event hosting, the feeling of social cohesion when consolidating sustainable growth with equity and, the impact of mega events on human health in long run are even more significant for the community than economic growth. It is thus necessary to understand these gaps from a people centric perspective through the eyes of sustainability using social sustainability assessment tools.

In addition, while skimming through the body of knowledge in the area of life cycle sustainability assessment in the construction sector, social indicators are not studied sufficiently. SLCA is still in its infancy and the applicability of SLCA is highly limited due to data needs, difficulties in data quantification, and the subjective nature of the social indicators (Onat et al., 2017). Furthermore, the circular economy applications for World Cup Stadiums in particular and the application of sustainability assessment in general is limited for green stadium designs. It is noteworthy that, there is a lack of concern when it comes to estimating the social impacts like human health under the circularity theme for mega events when sustainability scientists and decision makers raise voice on the increased impacts of emissions. Lastly, there is a lack of studies that conduct a complete social life cycle sustainability assessment (considering all the phases – cradle to cradle approach). Thus, in limelight of these gaps, this research aims to conduct the first of its kind social-life cycle assessment to quantify the human health related damages associated with the Ras Abu Aboud stadium construction.

2.7 Literature Summary

The current chapter provided an overview of existing researches related to the topic of this study, beginning with stadiums' construction and the various impacts the sector can have on sustainability. Then following a top-down approach in defining CE concept as a solution to resolve the respective impacts, its principles and historical background, as well as its various applications and environmental benefits in construction. Followed by going into the details of discussing LCA as a tool used in assessing the environmental, economic and social impacts, reviewing tool phases, guidelines and standards, also understanding the differences between ELCA and SLCA with more in depth focus on the social aspects. Finally, the chapter covered latest studies that conducted SLCAs on construction projects.

CHAPTER 3: METHODOLOGY

The research presented in this thesis is applying a quantitative method of social LCA to study the social impacts of Ras Abu Aboud (RAA) stadium construction. Figure 7 below shows a detailed flowchart of the steps to get a better understanding of the research approach. First, the context of the study is identified in the form of case study, goal and scope along with the system boundaries and the functional unit. Later, essential data is collected, and after determining the end point impact as human health, SLCA is applied based on impact category scores from Eco invent version 3.7.1. Finally, the sensitivity analysis is conducted, and results are visualized.

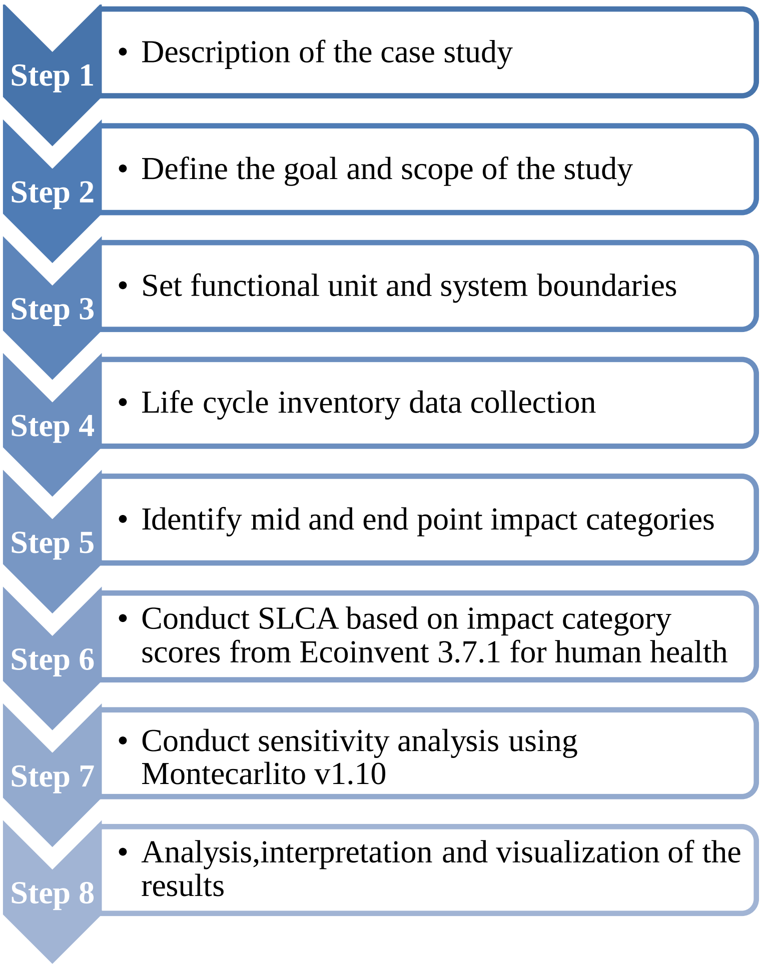

Figure 7. Research flow chart

The following sections of the chapter present and explain the case study of RAA stadium, and the research method of SLCA that includes the definition of goal and scope, system boundary, functional unit, life cycle inventory data, and life cycle impact assessment.

3.1 RAA Case Study

Ras Abu Aboud stadium is one of the eight stadiums set to host matches in the group stage and round of 16 for FIFA 2022 World Cup in Qatar. RAA is located on the waterfront with a 40,000-seat capacity. Its sustainable and innovative design is first-of-its-kind in the history of sports mega events. According to the Supreme Committee for Delivery and Legacy (SCDL), unlike other stadiums, a total of 972 shipping containers, structural components , and removable seats are used as modular blocks for construction in order to be easily repurposed and dismantled after the tournament. These parts are intended to be used in community facilities like hospitals and other projects whether sports related or not both locally and abroad (FIFA, 2020). From sustainability perspective, it is known that the use of concrete worldwide accounts for huge CO_2 emissions (Marie and Quiasrawi, 2012; Alsarayreh et al., 2020), hence the modular and prefabricated elements used in construction will seek to reduce the waste generated, carbon emissions, and the total amount of materials necessary for construction. Moreover, with the reuse of the seats, roof, and other parts of the stadium in developing countries; a positive legacy for Qatar will be established for years and even decades to come (FIFA, 2020). Figure 8 and 9 illustrate the container design used for RAA construction.

Figure 8. Modular design of Ras Abu Aboud stadium

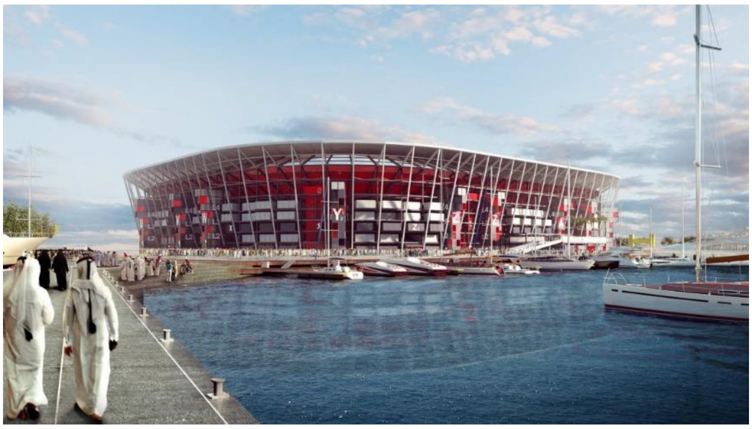

Figure 9. Shipping containers design for RasAbu Aboud stadium

3.2 Research Method: Social Life Cycle Assessment

The methodology framework applied in the current research follows the UNEP/SETAC guidelines for Social Life Cycle Assessment. According to these guidelines SLCA includes four main phases: first phase begins by identifying the goal and scope of the work and indicating system boundaries and functional unit; the second phase is life cycle inventory analysis which involves data collection ; the third phase is life cycle impact assessment in which mid and end point social impacts are selected; finally the fourth and the last phase covers analysis interpretation in which information from the results are evaluated. The SLCA analysis employed is directed towards assessing the social impacts of materials along their entire life cycle, by adopting “cradle to cradle” approach which considers raw material production, on-site construction and installation, operational phase, and , ultimately, the end-of-life management. In the following sections details of the SLCA phases are presented.

3.2.1 Goal and Scope Definition

The main goal of this research study is to develop a holistic social LCA of reusable container stadium of Ras Abu Aboud in Qatar. At first, the mid and end point social impacts are identified. When establishing the social impact of each stage, the different resources that are utilized in each stage like water, energy, and materials will be analyzed and compared to overall endpoint impact. Further, SLCA will be used for comparative assessment of two alternative scenarios; first of which will be using non-recycled (virgin) materials and the second more sustainable alternative in which recycled materials are utilized. Second goal of this study is to examine different end-of-life management circular applications for sustainable construction by considering numerous reuse scenarios of stadium components.

The results of this research will provide the means to detect the best socially sustainable alternatives as well as reveal areas for potential improvements. To further define the study scope, the research defined the system boundaries and the functional unit which were considered during this study.

3.2.1.1 System Boundaries

In this research study, cradle-to-cradle approach in evaluating stadium life cycle impacts constitutes boundaries of the system. The motivation for choosing this sustainable material flow approach was the positive footprint this approach seeks to leave on the society and the environment. The system boundary includes four different phases illustrated in the system boundary shown in Figure 10 which are (1) material production phase, (2) construction phase, (3) operation phase, and (4) end of life phase. The first phase (cradle start) considers the manufacturing and production of construction materials, pipeline systems, openings, and finishing materials. This phase also involves the burden avoided by the recycled materials, which were used in the production process of several materials. Next, the construction phase covers the total diesel consumed by heavy equipment and during the transportation processes of materials to the site, together with the freight transport of shipping containers through waterways. Furthermore, the consumed electrical energy, the consumed water, solid wastes and wastewater generation were covered in both the construction and the operation phases, knowing that the specified unit processes in the operation phase were determined on the annual basis. Since RAA stadium is the first fully demountable stadium in the World Cup history, the end of life management will cover some circularity scenarios for the reuse of the stadium's components for other purposes.

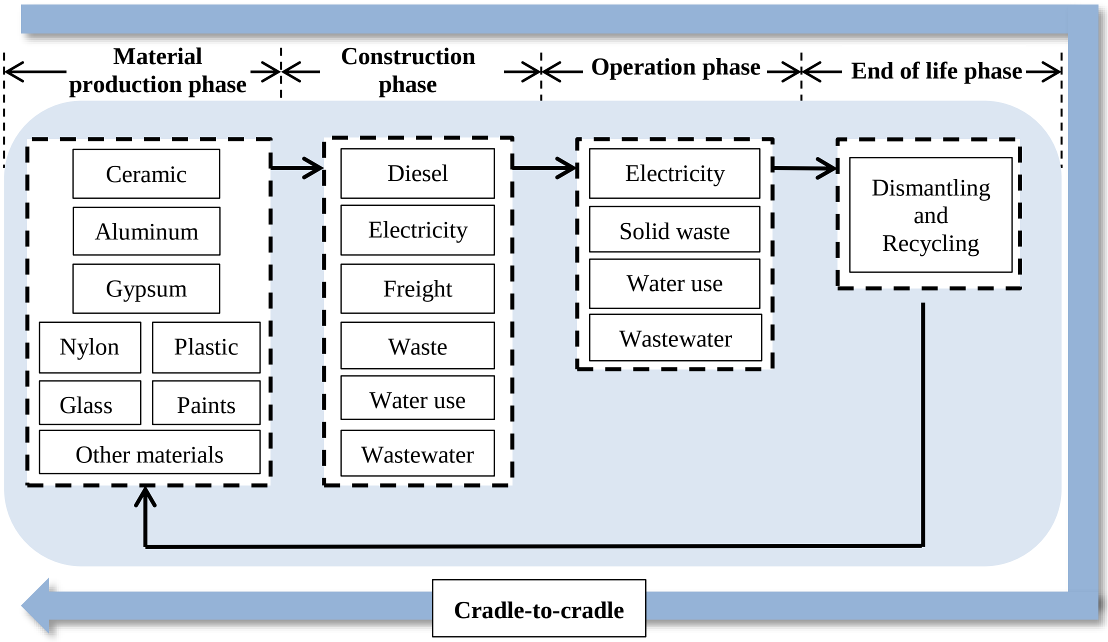

Figure 10. System boundary considered for Ras Abu Aboud stadium assesment

3.2.1.2 Functional Unit

As stated in UNEP/SETAC (2009) guideline, an essential part of defining the scope is specifying both the function ‘performance characteristics’ and the functional unit of the product in the goal and scope phase of the study. This research study set a functional unit of the entire area of the stadium, which constitutes 80,531 m^2 as this provides the necessary basis for the social impacts’ calculations.

3.2.2 Life Cycle Inventory Data

According to the requirement of the international standards, ISO 14040 and ISO 14044 series, the life cycle inventory analysis (LCI) is the second step in the LCA methodology, which includes the identification and quantification of all physical materials and energy flows entering and leaving the system. For this study, the LCI data presented in Table 4 represent site-specific data obtained from the SDCL at various stages of the RAA stadium’s life cycle. The recycled amount column in Table 4 indicates materials’ quantities that were avoided during the production phase, as recycled material was combined with the virgin material in the production process of some of the listed products. The ecoinvent v3.7 database has been utilized to aggregate the quantified data into several impact categories, which will be identified in the following sub-section. The activity and the reference product names in ecoinvent v3.7, which has been used to obtain the characterization factors for different impact categories, are also shown in Table 4. It is worth mentioning here that for each activity identified in ecoinvent v3.7, the geographical location dataset under the RoW shortcut was selected for the current study, which refers to Rest-of-the-World.

Table 4. Life cycle inventory data of RAA stadium obtained from the Supreme Committee for Delivery and Legacy in Qatar.

Materials/ Activities	Category	Virgin amount used	Recycled amount	Unit	Activity name in ecoinvent v3.7
Raw material phase					
Concrete	Concrete	241,364,493.8	6,967,629.5	kg	Concrete block production
Earthworks	Fill	0	369,325.7	kg	
Base plaster	Finishes	250,773.0		kg	Base plaster production
Ceramic tiles	Finishes	17,973.0		kg	Ceramic tile production
Epoxy resin	Finishes	358,741.0		kg	Epoxy resin production
Gypsum board	Finishes	1,325,393.0		kg	Gypsum plaster board
Nylon product	Finishes	269,079.0		kg	Nylon 6 production
Paint	Finishes	56,085.0		kg	Alkyd paint production, white, solvent-based, product in 60% solution state
Polypropylene fabric	Finishes	203,568.0		kg	Textile production, nonwoven polypropylene, spun bond
Stone plate	Finishes	257,974.0		kg	Natural stone plate production
Vinyl floor	Finishes	87,765.0		kg	Market for vinyl chloride
Coatings to Steelwork	Finishes	19369721.68		kg	Coating powder production
Intumescent Fire Protection	Finishes	841,234.1		kg	Cellulose fiber production
Containers Stairs	Finishes	12,834,046.7		kg	Hot rolling, steel
Average metal pipe product	Metals	867,120.0		kg	Drawing of pipe, steel
Steel	Metals	39,122,286.2	12,374,122.4	kg	Reinforcing steel production
Average metal product	Metals	66,007,691.0		kg	Market for aluminum oxide, metallurgical

Materials/ Activities	Category	Virgin amount used	Recycled amount	Unit	Activity name in ecoinvent v3.7
Glass	Openings	1,187,653.7	179,733.3	kg	Flat glass production, uncoated
Wood door	Openings	101,225.0		kg	Plywood production
Mineral pipe insulation	Other	1,580,133.0		kg	Tube insulation production, elastomer
Plastic and Metal	Other	57,240.0		kg	Extrusion, plastic pipes
Polyethylene foam	Other	62,730.0		kg	Market for polyurethane, rigid foam
Pitch	Other	2,048,163.0		kg	Market for pitch
PVC thermoplastic sheet	Thermal & Moisture	1,801,386.3	216,776.3	kg	Polyvinylchloride production, bulk polymerization
Construction phase					
Diesel		691,900.00		kg	Diesel production, petroleum refinery operation
Total electricity consumption		8,940,147.00		kWh	Market for electricity, high voltage
Water use		63,675.00		m^3	Market for tap water
Freight		687,412,363.00		tkm	Market for transport, freight, inland waterways, barge
Waste generation		826,398,000.00		kg	Market for inert waste
Wastewater		22,286.00		m^3	Market for wastewater, average
Operation phase					
Electricity and cooling total		4,384,835.00		kWh	Market for electricity, high voltage
Water use		18,981.79		m^3	Market for tap water
Waste generation		1,752.00		tonnes	Market for municipal solid waste
Wastewater		8,636.36		m^3	Market for wastewater, average

3.2.3 Life Cycle Impact Assessment and Interpretation

The life cycle impact assessment (LCIA) is the next step in which the impacts induced from the LCI data shown in Table 4 will be evaluated after assigning them to certain impact categories. For this purpose, in the Ecoinvent v3.7 database, the ReCiPe method has been implemented using the damage-oriented methodology (endpoint) to evaluate the social (S-LCIA) of the RAA stadium. In ReCiPe, three uncertainty perspectives are used to evaluates the life cycle impacts which are the individualistic perspective, the hierarchist perspective, and the egalitarian perspective. Out of these three perspectives, the egalitarian perspective, which considers all impact pathways with the longest time frame, will be used in this study. Moreover, while the ReCiPe method considers three damage categories in the end-point level namely, damage to human health, damage to ecosystems, and damage to resource availability, the human health damage category was selected as a social LCA indicator in this study. In this context, the results of mid-point indicators, connected to the human health damage category, have been investigated to observe the extent to which these indicators have affected the end-point indicator result. For every specified magnitude of the consumed materials, energy, or waste determined in the LCI step, the SLCIA calculations were carried as follows:

1) Select the mid-point characterization factors (CFm) for the respective mid-point indicators from the ReCiPe Midpoint (E) list in the ecoinvent v3.7 database, where (E) is referred to the egalitarian perspective.

2) Determine the end-point characterization factors (CFe) according to Eq. 1:

$$CFe = CFm \times F_{M \to E} \qquad \text{Eq. 1}$$

where $F_{M \to E}$ is the mid-point to end-point conversion factors obtained from the ReCiPe 2008 report (Goedkoop et al., 2009). The factors are as listed in Table 5.

3) Calculate the damage to human health in the unit of ‘disability adjusted life years’ (DALY) according to Eq. 2:

$$Damage\ (DALY) = CFe \times Q \qquad \text{Eq. 2}$$

where Q is related to the used quantities listed in Table 4. Details about the selected mid-points and end-point indicators are shown in Table 5 and briefly explained below:

- Human Health: measured by DALYs (disability adjusted life years), one DALY represents one year that is lost from person’s life (mortality), or a year in which the person is disabled due to an illness or accident or basically lost the quality of life (morbidity).
- Climate Change: the characterization factor chosen for climate change is the global warming potential (GWP), which quantifies the integrated infrared radiative forcing increase of a greenhouse gas (GHG), measured in kg CO2-eq
- Human Toxicity: the increased risk of cancer or non-cancer incident disease or in general human toxicity (HT), represent the characterization factor expressed in kg 1,4-DCB-eq to urban air.
- Ionizing Radiation: the potential increase in absorbed dose resulting from the excess energy emission of a radionuclide is set as the characterization factor also named as ionizing radiation (IR) characterized by kBq U-235 eq.

- Ozone Depletion: represents the gradual thinning of ozone layer or ozone depletion (OD), measured by kg CFC-11-eq to air.
- Particulate Matter Formation: the formulation of particles in the air and the possible change of concentration is characterized by particulate matter formation (PMF) and expressed kg primary PM2.5-equivalents.
- Photochemical Oxidant Formation (POF): represents the change of ozone levels due to the change of concentration in nitrogen oxides or non-methane volatile organic compounds (NMVOC) measure in kg NMVOC.

Table 5. ReCiPe mid-point and end-point indicators were used in this study.

Mid-point impact category	Characterization factor (CF)	Unit of CF	Mid-point to end-point conversion factors	Unit	Damage category	Unit
Climate change (CC)	Global warming potential	kg CO_2-eq	3.51×10^{-6}	DALY/ kg CO_2-eq	Human health	DALY
Human toxicity (HT)	Human toxicity potential	kg 1,4-DCB eq	7×10^{-7}	DALY/ kg 1,4-DCB eq		
Ionizing radiation (IR)	Ionizing radiation potential	kg U-235 eq	1.64×10^{-8}	DALY/ kg U-235 eq		
Ozone depletion (OD)	Ozone depletion potential	kg CFC-11 eq	1.76×10^{-3}	DALY/ kg CFC-11 eq		
Particulate matter formation (PMF)	Particulate matter formation potential	kg PM_{10} eq	2.6×10^{-4}	DALY/ kg PM_{10} eq		
Photochemical oxidant formation (POF)	Photochemical oxidant formation potential	kg NMVOC	3.9×10^{-8}	DALY/ kg NMVOC		

CHAPTER 4: RESULTS AND DISCUSSION

In this section, the mid-point impact indicator results will be highlighted first, then the resulted damage to human health end-point will be evaluated. Moreover, the key materials, processes, activities, and life stages that significantly contribute to the social impact of RAA stadium will be identified and analyzed to draw conclusions and make recommendations for possible areas of improvement in the future.

4.1 Social Life Cycle Impact Assessment

In the analysis, two scenarios concerned with the operation phase will be introduced. The first scenario considers the damage induced from 1 year of operation, after which the stadium will be entirely dismantled, whereas, in the second scenario, the damage was considered based on the assumption of 50 years of operation as a practical lifespan of the RAA stadium. At the mid-point level, it is apparent from the data in Figure 11 that the production phase acts as the first contributor out of all phases across the 6 impact categories, followed by the construction phase with a much lower contribution. Whereas no evident contribution can be noticed for the operation phase. A possible explanation for this might be related to the limited number of sports events that take place annually. This is beside the preparatory periods of sporting teams that lie in between the competitions period, during which the football stadiums are not operated. Data from Figure 11 can be compared with the data in Figure 12 which considers the second scenario of the operation phase. In the second scenario, the operation phase became the second-highest contributor across the 6 impact categories with considerable contributions of 42.9%, 35.6%, 37.6%, 34.5%, 46.2%, and 18.1% on CC, HT, IR, OD, PMF, and POF, respectively. What is striking about Figure 11 and 12 is that they show negative contribution, which corresponds to remarkable savings across the six mid-point impact categories due to the planned circularity activities of repurposing several materials at the end life of the stadium to cover some of the societies' needs without producing new materials from the same type.

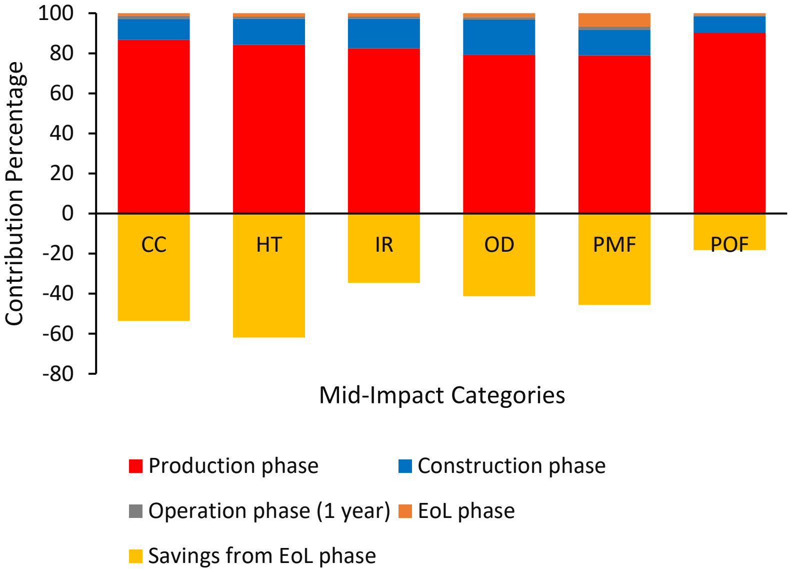

Figure 11. Contribution on mid-impact categories of all phases (1st scenario)

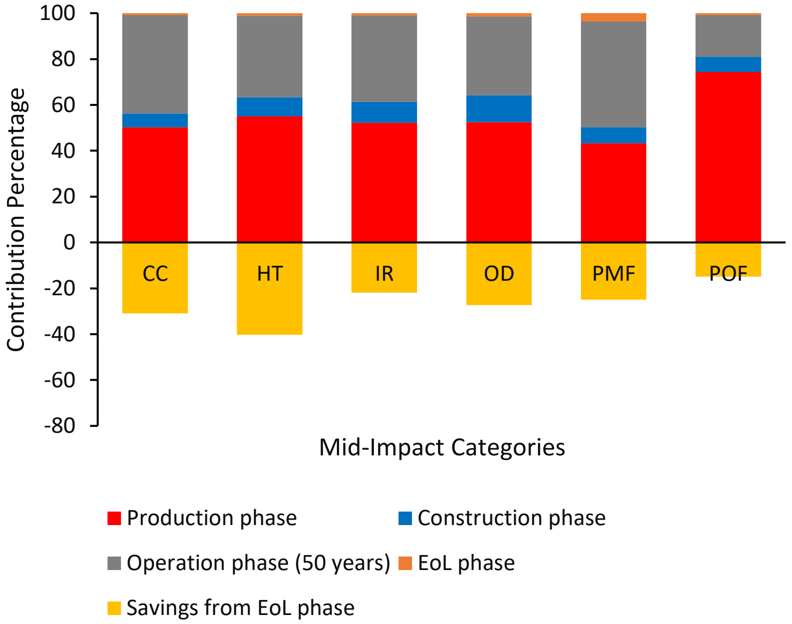

Figure 12. Contribution on mid-impact categories of all phases (2nd scenario)

To better understand the impact of the production, the construction, and the operation life cycle stages on the specified mid-point indicators, the percent contribution of each activity under each life stage is shown in Figure 13, 14, and 15, respectively. In the production phase, it can be seen from Figure 13 that the average metal product, coatings to steelwork, steel, and concrete are the most influential materials across the six mid-point indicators. On the other hand, the contribution of the remaining materials was marginal and ranging from 0 to 2%. The average metal product in this study was referred to (aluminum oxide, metallurgical), which had the highest contribution of 53% on HT, while it was ranging between 15% to 38% for the rest of the categories. The high contribution to HT is attributed to the high toxicity characterization factor of 76.089 kg 1,4-DCB eq/kg, which was assigned by the ReCiPe method. A 1:1 mixture of epoxy and polyester resin was assumed for the coatings to steelwork. The coatings were responsible for 51%, 39%, 36%, 34%, 31%, and 24% for IR, OD, POF, CC, PMF, and HT, respectively. In comparison to the average metal product and the coatings to steelwork, the contribution of steel and concrete on the six impact categories were significantly lower and ranging from 12% to 19% and 3% to 8.5%, respectively.

In the construction phase, from Figure 14, it can be seen by far that the greatest contribution is for the construction materials that have been freighted through ships, where the contributions were over 60% for the CC, IR, OD, PMF, and POF, however, only 11% contribution was revealed for the HT. In contrast, the generated waste highlighted the highest contribution to HT with 72%, but the range of contribution was from 8% to 15% for other mid-point indicators. The generated wastewater yielded a contribution range of 20% to 26% on IR, CC, PMF, and a range of 10% to 16% on OD, POF, and HT. Moreover, the diesel revealed a lower contribution for both the IR and

OD with 4% and 6%, respectively. By contrast, the six mid-point indicators appeared not to be affected by the water use activity.

In Figure 15, it can be seen that the annual wastewater generation in the operation phase reported significantly more contribution to the six mid-point impact categories than other activities in the same phase. Additionally, the annual waste generation activity was noticed to have the second-highest contribution on the HT, PMF, and POF with 24%, 18%, and 10%, respectively. Another finding to emerge from Fig. 3d is that the consumed electricity demonstrated 32%, 26%, and 8% impacts on the CC, OD, and POF, respectively.

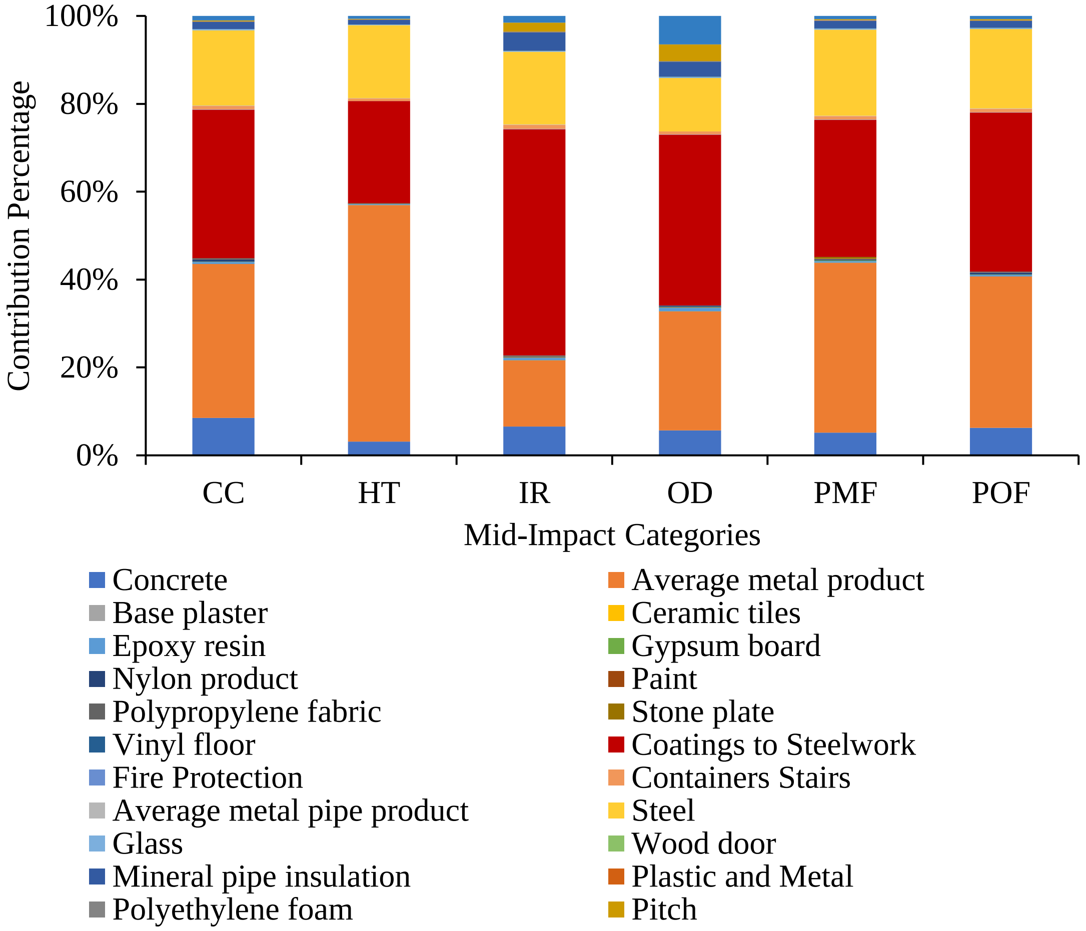

Figure 13. Percentage contribution on each mid-impact category of activities in the production phase

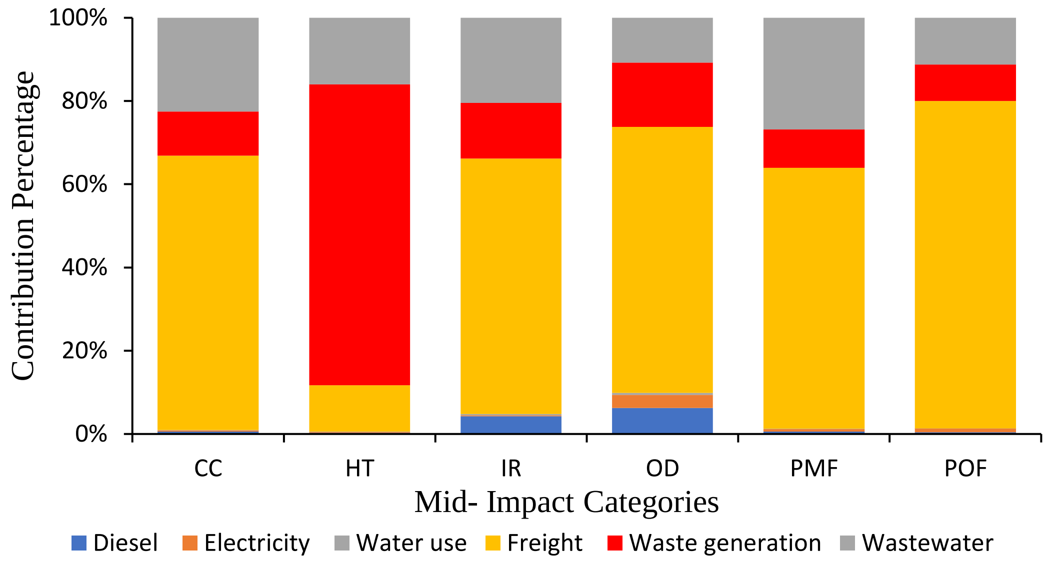

Figure 14. Percentage contribution on each mid-impact category of activities in the construction phase

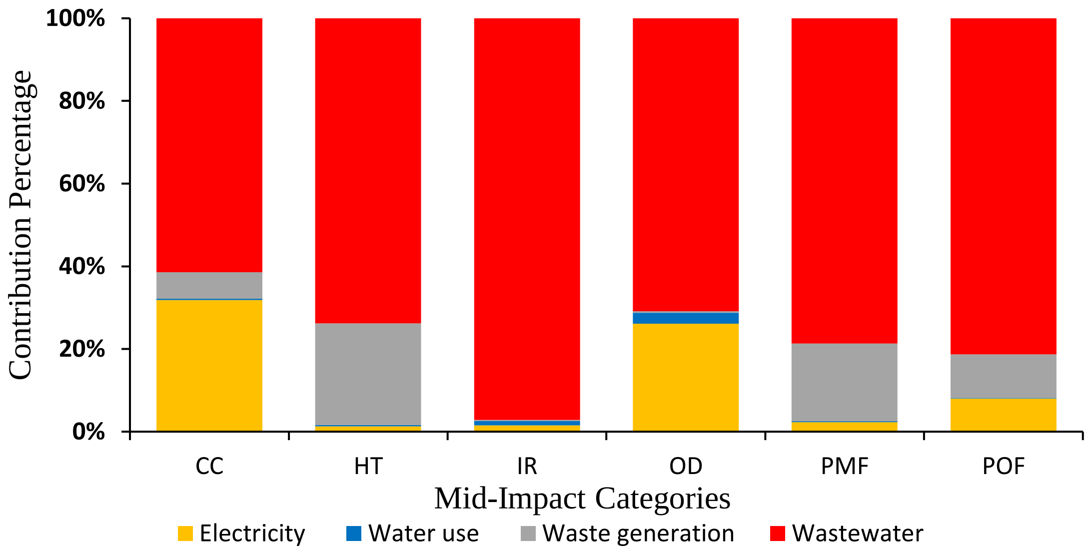

Figure 15. Percentage contribution on each mid-impact category of activities in the operation phase

At the end-point level, after analyzing the impacts of the stadium's life stages on the six mid-point impact categories, the relative damage contribution of each life stage to human health, measured in the unit of DALY, is illustrated in Figure 16 an 17. It can be seen that the majority of social impacts resulted from the production phase with a corresponding DALY value of 8207.5. The damage to human health from the construction and the operation phases was found to be significantly lower than that of the production phase by 85% and 98.6% with a respective DALY value of 1218 and 114.4. This is expected because in the production phase all up-stream activities were included such as raw material extraction and energy consumption in the manufacturing processes, which are all responsible for a wide range of harmful emissions. Figure 16 and 17 are quite revealing as it shows the human health damage that was avoided due to the incorporation of recycled materials in the production phase, which was estimated to be 285.4 DALY, of which 95.8% was due to the use of recycled steel material with a quantity of 1.24E+07 kg. Further analysis showed that for the operation phase, only 1.14% of the contribution to the total damage to human health was assigned to one year of operation shown in Figure 16, while over 30% of the total damage was assigned to 50 years of operation as seen in Figure 17. Overall, the total damage to human health, expressed in DALY, was estimated to be 9539.9 DALY in the first scenario, while it was estimated to be 15145.5 DALY in the second scenario as shown in Figure 18. This dramatic difference between the two scenarios is one of the main striking outcomes in this study owing to the avoided human health damage induced from electricity consumption, and municipal solid waste and wastewater generation for 49 years of operation that corresponds to 5605.6 DALY. Another interesting aspect of Figure 18 is the net benefits of end-of-life management, were due to the reusing and recycling of several materials mentioned in Table 3, the resulted savings was estimated to be 5822.1 DALY, which is equivalent to 61% and 38.4% reduction of the total human health damage in scenario 1 and 2, respectively.

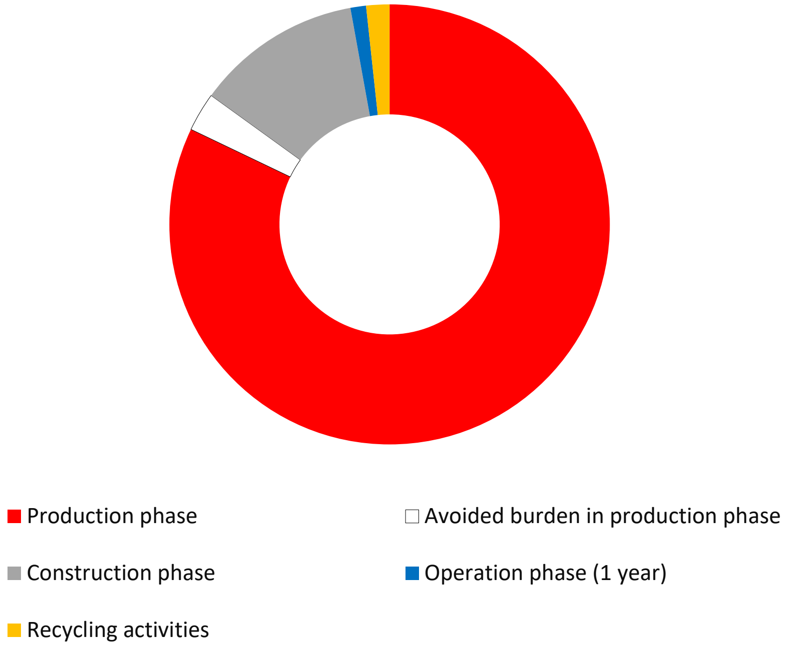

Figure 16. Contribution of each phase to the human health end-point (1st scenario

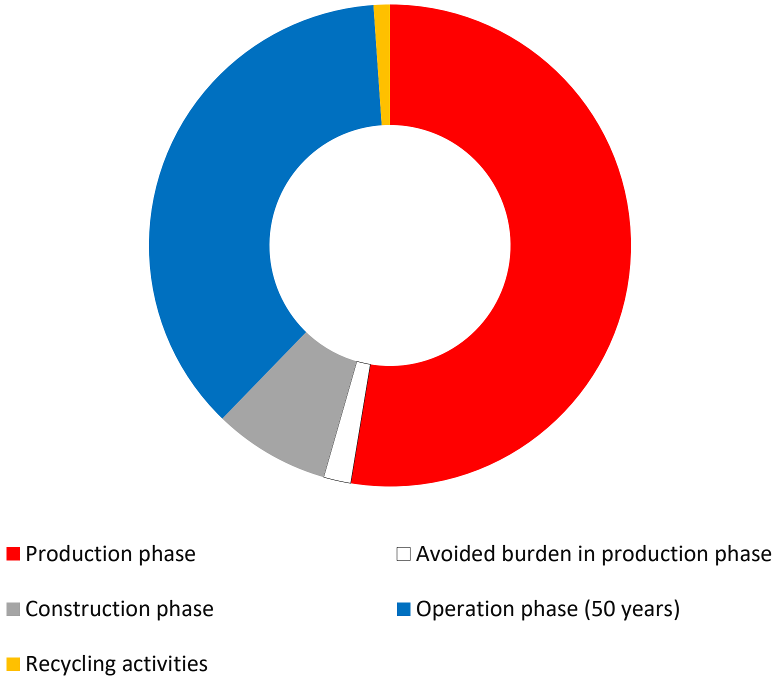

Figure 17. Contribution of each phase to the human health end-point (2nd scenario)

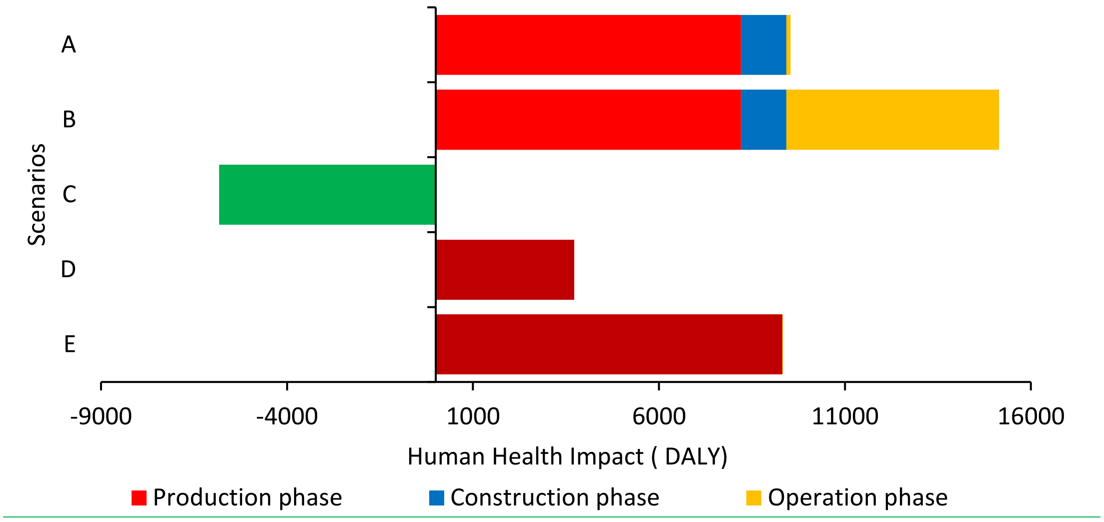

Figure 18. Total human health impacts of A) Scenario 1; B) Scenario 2; C) net savings from EoL phase; D) Net impact in Scenario 1; E) Net impact in Scenario 2 (expressed in DALY)

4.2 End-of-life Scenario

Well known for its reusability post-2022 for building various sporting facilities overseas from the shipping containers, several materials within the defined system boundaries of RAA stadium can be put into use by applying environmental waste (e-waste) management and CE principles. Thus, a prognostic scenario assessment is carried out to understand the end-of-life phase of RAA stadium from a CE perspective. Optimistic and Pessimistic scenarios were studied in brief, where the optimistic scenario takes into account the best possible alternatives that can be applied to the case of stadium construction end-of-life, most applicable in the case of RAA stadium; and, the pessimistic scenario that brings out the worst-case alternative in terms of waste treatment. The optimistic scenario considers the best-referenced e-waste treatment channels for materials that show a significantly high impact on human health that was used for the Ras Abu Aboud stadium. LCIA was performed using the Eco-invent v3.7 database for the EoL scenario. The results aid in understanding the benefits of reuse and recycle in comparison to the extraction of new materials for future use. Assumptions were made considering all possible e-waste treatment measures for the chosen units with a possibility of relatively low damage to human health for the pessimistic scenario accounting to previously existing literature. The percentage contribution across each impact category can be in section 4.1. The end-of-life scenarios based on possible e-waste treatment alternatives are presented in Table 6.

Several studies have shown a medium to low potential for the reuse of concrete due to several deconstruction difficulties. Concrete beams and columns however can be reused in the case of RAA stadium as the concrete panels used are reclaimed and prefabricated materials. Such reclaimed and pre-fabricated concrete panels account for approximately 23.3% of reuse in construction projects (Hradil, et al., 2014). However, from an optimistic point of view, crushed concrete has a high grade of applicability when it comes to the use of crushed concrete as an aggregate in Portland cement (Public works technical bulletin, 2004). Nearly, almost all the steel used in the stadium construction can be put to recycling. 98% of the structural steel and metal-support profiles used for low rise-to-medium rise buildings and monuments are recycled (Blander, 2019). This aptly fits the profile of RAA stadium's "end-of-life" scenario. While only 71% of the metals used as reinforcing materials in concrete structures are recycled due to sorting difficulties. Studies have also shown energy-saving benefits when attempting to recycle premium quality window glass by 25% (Kasper, 2006). These recycled premium quality glass can be used in other upcoming construction projects within the state. The energy saved can support the carbon-neutrality goals of Qatar’s construction sector as a whole once the stadium is dismantled. On the other hand, contaminated glass can also be recycled to be used as grit for sandblasting. The wastewater in the end-of-life phase is treated and can be reused in the district cooling plants and for possible irrigation purposes within the state. PVC thermoplastic sheets can be recovered from landfills to be used in "waste-to-energy" plants (Modern Building Alliance, 2018). For every specified magnitude of the consumed materials, energy, or waste determined in the LCI step, the SLCIA calculations were carried out using Eq. 1 and Eq. 2 (in section 3.2.3) to find the potential impacts on human health in the End-of-life scenario. The total savings from the end-of-life stage due to recycling and reuse strategies specified in Table 6 were also calculated to show how RAA stadium from a cradle-to-cradle perspective can be seen as the most sustainable stadium design inflicting low damage to human health, preserving social sustainability and circularity themes in construction.

Table 6. End-of-life scenario

Units	E-waste treatment alternatives	Optimistic	Pessimistic
Metal support -profile	Dismantling and recycling	100% recycling with source-segregation and sorting of waste tinplate, ferrous metal, and aluminum from residues.	a) 71% recycled for one's used as reinforced material. b) 92% recycled avoiding landfills.
Steel	Endless recycling	100%	98%
Concrete	Reuse/Recycle	100% crushed and stockpiled	23.3% total reuse and landfill
Glass	Recovery and glass furnace recycling	a) Recycling cullet to flat glass furnace b) Grit for sandblasting	Landfill
PVC Thermoplastic sheet	Incineration with energy recovery	100% reuse	a) Incineration with sorting loss b) Landfill recovery with sorting loss

CHP: Combined heat and power production

4.3 Sensitivity Analysis

A sensitivity analysis was conducted to further analyze the most sensitive impact categories across each life cycle stages and compare them for possible volumetric variations under a probabilistic scenario. Montecarlito v1.10 package was used to conduct the sensitivity analysis. Sensitivity analysis helps in choosing the alternatives that generate the lowest damage to the human health category. Based on the percentage contribution of components in each phase of the life cycle across independent impact categories, the highest contributing components were chosen as the variables in the analysis, subject to volumetric changes. The volumetric changes in each material across the life cycle stages resulted in possible variations in the sensitivity levels for each environmental impact categories considered in the study. The sensitivity level for each mid-point impact category was identified by increasing and decreasing the material quantity by ± 0%, ± 10%, ± 20% and ± 30%. In the production of raw material phase, the materials including concrete, average metal product, coatings to steel work upper floors, steel and mineral pipe insulation were considered as the input data due to their high percentage contribution across the impact categories. The volumes of these inputs were then changed to understand the sensitivity level keeping other materials constant. Other materials were not considered for volumetric changes due to their negligible contribution to the environmental impacts. Results for volumetric changes on material quantity in the production of raw material phase can be seen in Table 7. The trends in relation to the volumetric changes are illustrated in Figure 19. Taking the slope of each curve, we can see that human toxicity is the most sensitive impact category in this life cycle phase followed by climate change, particulate matter formation, ionizing radiation, photochemical oxidant formation, and lastly ozone depletion as the least sensitive impact category.

Table 7. Results for volumetric changes on material quantity in the production of raw material phase.

Impact category	-30%	-20%	-10%	0%	10%	20%	30%
Climate change	9.95E+02	1.13E+03	1.27E+03	1.40E+03	1.54E+03	1.68E+03	1.81E+03
Human toxicity	4.61E+03	5.25E+03	5.89E+03	6.53E+03	7.17E+03	7.81E+03	8.45E+03
Ionizing radiation	2.38E-01	2.70E-01	3.03E-01	3.36E-01	3.68E-01	4.01E-01	4.34E-01
Ozone depletion	3.98E-02	4.52E-02	5.07E-02	5.62E-02	6.17E-02	6.71E-02	7.26E-02
Particulate matter formation	1.92E+02	2.18E+02	2.44E+02	2.70E+02	2.96E+02	3.22E+02	3.48E+02
Photochemical oxidant formation	5.29E-02	6.01E-02	6.73E-02	7.45E-02	8.16E-02	8.88E-02	9.60E-02

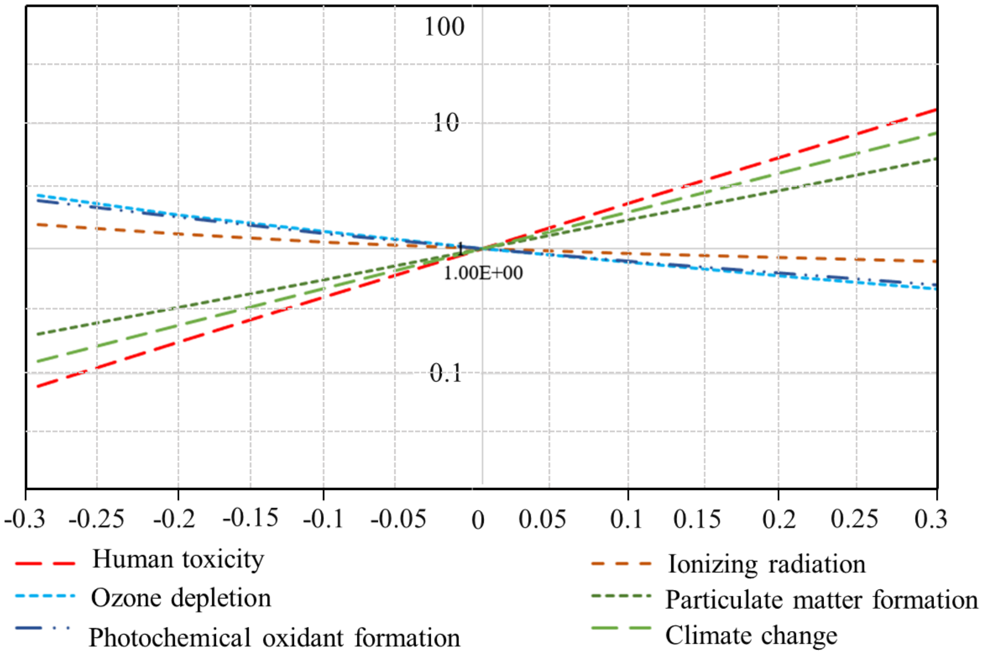

Figure 19. Sensitivity analysis results for impact categories in relation to volumetric changes in the production of raw material phase

In the construction phase shown in Table 8, the volume of waste per kg and freight were changed proportionally, keeping waste water, total power used in Kwh and, water use values unchanged. While, observing the slope of the curves from Figure 20, it can be seen that human toxicity is most sensitive to volumetric changes. This trend is followed by climate change, particulate matter formation, photochemical oxidant formation, ozone depletion, and finally ionizing radiation, classed as the least sensitive environmental impact category.

Similar to the above two phases, volume of waste water, water use and, electricity and cooling were changed by ± 10%, ± 20% and ± 30% in the operations phase of the Ras Abu Aboud stadium S-LCIA results. The rest of the elements were kept constant. Results for volumetric changes on material quantity in the operations phase of the life cycle are shown in Table 9.

Table 8. Results for volumetric changes on material quantity in the construction phase of the life cycle

Impact category	-30%	-20%	-10%	0%	10%	20%	30%
Climate change	9.35E+01	1.07E+02	1.19E+02	1.32E+02	1.45E+02	1.58E+02	1.71E+02
Human toxicity	5.93E+02	6.77E+02	7.61E+02	8.44E+02	9.28E+02	1.01E+03	1.10E+03
Ionizing radiation	1.03E+00	1.04E+00	1.04E+00	4.74E-02	5.21E-02	5.68E-02	6.15E-02
Ozone depletion	8.21E-03	9.20E-03	1.02E-02	1.12E-02	1.22E-02	1.32E-02	1.42E-02
Particulate matter formation	2.25E+01	2.57E+01	2.88E+01	3.19E+01	3.51E+01	3.82E+01	4.13E+01
Photochemical oxidant formation	1.23E-02	1.40E-02	1.57E-02	1.74E-02	1.91E-02	2.08E-02	2.26E-02

Table 9. Results for volumetric changes on material quantity in the operations phase of the life cycle

Impact category	-30%	-20%	-10%	0%	10%	20%	30%
Climate change	5.46E+00	6.22E+00	6.99E+00	7.76E+00	8.53E+00	9.29E+00	1.01E+01
Human toxicity	1.03E+00	1.18E+00	1.32E+00	1.47E+00	1.61E+00	1.76E+00	1.90E+00
Ionizing radiation	9.13E-05	1.04E-04	1.17E-04	1.30E-04	1.44E-04	1.57E-04	1.70E-04
Ozone depletion	1.49E-04	1.70E-04	1.92E-04	2.13E-04	2.34E-04	2.55E-04	2.76E-04
Particulate matter formation	1.06E-01	1.21E-01	1.36E-01	1.51E-01	1.66E-01	1.81E-01	1.96E-01
Photochemical oxidant formation	6.10E-05	6.97E-05	7.83E-05	8.70E-05	9.57E-05	1.04E-04	1.13E-04

The volumetric changes demonstrated climate change as the most sensitive environmental impact category followed by human toxicity, particulate matter formation, ozone depletion, ionizing radiation, and finally photochemical oxidant formation as the least sensitive impact category across the operations phase of the life cycle. These trends can be observed from Figure 21.

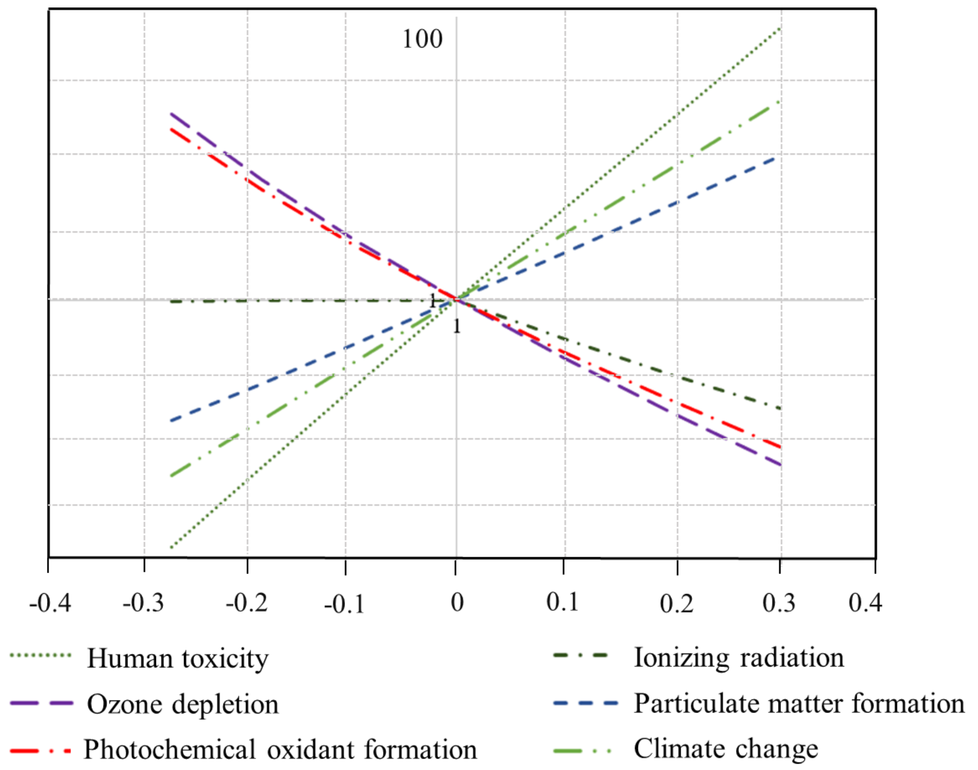

Figure 20. Sensitivity analysis results for impact categories in relation to volumetric changes across construction phase

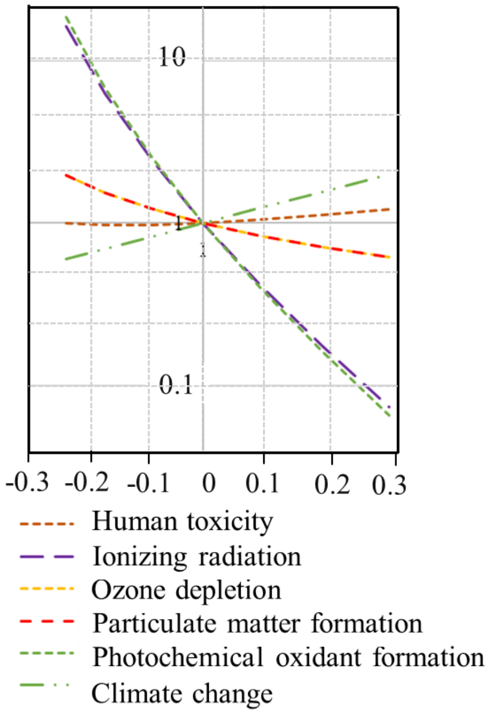

Figure 21. Sensitivity analysis results for impact categories in relation to volumetric changes across operations phase

4.4 Reimaging Legacy Post-FIFA 2022

The demountable shipping containers used in Ras Abu Aboud stadium act as elementary units for several aesthetically pleasing reuse alternatives in real-time applications for sustaining possible future legacies, a pan-Asian legacy initiative of FIFA World Cup 2022^{TM}. Panning out the use of shipping containers post-event helps in cutting down the global carbon footprint from the construction sector, supporting the United Nations Urban Agenda 2030 and 2016 Paris Agreement. It is important to align the possible re-use alternatives of shipping containers with the FIFA World Cup post-event strategies and United Nations 2030 Sustainable Development Goals (UN SDGs) shown in Figure 22 below, to bring the essence of a truly sustainable World Cup event with an ever-lasting legacy from the eye of circularity. The authors have mapped possible reuse alternatives of steel shipping containers with Qatar's Supreme

Committee (SC) vision of rethinking legacy to understand how well these alternatives support harmonizing SDGs post-World Cup.

Qatar has firmly believed in the power of education, a pillar of Qatar National Vision 2030, and supports knowledge management partnerships (SDG 17) to spread quality education in the region and around the globe. The use of shipping containers dismantled from Ras Abu Aboud stadium to construct modular schools supports this vision and can contribute to many SDGs such as quality education (SDG 4), climate action (SDG 13), and sustainable cities and communities (SDG 11). The use of steel shipping containers as sports facilities can also contribute to many SDGs such as innovation (SDG 9), climate change mitigation due to sustainable construction practices (SDG 13), and responsible production and consumption (SDG 12).

Figure 22. United Nations 2030 sustainable development goals (SDGs)

CHAPTER 5: CONCLUSION AND FUTURE WORKS

This research is the first of its kind to conduct a full S-LCIA for reusable container stadiums tailored for FIFA World Cup mega events, taking the case of Ras Abu Aboud stadium in the State of Qatar. This study investigated the impacts of utilizing materials, energy, water, and waste on human health under a circular economy model using the cradle-to-cradle approach. The study commenced with data collection for a thorough system boundary starting with material production, followed by construction and operation phases, ending with end-of-life management to assess the potential social impacts associated with all life cycle phases on the end point damage category Human health. Ecoinvent v3.7.1 life cycle impact database using the ReCiPe 2008 Egalitarian model was employed to calculate the endpoint impact values for the human health category. Results have shown that the production phase was responsible for nearly 86% of the total damage to human health with a DALY value corresponding to 8,207, whereas the construction and the operation phases were responsible for significantly lower damage with a DALY value of 1,218 and 114.4, respectively. Based on the S-LCIA results, it was seen that 5% of the total social burden, which corresponds to 456 DALY, was avoided due to the use of recycled materials in the construction of Ras Abu Aboud stadium. A possible end-of-life scenario from an e-waste management perspective was also presented in this research. This helps the research community in thinking outside the box when attempting to tackle the significant environmental concerns from land-filling large quantities of construction waste generated annually. The sensitivity analysis revealed human toxicity as the most significant impact category for possible percentage variations across the production of raw material and construction phase. While climate change was the most sensitive impact indicator in the operations phase, subject to volumetric variations in the quantity of materials used.

Further reflection of the research findings shows that overall social impacts can be reduced by various strategies like using some examples of alternative low-energy materials, applying prefabrication to reduce construction emissions, and end-of-life recycling. In this regard, many studies have discussed the applicability of sustainable alternatives, for instance, concrete can be substituted by using blended cements that contain high volume of cementing complementary materials. Whilst, recycling and reuse of steel and metals can result in considerable savings of energy; see (Reddy, 2009; Hertwich, et al., 2019). Additionally, a shift towards sustainable construction and environmental preservation can be embraced by a circular model or approach for end-of-life materials recycling.

Ras Abu Aboud stadium being a reusable container stadium can be dismantled and brought back to picture at ease in relation to the traditional tip-to-toe construction, where the stadium design acts as a blueprint for any sustainable mega event across the globe in future. In this regard, further study can be conducted to quantify the social impacts of modular versus conventional stadium design for an innovative reusable stadium. The authors suggest the use of attributional life cycle assessment (A-LCA) an ISO 14040:2006 standardized life cycle tool to better understand the system flows when using a cradle-to-cradle approach. A hybrid-LCA model combining process-LCA with input-output approach is well suggested to identify the embodied socio-economic and environmental impacts of stadium construction projects. A full-life cycle impact assessment model integrated with life cycle costing approach is suggested to quantify the economic costs along with the environmental impacts. A probabilistic weighted likelihood estimation can be used to model the end-of-life scenarios, where the weights assigned to each unit is a statistical distribution and a range of values can be obtained for each pessimistic and optimistic scenarios by varying the likelihood value. However, complexities arises as the number of units in the end-of-life approximation increases. Non-parametric methods including Data Envelopment Analysis (DEA) combined with LCA and carbon footprint accounting can be used to study the big picture sustainability performance of all the world cup stadiums in Qatar to understand the pre and post world cup impacts on the State of Qatar and neighboring countries. The shipping containers utilized in Ras Abu Aboud stadium can be reused for various applications. To give an instance, locally the containers can be applied in the growing trend of urban farming for ecological food production, as retail units, temporary storages etc. More value can be earned from shipping the containers to other countries, especially with high refugee and low-income population, to be adapted for affordable housing projects, schools and mobile healthcare units.

The presented research act as a roadmap for developing economies that target to address sustainability when hosting future world cup mega events; however, the research study has several limitations that are worth mentioning. In the first place, this research study was conducted during the construction phase of Ras Abu Aboud stadium, therefore, there is a great deal of assumptions made regarding the operational phase data provided by the World Cup 2022 hosting committee. Another limitation is the focus of this study on S-LCA approach that considers the human health damage point alone, ruling out the ecosystem quality and resource depletion damage points, that hold a great scope for a life cycle impact assessment comparative study. These limitations can pave pathways for further research in this selected area of knowledge. The current study has focused on evaluating the social impacts of the stadium life cycle, yet more socioeconomic impact categories namely employment and income generation can be added to the analysis and further broadened. The circular economy strategies presented for end-of-life phase can be extended in a more detailed study that would quantify the benefits and costs of each alternative, which would in return help in better decision making. Also, applications of more advanced multi-criteria decision techniques would further assist decision makers on choosing best alternatives while incorporating green design practices and possible retrofits.

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