



LIFE CYCLE ASSESSMENT OF PRESTRESSED CONCRETE RAILWAY BRIDGES IN HIMALAYAN REGION: A CRITICAL REVIEW

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ABSTRACT

This paper explores the imperative of adopting sustainable design approaches in infrastructure development to align with the United Nations' Sustainable Development Goals (SDGs). It investigates the application of multi-criteria decision-making methods in assessing infrastructure sustainability, with a focus on prestressed concrete bridges, pivotal components of modern infrastructure. Through an examination of sustainability impacts and criteria, the study highlights the prevalent use of the Analytic Hierarchy Process and the Simple Additive Weighting method in decision-making processes. Despite the regular employment of life cycle assessment, adherence to standardized concepts remains somewhat limited, presenting opportunities for refinement, particularly regarding the handling of linguistic variables. Prestressed concrete bridges are recognized for their numerous advantages, including extended spans and reduced maintenance requirements, yet they pose challenges such as specialized material and skilled labour demands. This paper concentrates on prestressed railway bridges in the Himalayan region, acknowledging the unique challenges presented by this environment and the critical need for sustainable infrastructure solutions in such contexts.

Keywords: Sustainability, Bridges, Economics, Society and Environment

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1. INTRODUCTION

The cornerstone of defining sustainable development originates from the Brundtland Commission report (WCED, 1987), which frames it as "development that satisfies the needs of the current generation without jeopardizing those of future generations." This concept identifies the economic, environmental, and social aspects as the fundamental components or pillars. Thus, achieving sustainable development implies a harmonization of these three primary aspects, each typically pursuing distinct objectives. The figure referenced below, identified as Figure 1, demonstrates the interconnection of economic, social, and environmental elements (Mebratu, 1998). This depiction underscores that sustainable development relies on the three pillars of the Triple Bottom Line (TBL) approach.



Figure 1: Sustainable Development model from Mebrahtu 1998

The construction sector is notably dynamic, exerting significant influence on global economic, environmental, and social dimensions. This highlights the urgent need for a transition toward sustainable practices in building and infrastructure development. Bridges, emblematic of engineering and architectural prowess, serve not only to connect land masses but also to facilitate efficient transportation between diverse locations. Thus, ensuring sustainable practices throughout their entire life cycle is crucial. While economic and environmental aspects have received considerable attention in sustainability assessments, the social dimension has been comparatively overlooked, with limited research available. Recent studies indicate that the infrastructure industry is a major contributor to environmental stress, accounting for significant energy consumption (30 percent), greenhouse gas emissions (30 percent), and raw material extraction (40 percent) (Choi, 2019). Projections suggest a substantial increase (40 % approximately) in cement production by 2030 compared to 2013 levels (Imbabi et al.2013).

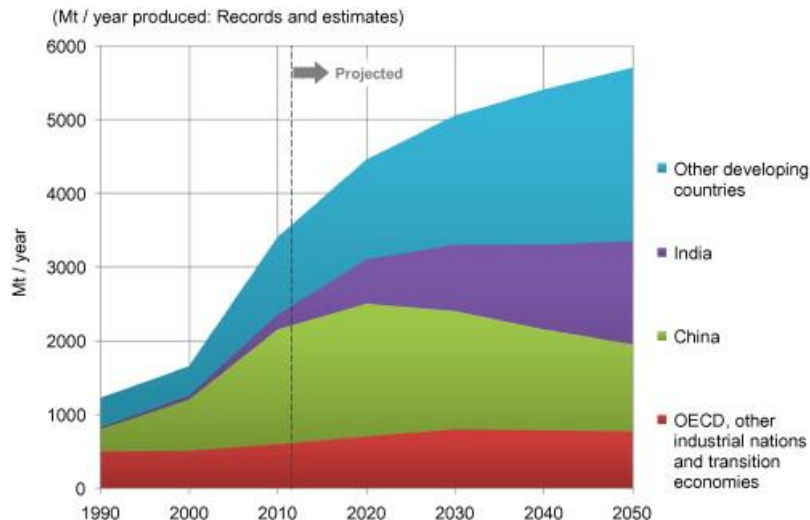


Figure 2: World Portland cement production rate 1900-2050

Estimates from the International Monetary Fund suggest that increasing infrastructure investment in Gross Domestic Product (GDP) by just 1%, could result in an overall 1.5% increase in global GDP in four years. Coincidentally, approximately 20% of loan granted by World Bank have been directed towards transportation infrastructure. Additionally, the construction sector contributes roughly 9% to the GDP of Europe and supports 18 million jobs directly (Favier et al., 2018). With growing concerns about the economic, environmental, and social impacts of the construction sector, sustainability in infrastructure development has gained prominence. This urgency was recognized by the United Nations through the establishment of SDG 9 in 2015, emphasizing the immediate need for reliable, sustainable, and resilient infrastructure by 2030. Research conducted by NCE (2016) highlights the positive effects of sustainable infrastructure design, linking it to the achievement of multiple Sustainable Development Goals (SDGs). Sustainable infrastructure not only fosters economic growth and reduces inequalities but also promotes responsible consumption and facilitates the development of sustainable cities. Moreover, it plays a crucial role in addressing climate change and protecting biodiversity, directly contributing to SDGs 13 and 15. In conclusion, NCE (2016) appropriately emphasizes that investing in sustainable infrastructure is crucial for addressing global challenges and securing a sustainable future for all. Given these circumstances, particular attention is required for infrastructure exposed to extreme environmental conditions that may accelerate degradation processes, compromising their functionality and leading to substantial demand in maintenance throughout the service life. Concrete, being the most utilized construction material in the world and most used substance globally following water, poses one of the most challenging issues in recent times for the construction industry. Additionally, maintenance of wear and tear of structures made with concrete have quoted greater challenges in recent times for the construction industry (Gjørsv, 2013). The annual costs incurred for repair activities in only Europe on concrete structures exceed €15 billion, which is 50% on higher side than of the continent's budget on construction works annually (Zewdu et al., 2013). The impact of maintenance activities of concrete structures becomes precisely significant in the harsh hilly environment where the most recognized threat is rainfall. According to a report by NACE (2016), the direct cost associated with wear and tear is nearly 3.4% of the world's GDP. Implementing effective wear and tear control practices could result in economic savings ranging between 15% and 35% of the yearly losses due to wear and tear.

It is essential to emphasize here that the maintenance needs associated with wear and tear lead to considerable environmental emissions due to the resulting increase in demands for concrete and cement production. Concrete production alone accounts for annual emission of 8% carbon dioxide globally (Olivier et al., 2012).

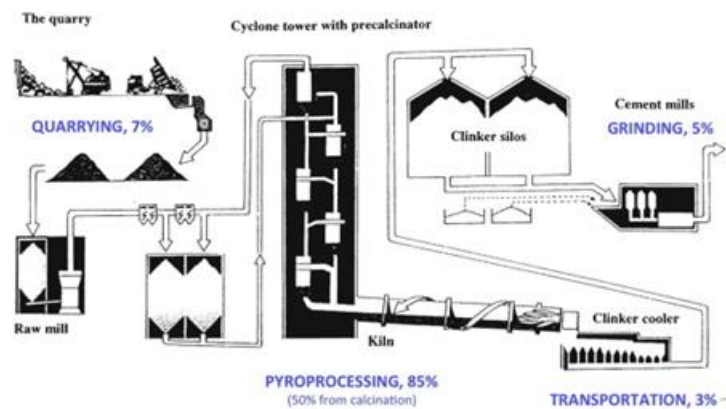


Figure 3: Share of total CO₂ emissions across the Portland cement production process.

Approximately 20% of Europe's cement production is utilized for maintenance and rehabilitation projects (Favier et al., 2018). The proportion of consumption of cement in Western Europe dedicated to works related to rehabilitation endeavours has risen from approximately 34% of total construction-related consumption in 2007 and in the year 2017 is about 44%.

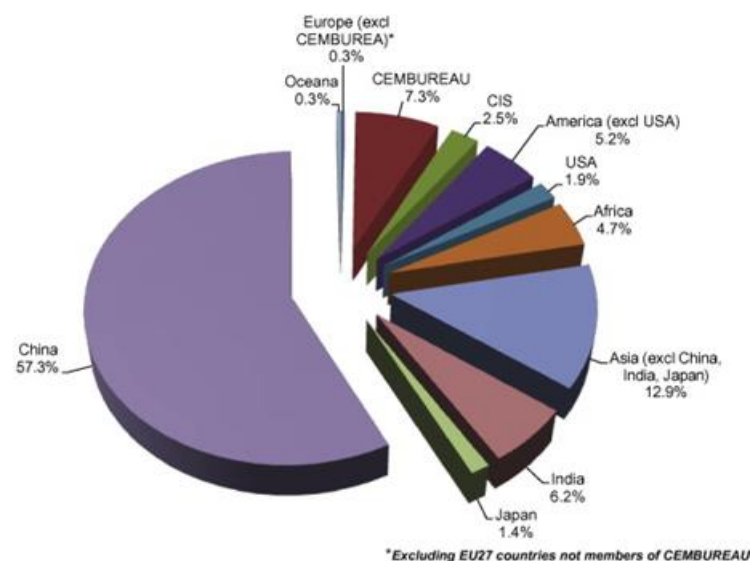


Figure 4: World Portland cement production

Given the profound impact of the construction sector on society, economy, and the environment, particularly in regions like the Himalayas where corrosion poses significant challenges, it is imperative for the 2030 Agenda to prioritize sustainability considerations in structural design. Sustainable designs involve weighing economic, environment, and social factors. However, current infrastructure sustainability assessment often overlook the social dimension, focusing primarily on economic and environmental aspects with less attention on social aspect (Diaz-Sara Chaga et al., 2016). There exists a considerable knowledge gap in evaluating societal impacts throughout a product's lifecycle (Jorgensen, 2013).

It is understood that life cycle assessment (LCA) methodologies on environmental lifecycle are well-established not only methodologically (ISO, 2006a) but also in its implementation practically (ISO, 2006b), however the social life cycle assessment (SLCA) is still in its new and requires further development efforts (Sierra et al., 2018a). Although guidelines for SLCA have been established (UNEP/SETAC, 2009), inconsistencies in defining social criteria and applying evaluation techniques underscore the need for coherent ISO 14040 methodology aligned with accepted LCA standards for social assessment. Despite the existence of tools and standards for life cycle assessments, there is still no consensus on their integration into infrastructure sustainability assessments (UNEP/SETAC 2013). Goodland's quoted "The urgency for sustainability arises from the realization that profligate, extravagant and inequitable nature of current patterns of development are unsustainable and lead to biophysical impossibilities" (Goodland, 1995). The concept of sustainability gained traction with the Brundtland Commission's 1987 report "Our Common Future" and was further reinforced at the 2002 World Summit on Sustainable Development. The adoption of the Kyoto Protocol in 1997 was a pivotal moment, laying the groundwork for reducing greenhouse gas emissions within the context of sustainable development.

Quoting the 1987 Brundtland Report, "sustainable development is described as meeting present needs without compromising the ability of future generations to meet their own needs". This commitment to sustainability necessitates integrating this perspective into every stage of a project's lifecycle, especially during design. Thoughtful design and planning can lead to environmentally friendly projects, reducing energy and resource consumption. Eco-design involves assessing existing products throughout their lifecycle to identify areas for improvement and addresses products in early development stages to proactively minimize future environmental and socio-economic costs. Regardless of the focus on economic (Norris, 2001), environmental, or social (O'Brian M. et al., 1996) considerations, any method of assessment should encompass the lifecycle of the system entirely under study. The Life Cycle approach has become essential for sustainable design.

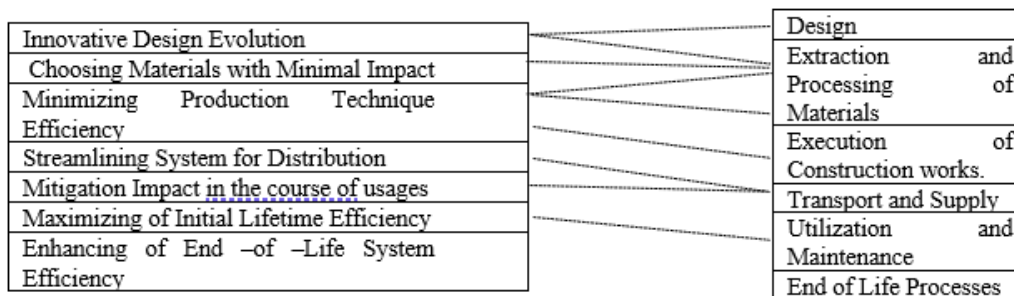


Figure 5: Relation between eco-design strategies and life cycle of product

Through the implementation of efficient environmental management practices, companies can achieve tangible advantages, including lower energy and resource usage, reduced environmental penalties, and the opportunity to capitalize on positive eco-friendly branding. Nowadays, society places growing emphasis on environmental concerns, hence, a strong environmental management system becomes a cornerstone in corporate strategies, laying the foundation for competitive advancement where a sustainable future is the central goal (Hart, 1997).

2. EVALUATION OF THE CURRENT METHOD OF WORKFLOW

2.1. Sustainable Construction

The construction sector plays a significant role in Europe's resource and energy usage, waste production, and greenhouse gas emissions. Sustainable construction is of paramount importance to engineers and developers, who are responsible for creating environmentally conscious structures. To achieve this goal, sustainable construction is integrated into European policies and is supported by various standards and regulations governing processes and materials in the building sector. Sustainable construction goes beyond designing and constructing new buildings and infrastructure with good environmental performance; it also involves assessing existing structures for areas needing modifications to meet sustainability goals. Engineers should explore the use of eco-friendly materials or processes when evaluating these existing constructions to reduce the impact of demolition or waste disposal. Additionally, creating structures that require fewer maintenance operations over their lifespan helps reduce energy and resource consumption and prolongs their service life, minimizing the need for premature replacement.

Recently, environmental concern has become a priority in the construction structure, responsible for consumption of 30% of energy globally, 40% of extraction of raw material, and 30% of emission of greenhouse gases (Choi, 2019). Interestingly, cement production for concrete alone contributes roughly 8% of the world's CO₂ emission annually (Olivier et al., 2012). On the other hand, investments in public infrastructure, such as transportation projects, play a vital role in promoting economic prosperity and social advancement. These projects enhance regional connectivity and provide essential services, with approximately 20% allocation of recent World Bank loans for the development of infrastructure in the field of transportation (Kyriacou et al., 2019). Recognizing the significant impact of infrastructure design, especially considering their long-term service to diverse segments of society, researchers have increasingly focused on assessing various sustainability dimensions in reference to the design of infrastructure. Studies have explored cost optimization in both design of infrastructure (Yepes et al., 2017; Garcia-Segura et al., 2014a) and maintenance (Safi et al., 2015; Frangopol, 2011). Impact of Environmental throughout the life cycle of structures, from bridges (Zhang et al., 2016; Navarro et al., 2018c; García-Segura et al., 2018) to buildings (De Belie & Van den Heede, 2014), and specific construction processes like production of concrete (Braga et al., 2017), have been subjects of investigation. Social impacts associated with the use of various materials used in construction of building (Hossain et al., 2018) and also for connectivity driven projects related to road development (Sierra et al., 2018b) have been recently shortlisted. Despite the presence of standardized tools for quantifying the product's life cycle impacts, currently there is no commonality on objective and universal methodology for evaluating the sustainability of design of a particular infrastructure. The lack of agreement extends to how to simultaneously consider the three pillars defining sustainability or which specific criteria should guide in the process of decision making in sustainable design of infrastructure (Montalban-Domingo et al., 2018). To address the assessment of conflicting sustainability dimensions in a long-term context and multi-stakeholder in the design of infrastructure, the use of multi-criteria decision-making (MCDM) techniques has emerged as the most suitable approach compared to other commonly used methods in infrastructure design, such as single or multi-objective optimization. MCDM techniques enable decision makers to evaluate problem complexity comprising of divergent and multiple parameters based on the subjective judgments of a panel of experts or stakeholders who are most influenced by the decision.

2.2. Review stages

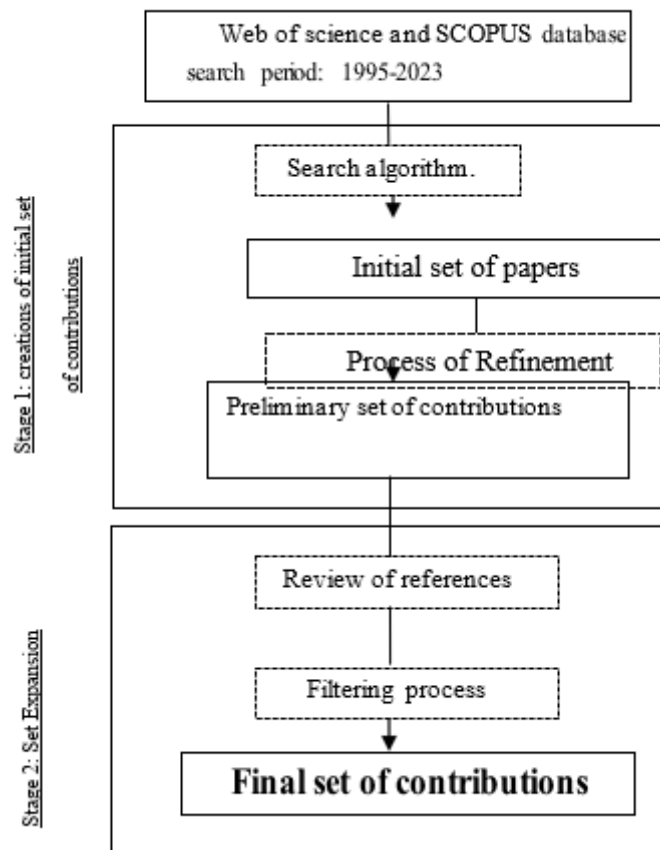


Figure 6: Different stages of review

The exploration utilizes scientific database from bibliographs like SCOPUS, Web of Science, and others. Also from 1995 to 2023 is the considered timeframe range, as no relevant contributions have been identified before this period. The algorithm used to identify initial articles involves a combination of terms such as "Multi criteria decision making," "MCDM," and "Sustainability," along with other terms related to civil engineering, such as "Construction" or "Infrastructure." This is accomplished using "AND" and "OR." From Boolean algebra.

To enhance the quality of the obtained results, various criteria for exclusion were adopted to form the initial set of papers. Initially, only original, scientific peer-reviewed articles and proceedings of conference were taken into account. Moreover, manuscripts deprived of clear identification of use of MCDM technique used or which do not follows the criteria of sustainability considerations were excluded. Additionally, articles were required to evaluate at least two of the three dimensions of sustainability through a thoughtful selection of decision criteria. Lastly, only English-language articles were included in this study.

After compiling the initial set of contributions, the cited references in the manuscript selected underwent scrutiny. Sets by applying the filtering process to the referred articles in the papers sorted in the earlier lot were then expanded, resulting in the expansion of final set of manuscripts. The same technique of sampling has been earlier seen in previous literature review work (Sierra et al., 2018; Zamarron-Mieza et al., 2017), yielded a total of 83 contributions.

However, in 2007, there was a notable increase in publications addressing sustainability assessment of infrastructures, followed by a significant surge observed in 2015. More than half of the reviewed publications utilizes techniques of MCDM for sustainable design of infrastructure emerged after 2015, indicating a notable shift compared to the preceding decades (1996 to 2014). This surge can be attributed to the establishment of the Sustainable Development Goals by the United Nations General Assembly in 2015. Among the 17 nos of Goals outlined, several are directly related to growth of economy sustainably, resilient, decent work, and infrastructures sustainability, and climatic action. This highlights the considerable efforts made by the scientific and research community since 2015 to facilitate the sustainable design of infrastructures.

As suggested by information the data gathered after study of publication from 1996 to 2023, the MCDM techniques can be broadly applied in 6 main categories which are as follows:

- **Buildings:** With 38.6% (32 publications), MCDM techniques have been widely applied for assessment of aspects of sustainability for design of buildings. Authors have primarily emphasised either on assessment of designs of particular structural elements of buildings such as columns (Pons & De la Fuente, 2013), slabs (Blanco et al., 2016; Reza et al., 2011), and beams (Mosalam et al., 2018), or the research on assessment of sustainable design of building envelopes namely Guzmán-Sánchez et al., 2018; Hashemkhani et al., 2018; Invidiata et al., 2018; Kamali et al., 2018; Moussavi et al., 2017; Gilani et al., 2017; Jalaei et al., 2015; Perini & Rosasco, 2013; Saparauskas et al., 2010 along with comparison of different construction materials by Motuziene et al. & Nassar et al., Samani et al. (2015), Akadiri et al. (2013), and Pons and Aguado (2016). Moreover, apart from that some publications have also been made for development of the indicators suitable for measuring the sustainability of buildings such as Mahdiraji et al., 2018; Ignatius et al., 2016; Drejeris & Kavolynas, 2014; Yu et al., 2012; Alwaer & Clemens-Croome, 2010. Special emphasis is given to the sustainable planning of industrial structures. by Heravi et al., 2017; Cuadrado et al., 2016; Cuadrado et al., 2015; Lomber & Aprea, 2010. Formisano and Mazzolani (2015), as well as Terracciano et al. (2015), aim to assess sustainability of various options for energy retrofitting of buildings in regions with high seismic activity. Additionally, other objectives are addressed, including restoration alternatives for abandoned buildings (Zavadskas et al.2010,2007), and optimal building placement (Hosseini et al.,2016).
- **Bridges:** Thirteen papers, accounting for 15.7% of the examined manuscripts, focus on the sustainability assessment of bridges. Top of Form Assessment is mainly categorized on sustainability of bridge deck designs (Kripka et al., 2019; Yepes et al., 2015a; Jakiel & Fabianowsky, 2015; Balali et al., 2014; Gervásio & Da Silva, 2012; Farkas, 2011; Malekly et al., 2010).
- **Energy Infrastructures:** Twelve papers, constituting 14.5% of the overall publications, delve into the sustainability of various aspects of energy infrastructure. These topics include the evaluation of one of the most versatile sustainable systems in energy production (Väisänen et al., 2016; Montajabiha, 2016; Barros et al., 2015; Klein & Whalley, 2015; Barros et al., 2015; Kaya & Kahraman, 2010; Jovanovic et al., 2009; Begic & Afgan, 2007). Conversely, discussions have revolved around the optimal siting of energy production plants and the for sustainable performance evaluation of various designs of wind turbines and towers by González et al., 2018; Fetanat & Khorasaninejad, 2015 and De la Fuente et al., 2017a; Pons et al., 2017; Gumus et al., 2016 respectively.
- **Hydraulic Infrastructure:** Approximately 13.3% numbers of the publications discuss the sustainability considerations of various hydraulic infrastructure, encompassing dams (Afshar et al., 2011; Sun et al., 2013; Gento, 2004), urban drainage (Martin et al., 200; Yazdandoost & Tahmasebi, 2018; Dong et al., 2008), sewerage systems (De la Fuente et al., 2016b), and systems of supply of water (Chhipi-Shrestha et al., 2017; Pascal et al., 2017; Abrishamchi et al., 2005; Jaber & Mohsen, 2001).

- Transport Infrastructure: A portion of 7.2% of the research literature focuses on elements and concepts associated with the transport system, addressing aspects such as the sustainable design of road pavements (Santos et al., 2019; Torres-Machí et al., 2015; Kucukvar et al., 2014; Jato-Espino et al., 2014). This includes topics like the optimal selection of road locations (Hashemkhani et al., 2011) and the creation of assessment tools for evaluating transport projects (Oses et al., 2017).
- Transport Infrastructure: Around 7.2% of the research literature focuses on elements and concepts related to the transport system, covering aspects such as the design sustainability of road pavements (Santos et al., 2019; Torres-Machí et al., 2015; Kucukvar et al., 2014; Jato-Espino et al., 2014). This also includes topics such as the optimal selection of road locations (Hashemkhani et al., 2011) and development of tools for assessing and evaluating transport infrastructure projects (Oses et al., 2017).
- Others: The remaining 10.7% of papers encompass a range of topics covering various aspects of sustainable design. These include assessments for tunnel projects (De la Fuente et al., 2017b & 2016a), ports (Asgari et al., 2015), the location of demolition waste facilities (Banas et al., 2010), the selection of coating materials for construction (Rochikashvili & Bongaerts, 2016), and the development of assessment tools for evaluating construction projects in general terms. (Dobrovolskiiene & Tamosiuniene, 2016; Reyes et al., 2014; Saparauskas, 2007; Ugwu & Haupt, 2007).
- Others: The remaining 10.7% of paper covers various aspects of sustainable design. These include assessments for projects related to tunnel (De la Fuente et al., 2017b & 2016a), port development (Asgari et al., 2015), the demolition waste facilities sitting (Banas et al., 2010), the selection of construction coating materials (Bongaerts & Rochikashvili, 2016), and the development of tools for evaluating construction projects more broadly (Dobrovolskiiene & Tamosiuniene, 2016; Reyes et al., 2014; Saparauskas, 2007; Ugwu & Haupt, 2007).

Economic Criteria

Only 7 Out of the 83 reviewed manuscripts do not consider economic criteria in their sustainability assessments. In rest 76, three main economic impacts have been identified, namely the construction or implementation costs, the costs derived from maintenance and operation of the infrastructure, and the costs resulting from the end-of-life stage. 94.7% of the reviewed papers that consider the economic dimension of sustainability assumes the costs derived from the installation of the infrastructure relevant in the assessment. Only 13.3% of the reviewed papers consider the direct costs associated with the disposal of the infrastructure in their assessments, and 63.9% the costs of the maintenance and operation life cycle stage.

It is to be noted that, among the papers reviewed, only 5 explicitly present the assumed discount rates that allow to transform future costs into present currency values. In the case of building design, Mosalam et al. (2018) consider a discount rate of 3%, Jalei et al. (2015) assumes a discount rate of 5%, and Perini and Rosasco (2013) evaluates three different economic scenarios, with discount rates that range from 4.5% to 5.5%. Torres- Machi et al. (2015), when assessing the sustainability of road pavement treatments, assume a discount rate of 5%. Klein and Whalley (2015) evaluate a cost discounting range that varies from 3% up to 10%.

2.2.1.2. Environmental Criteria

Referring aspects of sustainability with respect to the environmental dimensions, studies are widely reviewed and discussed which further can be fractionated between 7 main impact categories namely emissions of pollutants, consumption of energy, raw material (resource) consumptions, generation of wastes, use of land, eutrophication, and depletion of ozone layer. Below mentioned table may be referred to assess the category wise references:

Table 1: Major Environmental indicators and criteria

Environmental Criteria	Indicator	Type of Assessment	References
(i)Emission of Pollutants	Kg CO ₂ /Output unit	Quantitative	Santos et al. (2019); Guzmán Sánchez et al. (2018); Invidiata et al. (2018); Medina-González et al. (2018); Osés et al. (2017); Gilani et al. (2017); Moussavi et al. (2017); Pons et al. (2017); De la Fuente et al. (2017a, 2017b, 2016a, & 2016b); Motuziene et al. (2016); Nassar et al. (2016); Väisänen et al. (2016); Blanco et al. (2016); Torres-Machí et al. (2015); Klein & Whalley (2015); Barros et al. (2015); Samani et al. (2015); Yepes et al. (2015); Kucukvar et al. (2014); Jato-Espino et al. (2014); Pons & De la Fuente (2013); Pons & Aguado (2012); Reza et al. (2011); Jovanovic et al. (2009); Begic & Afgan (2007)
	Kg SO ₂ /Output unit	Quantitative	Medina-González et al. (2018); Osés et al. (2017); Väisänen et al. (2016); Klein & Whalley (2015); Barros et al. (2015); Samani et al. (2015); Reza et al. (2011); Begic & Afgan (2007)
	Kg NO _x /Output unit	Quantitative	Medina-González et al. (2018); Osés et al. (2017); Väisänen et al. (2016); Klein & Whalley (2015); Barros et al. (2015); Samani et al. (2015); Reza et al. (2011); Begic & Afgan (2007)
	€/kg pollutant removed	Quantitative	Perini & Rosasco (2013)
	Costs of medical care needs due to pollution (€)	Quantitative	Mikawi (1996)
	Oxygen, Nitrogen and Phosphates emitted to water	Quantitative	Dong et al. (2008)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018); Kamali et al. (2018); Mahdiraji et al. (2018); Tahmasebi & Yazdandoost (2018); Pascal et al. (2017); Heravi et al. (2017); Rashidi et al. (2017 & 2016) Montajabiha (2016); Gumus et al. (2016); Rochikashvili & Bongaerts (2016); Dobrovolskiene & Tamosiuniene (2016); Jalaei et al. (2015); Cuadrado et al. (2015); Jakiel & Fabianowski (2015); Fetanat & Khorasaninejad (2015); Asgari et al. (2015); Drejeris & Kavolynas (2014); Balali et al. (2014); Chen (2014); Reyes et al. (2014); Sun et al. (2013); Akadiri et al. (2013); Yu et al. (2012); Farkas (2011); Hashemkhani et al. (2011), Kaya & Kahraman (2010); Saparauskas et al. (2010); Wang et al. (2008); Dabous & Alkass (2008); Ugwu & Haupt (2007); Jaber & Mohsen (2001)

(ii) Energy Consumption	MJ(MWh)/output unit	Quantitative	Santos et al. (2019)
	Assessment by experts through point scale	Qualitative	Guzmán-Sánchez et al. (2018); Invidiata et al. (2018); Medina-González et al. (2018)
(iii)Raw material consumption (Resource Depletion)	Consumption/output unit	Quantitative	Santos et al. (2019); Medina-González et al. (2018); Guzmán Sánchez et al. (2018); Gilani et al. (2017); Moussavi et al. (2017); De la Fuente et al. (2017a, 2017b, 2016a); Blanco et al. (2016); Samani et al. (2015); Klein & Whalley (2015); Jato-Espino et al. (2014); Kucukvar et al. (2014); Pons & De la Fuente (2013); Reza et al. (2011); Gento (2004)
	Assessment by experts through point scale	Qualitative	Kamali et al. (2018); Heravi et al. (2017); De la Fuente et al. (2016b); Ignatius et al. (2016); Cuadrado et al. (2015); Jalaei et al. (2015); Drejeris & Kavolynas (2014); Akadiri et al. (2013); Yu et al. (2012); Lombera & Aprea (2010); Baniyas et al. (2010); Ugwu & Haupt (2007)
(iv)Waste generation	Kg/output unit	Quantitative	Medina-González et al. (2018); Gilani et al. (2017); Samani et al. (2015); Kucukvar et al. (2014); Pons & Aguado (2012)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018); Kamali et al. (2018); Heravi et al. (2017); Cuadrado et al. (2015); Asgari et al. (2015); Drejeris & Kavolynas (2014); Reyes et al. (2014); Akadiri et al. (2013); Yu et al. (2012); Lombera & Aprea (2010); Baniyas et al. (2010); and Ugwu & Haupt (2007)
(v) Eutrophication	Aquatic ecotoxicity, salinity, biological indices kg Phosphate/output	Quantitative	Vaisanen et al. (2016); Dong et al. (2008); Martin et al. (2007); Santos et al. (2019); Medina-González et al. (2018); Väisänen et al. (2016); Nassar et al. (2006); Samani et al. (2015)
	Assessment by expert through point scale	Qualitative	Sun et al. (2013); Afshar et al. (2011) Lombera & Aprea (2010); Ugwu & Haupt (2007)
(vi) Ozone depletion	Kg CFC (Chlorofluorocarbons)/output unit	Quantitative	Santos et al. (2019); Medina-González et al. (2018); Motuziene et al. (2016); Nassar et al. (2016); Väisänen et al. (2016); Samani et al. (2015)
	Assessment by experts through point scale	Qualitative	Akadiri et al. (2013); Lombera & Aprea (2010)

The emission of pollutants stands out as a primary focus in the literature reviewed when assessing the impact of environment on infrastructure. This criterion encompasses emissions from both the production of construction materials and activities, as well as external factors such as congestion in traffic congestion during construction and maintenance (Mikawi, 1996). Some researchers have specifically targeted air pollutants like carbon dioxide (Kripka et al., 2019; Invidiata et al., 2018; Moussavi et al., 2017; De la Fuente et al., 2016a; Perini & Rosasco, 2013), sulfur dioxide (SO₂), or nitrogen oxides (NO_x) (Vaisanen et al., 2016; Begic & Afgan,

2007), and broader greenhouse gases (Kamali et al., 2018; Gumus et al., 2016). Additionally, attention has been given to pollutants discharged into water systems within urban contexts (Dong et al., 2008; Yazdandoost & Tahmasebi, 2018; Martin et al., 2007).

Energy consumption emerges as another significant criterion highlighted in the reviewed literature, with approximately 46.3% of articles recognizing its importance as a supplementary metric for evaluating the impact of environment on the infrastructure. The focus of many studies lies in analyzing the energy expended in producing construction materials and executing the infrastructure projects under scrutiny (Pons et al., 2017; Kamali et al., 2018; Motuziene et al., 2016). Additionally, certain researchers take into consideration energy conservation resulting from innovative building envelope designs (Perini & Rosasco, 2013).

Furthermore, depletion of natural resource is underscored as a fundamental consequence of unsustainable construction practices. About thirty-two studies incorporate an assessment of natural resource consumption in their sustainability analyses, with particular emphasis on the utilization of construction materials. Some authors also explore the positive environmental impacts stemming from the adoption of recycled materials (Guzman-Sanchez et al., 2018; Jalaei et al., 2015; Jato-Espino et al., 2014) or the utilization of potentially reusable materials (Santos et al., 2019; Gilani et al., 2017; Nassar et al., 2016; Akadiri et al., 2013).

Acknowledging the significant contribution of construction industry to global waste production (Azab & Marzourk, 2014), efforts are now being made to address its adverse environmental impact through various initiatives. Approximately 25.3% of the analyzed manuscripts include an evaluation of waste generation stemming from various processes used in the industries involved in producing materials used in the construction sector or from activities like demolition work. This assessment encompasses both solid waste from construction materials (Gilani et al., 2017; Mosalam et al., 2018) and wastewater (Chhipi-Shrestha et al., 2017).

Land use is a critical environmental consideration that encompasses both land occupation and its transformation. The construction of infra projects often leads to ecosystem damage and also biodiversity loss. About 25 (i.e 30%) of the articles reviewed, points use of land for as representation of environmental harm associated from the setup of infrastructure. As a consequence of such use of land there has been an observance of disturbance in the ecosystem of in the vicinity of the project (Baniyas et al., 2010), wildlife habitat destruction (Hashemkhani et al., 2011; Heravi et al., 2017;), proximity to paths of migratory birds (Khorasaninejad & Fetanat, 2015), and impacts on biodiversity and its changes thereon (Vaisanen et al., 2016; Guzman-Sanchez et al., 2018). Perini and Rosasco (2013) in their study observed the creation of new habitats due to infrastructure works. Approximately 10.8% described in 9 articles explains emission of pollutants, predominantly phosphates accounts from the activities of humans in pollution of water bodies that tends to cause eutrophication which encourages uncontrolled growth and spread of algae eventually endangering the survival of species present in that water body as a whole. Dying of lakes is one of the activities seems common due to eutrophication. In the lower layer of stratosphere, the gas present is Ozone. It is a formed by covalent bond between three oxygen atom. It is a protective layer in our atmosphere and acts as a blanket to protect the Earth against exposure to harmful ultraviolet radiation coming from the Sun. The density of Ozone layer is variable and its density is lesser near the earth's surface compared to a height of 30 km in atmosphere. There is a depletion in the layer of Ozone primarily because of the increase in emission of substances containing chloro fluoro carbons, chlorine and bromine atoms have been pointed as a surplus indicator capable of assessing and measuring the extent of damage to the environment due to infrastructures and their associated activities in almost 8 reviewed papers.

2.2.1.3 Social Criteria

The criteria assessed in the studies exploring the sustainability of social dimension can be categorized in majorly eight major indicators which are mentioned along with reference details in the below mentioned table:

Table 2: Major Social indicators and its criteria

Social Criteria	Indicator	Type of Assessment	References
(i) Social Wellbeing	Increase of income of local population (€/year)	Quantitative	Zavadskas & Antucheviciene (2010, 2007)
	Assessment by expert through point scale	Qualitative	Guzmán-Sánchez et al. (2018); Hashemkhani et al. (2018); Kamali et al. (2018); Mahdiraji et al. (2018); Tahmasebi & Yazdandoost (2018); Heravi et al. (2017); Dobrovolskiiene & Tamosiuniene (2016); Gumus et al. (2016); Ignatius et al. (2016); Montajabiha (2016); Nassar et al. (2016); Fetanat & Khorasaninejad (2015); Jalaei et al. (2015); Drejeris & Kavolynas (2014); Jato-Espino et al. (2014); Afshar et al. (2011); Sun et al. (2013); Hashemkhani et al. (2011); Kaya & Kahraman (2010); Ugwu & Haupt (2007)
	Habitability Increase (m2)	Quantitative	Pons & De la Fuente (2013)
(ii) Comfort Aesthetics (hours/year)	Assessment by experts through point scale	Qualitative	Invidiata et al. (2018); Kamali et al. (2018); Tahmasebi & Yazdandoost (2018); Moussavi et al. (2017); Rashidi et al. (2017); Ignatius et al. (2016); Rochikashvili & Bongaerts (2016); Barros et al. (2015); Cuadrado et al. (2015); Jalaei et al. (2015); Fetanat & Khorasaninejad (2015); Jakiel & Fabianowski (2015); Balali et al. (2014); Chen (2014); Jato-Espino et al. (2014); Akadiri et al. (2013); Perini & Rosasco (2013); Yu et al. (2012); Farkas (2011); Afshar et al. (2011); Banias et al. (2010); Lombera & Aprea (2010); Malekly et al. (2010); Saparauskas et al. (2010); Wang et al. (2008); Ugwu & Haupt (2007); Gento (2004)
(iii) Work/Output	Job creation Hours of unit	Quantitative	Väisänen et al. (2016); Klein & Whalley (2015); Kuku et al. (2014); Jovanovic et al. (2009); Begic & Afgan (2007)
	Gross Value added /hour worked	Quantitative	Saparauskas (2007)
	Unemployment rate	Quantitative	Banias et al. (2010)
	Employment increase(%)	Quantitative	Zavadskas & Antucheviciene (2010, 2007)
	Assessment by experts through point scale	Qualitative	Heravi et al. (2017); Gumus et al. (2016); Montajabiha (2016); Afshar et al. (2011); Kaya & Kahraman (2010)
(iv) Development of Local economics	GDP increase (€)	Quantitative	Zavadskas & Antucheviciene (2010, 2007); Saparauskas (2007)

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

	Land value degradation (€/m ²)	Quantitative	Banias et al. (2010)
	Assessment by experts through point scale	Qualitative	Kamali et al. (2018); Heravi et al. (2017); Gumus et al. (2016); Barros et al. (2015); Fetanat & Khorasaninejad (2015); Akadiri et al. (2013); Sun et al. (2013); Afshar et al. (2011); Ugwu & Haupt (2007)
(v) Externalities	Noise pollution (dB)	Quantitative	Santos et al. (2019); Oset al. (2017); De la Fuente et al. (2017b); Blanco et al. (2016); De la Fuente et al. (2016a); Banias et al. (2010);
	Traffic congestion (traveltime)	Quantitative	Santos et al. (2019)
	Vehicle operating costs (€), User delay costs (€)	Quantitative	Gervásio & Da Silva (2012)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018); Kamali et al. (2018); Heravi et al. (2017); Rashidi et al. (2016) Balali et al. (2014); Chen (2014); Drejeris & Kavolynas (2014); Reyes et al. (2014); Lombera & Aprea (2010) Malekly et al. (2010); Dabous & Alkass (2008)
(vi) Innovations	Assessment by experts through point scale	Qualitative	Heravi et al. (2017); Ignatius et al. (2016); Drejeris & Kavolynas (2014); Yu et al. (2012); Ugwu & Haupt (2007); Gento (2004)
(vii) Culture	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018); Kamali et al. (2018); Heravi et al. (2017); Rashidi et al. (2017); Fetanat & Khorasaninejad (2015); Yu et al. (2012); Afshar et al. (2011); Ugwu & Haupt (2007)
(viii) Health and Safety	Injuries/output unit	Quantitative	Barros et al. (2015); Kucukvar et al. (2014); Jovanovic et al. (2009)
	Fatalities/output unit	Quantitative	Klein & Whalley (2015)
	Particulate Matter (PM) concentration (PM _{2,5} /PM ₁₀)	Quantitative	Santos et al. (2019) Nassar et al. (2016)
	Safety costs (€)	Quantitative	Gervásio & Da Silva (2012)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018); Kamali et al. (2018) Pascal et al. (2017); Heravi et al. (2017); De la Fuente et al. (2017b) Blanco et al. (2016); Dobrovolskiiene & Tamosiuniene (2016) Rashidi et al. (2016); Rochikashvili & Bongaerts (2016) De la Fuente et al. (2016a); De la Fuente et al. (2016b); Cuadrado et al. (2015); Drejeris & Kavolynas (2014); Jato-Espino et al. (2014); Reyes et al. (2014); Akadiri et al. (2013); Pons & De la Fuente (2013) Pons & Aguado (2012) Afshar et al. (2011); Hashemkhani et al. (2011) Lombera & Aprea (2010); Dabous & Alkass (2008); Wang et al. (2008); Ugwu & Haupt (2007); Gento (2004)

Among the articles reviewed, approximately 41% (34 manuscripts) delve into the infrastructural impact on social well-being, alongside other considerations such as public acceptance (Dobrovolskiene & Tamosiuniene, 2016; Kamali et al., 2018; Hosseini et al., 2016; Väisänen et al., 2016; Montajabiha, 2016; Kaya & Kahraman, 2010), enhancement of social welfare and income (Tahmasebi & Yazdandoost, 2018; Gumus et al., 2016; Khorasaninejad & Fetanat, 2015; Zavadskas et al., 2007), accessibility (Martin et al., 2007; Chhipi- Shrestha et al., 2017; Sun et al., 2013), and recreational opportunities (Gento, 2004). Furthermore, assessments focusing on the comfort of users encompass various infrastructural designs such as buildings, roads, and others (Jato-Espino et al., 2014; Gilani et al., 2017; Invidiata et al., 2018; Heravi et al., 2017; Moussavi et al., 2017; Oses et al., 2017).

Aesthetics has emerged as a crucial aspect of social sustainability, closely linked to the societal acceptance of a project. This aspect has been deliberated in 26 articles, encompassing the aesthetic perception of the infrastructure itself and its harmonious integration into both urban (Hosseini et al., 2016; Cuadrado et al., 2015) and rural environments (Zavadskas et al., 2010, 2007).

It is undeniable that the construction and maintenance phases of infrastructure bring forth numerous job opportunities, both directly and indirectly. Sixteen papers elucidate how this surge in employment opportunities is closely linked to an improvement in social welfare. While the methodological guidelines for social life cycle assessments developed by UNEP/SETAC (2013) give preference to employment generated specifically for local communities rather than employment in general, it is a common practice in social life cycle assessments to use overall employment generation as an indicator of social sustainability (Navarro et al., 2018b; Hunkeler et al., 2008).

Aesthetics has emerged as a pivotal facet of social sustainability, intricately connected to the societal acceptance of a project. This aspect has been deliberated in 26 papers, encompassing perceptions of aesthetics of the infrastructure and its seamless integration with not only urban atmosphere (Hosseini et al., 2016; Cuadrado et al., 2015) but also rural atmosphere (Zavadskas et al., 2010, 2007).

The construction phase and maintenance phases of an infrastructure is undeniably creating abundant job opportunities, both directly and indirectly. Sixteen papers elaborate on how this increase in employment opportunities is closely associated with causing social upliftment and welfare activities. While the available methodological guidelines for assessment of social life cycle outlined by UNEP/SETAC (2013) give precedence to employment specifically generated for local communities rather than general employment, overall employment generation often serves as a key indicator of social sustainability in social life cycle assessments (Navarro et al., 2018b; Hunkeler et al., 2008).

The evaluation of an infrastructure's impact on the local development of a particular region has been conducted in 16 papers. This evaluation encompasses factors such as the increase in Gross Domestic Product (Saparauskas, 2007; Zavadskas et al., 2010), tourism growth (Sun et al., 2013; Afshar et al., 2011), and the benefits in regional economics driven by the utilization of local materials and available resources locally (Gilani et al., 2017; Väisänen et al., 2016; Akadiri et al., 2013; Haupt & Ugwu, 2007) that falls in the category of social impact.

The study examining Profit or Loss arising from infrastructure construction, particularly from maintenance of infrastructure, have been considered in 33.7% of papers reviewed. Considering the effects on disruption of traffic (Rashidi et al., 2017; Santos et al., 2019; Balali et al., 2014; Chen, 2014; Mikawi, 1996) or increase in operation cost of vehicle due to detours implementation (Dabous & Alkass, 2008; Gervásio & Da Silva, 2012; Mikawi, 1996) are consistently utilized as social indicators while assessing bridge infrastructure's sustainability.

Other additionally analysed externalities include noise and pollution caused due to dusts resulting from activities in construction works (Heravi et al., 2017; Mosalam et al., 2018).

The incorporation of innovation in designing an infrastructure is also considered as social indicator, aiming to promote progress of the society and development of technologies. Nine of the reviewed articles have pointed out consideration of this aspect. The assessment of this either based on a binary indicator, scoring 1 if the infrastructure design consists of either patented materials or solutions or both (; De la Fuente et al., 2017a; Mosalam et al., 2018; Pons et al., 2017), or the selected panel expertise (Ignatius et al., 2016; Clemens-Croome & Alwaer, 2010).

Culture is included as a measurement tool for social sustainability in 13.3% of the examined papers, with a particular emphasis on respecting the region's cultural heritage (Kamali et al., 2018; Hashemkhani et al., 2018; Alwaer & Clemens-Croome, 2010; Yu et al., 2012; Heravi et al., 2017; Rashidi et al., 2017) or its traditional/native architecture (Gilani et al., 2017). Given the challenges in quantity assessing cultural indicators (UNEP/SETAC, 2013), majority of authors rely on the expertise of their chosen expert panels for accessing cultural impacts (Fetanat & Khorasaninejad, 2015; Heravi et al., 2017; Afshar et al., 2011).

Both construction and industrial companies give emphasis on efficient practices related to health and safety, aiming not only to safeguard workers from fatalities and major injuries but also to protect infrastructure users from the risk of accidents. In 42 articles (i.e 50.6%) of the reviewed article, The impact of activities that are practised in the construction and maintenance of infrastructure that has an effect on the safety of workers involved, also the risk on health on the infrastructure users, has been considered.

Authors	Title of Papers	Discussion/Conclusions/Findings
Rabindra Adhikari, Pratyush Jha, Lalit Bhatt, Dipesh Thapa, Davide Forcellini and Dipendra Gautam (2021)	Failure investigation of under construction prestressed concrete bridge in Chitwan, Nepal	- The construction of the Thimura bridge faced a major challenge due to the use of poorly graded cohesionless sand for the embankment supporting the falsework. - This type of sand lacks binding properties and has low bearing capacity, making it prone to displacement and settlement. Vibrations from construction activities can further weaken the sand's resistance, leading to instability. - The falsework had to be specifically designed to accommodate potential settlements and consider the limitations of the erection towers used during prestressing. To mitigate risks, careful planning of settlement strategies, vibration control measures, and robust falsework design were essential.
Elisa Khouri Chalouhi (2019)	Optimal design solutions of concrete bridges considering environmental impact and investment cost.	- This comprehensive software package streamlines the bridge design process, from initial site analysis to detailed reinforcement design. It optimizes span counts, pier placements, and connection types, while ensuring compliance with Eurocode requirements. - Leveraging advanced algorithms, it finds cost-effective and environmentally friendly designs. Integrated with commercial FEM software, it offers detailed structural analysis, and its smart memory system ensures efficient processing. Modules include span/pier selection, deck dimensioning, FEM analysis, and reinforcement design.
Lorea García San Martín (2011)	Life Cycle Assessment of Railway Bridges.	- In terms of environmental impact, global warming is the primary concern, followed by eutrophication and abiotic depletion. Greenhouse gas emissions from steel, concrete, and timber production contribute significantly, with steel having the largest footprint. - Despite timber's contribution to eutrophication, its overall impact is lower than that of steel and concrete. Eutrophication and abiotic depletion are mainly associated with material production processes. - Ozone layer depletion and photochemical oxidation are minor concerns in this analysis. The EDIP method may offer a more detailed assessment of ozone layer depletion, although it does not evaluate

Authors	Title of Papers	Discussion/Conclusions/Findings
		abiotic depletion.
Abdel-Basset, M., Manogaran, G., Mohamed, M., & Chilamkurti, N. (2018)	Three-way decisions based on neuromorphic sets and AHP-QFD framework for supplier selection problem.	- The neuromorphic set embodies the three-way decisions theory more effectively, efficiently, and flexibly than fuzzy and intuitionistic fuzzy sets. Two decision-making rules are proposed based on studying three-way decisions. - An evaluation function for three-way decisions calculates weights of alternatives. An integrated neuromorphic AHP-QFD approach is presented for selecting the best supplier among various alternatives.
Navarro, I. J., Yepes, V., & Martí, J. V. (2018b)	Social life cycle assessment of concrete bridge decks exposed to aggressive environments.	- After a four-step assessment, our analysis of 15 concrete bridge deck designs indicates that those incorporating stainless steel reinforcement or utilizing concrete enhanced with silica fume or polymers demonstrate superior social sustainability. - This underscores the importance of considering maintenance-related social impacts in evaluating a structure's overall sustainability performance.
Peng, J. J., Wang, J., & Yang, W. (2017)	A multi-valued neutrosophic qualitative flexible approach based on likelihood for multi-criteria decision-making problems.	- Preference relations of MVNNs based on likelihood were established, leading to the development of an extended qualitative flexible multiple criteria method (QUALIFLEX) for addressing MCDM problems expressed using MVNNs. - An example illustrating the application of this decision-making approach demonstrates its feasibility and credibility.
Braga, A. M., Silvestre, J. D., & de Brito, J. (2017)	Compared environmental and economic impact from cradle to gate of concrete with natural and recycled coarse aggregates.	- Substituting fresh coarse aggregates with recycled ones in concrete reduces environmental impacts and costs significantly, with cement being the primary contributor to both. - Additionally, recycled concrete offers superior mechanical properties, leading to reduced long-term costs and environmental burdens.
Sarhosis, V., De Santis, S. and de Felice, G. (2016)	A Review of Experimental Investigations and Assessment Methods for Masonry Arch Bridges.	- The research focuses on three main areas: material characterization, experimental testing on model bridges and real structures, and structural assessment methods. - It aims to provide reliable information on a bridge's safety level and residual service life under traffic loads, considering factors such as ageing, deterioration, and fatigue.
Zhang, Y., Wu, W. and Wang, Y. (2016)	Bridge Life Cycle Assessment with Data Uncertainty.	- Normal distribution can be applied to model environmental substances and their impact on steel production for bridges. - The weighted values of human health damage, ecological system damage, and resource/energy consumption can be approximated by similar normal distribution functions.
Abdullah, L., & Najib, L. (2016)	Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: choosing energy technology in Malaysia	- The new Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) was utilized to establish preferences in sustainable energy planning decision-making. - Three decision-makers from Malaysian government agencies provided linguistic judgments prior to the analysis. Nuclear energy emerged as the top choice among seven alternatives, based on the highest ranking obtained.

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

Authors	Title of Papers	Discussion/Conclusions/Findings
Ali, M., Aslam, M. S., & Mirza, M. S.(2016)	A sustainability assessment framework for bridges – a case study: Victoria and Champlain Bridges, Montreal	- A summary of the design, construction, maintenance, and rehabilitation/renovation details for the four versions of the 3-km long Victoria Bridge (1858, 1898, 1958, and 1988) is provided. - All versions of the Victoria Bridge were deemed suitable for bridge operations, while the Champlain Bridge is comparatively unsustainable.
Arya, C. Amiri, A and Vassie, P (2015)	A new method for evaluating the sustainability of bridges	- A study compared three designs for a motorway over-bridge to determine the most sustainable option. Indicators included climate impact, resource use, waste, biodiversity, noise, and aesthetics. - The chosen design was assessed using various parameters to calculate an overall sustainability score. The paper suggests strategies for enhancing the sustainability of the selected design.
Safi M., Du, G., Karourni, R., &Sundquist, H. (2015)	Holistic approach to sustainable bridge procurement considering LCC, LCA, User-cost and Aesthetics	- A new procurement method is proposed for ensuring the most sustainable bridge construction within Design-Build contracts. - It extends beyond conventional cost analysis by considering aesthetic appeal and environmental impact. Agencies assign monetary values to these aspects upfront and include them in tender documents.
Pang, B., Yang, P., Wang, Y., Kendall, A., Xie, H. and Zhang, Y (2015)	Life Cycle Environmental Impact Assessmentof a Bridge with Different Strengthening Scheme.	- An analysis of various bridge maintenance and strengthening strategies revealed that the maintenance phase contributes a substantial 66% to the total environmental impact, with detours accounting for half of this figure. - Repaving and strengthening measures also have notable impacts, contributing 12% and 4% respectively.
Torres-Machi, C., Chamorro, A., Pellicer, E., Yepes, V., & Videla, C. (2015).	Sustainable Pavement Management. Integrating Economic, Technical, and Environmental Aspects in Decision Making.	- AHP is effective for small projects with fewer than seven factors, providing a structured way to prioritize weights. - For complex scenarios with many options or criteria, weighted sum or multi-attribute approaches are better suited, as they can handle larger datasets and nuanced trade-offs.
Yadaollahi, M.,Ansari, R., Abd Majid, M. Z., & Yih, C. H. (2014)	A multi-criterion analysis for bridge sustainability assessment: a case study of Penang Second Bridge, Malaysia.	- This study developed specific hierarchies of bridge attributes for different sustainability rating systems and used the analytical hierarchy process to evaluate the bridge's sustainability in relation to those attributes. - Overall, the bridge met most sustainability criteria outlined by the various systems, indicating strong performance.
Kabir, G., Sadiq, R.,& Tesfamariam, S. (2014)	A review of multi-criteria decision making methods for infrastructure management	- The increasing significance of Multi-Criteria Decision Making (MCDM) in infrastructure management is evident from this review. - Over the past decade, there has been a notable rise in MCDM applications, and the integration of various MCDM methods into decision support tools has shown to be highly effective.

Authors	Title of Papers	Discussion/Conclusions/Findings
Marzourk, M., & Azab, S. (2014).	Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics. Resources, Conservation and Recycling.	- This study addresses the pressing issue of construction waste through a sophisticated system dynamics model. By evaluating economic and environmental impacts of waste management choices, the model highlights the significant costs of unmanaged waste compared to recycling. - The research underscores construction and demolition waste recycling as vital for sustainable development, benefiting both the environment and the economy.
Bolzoni, F., Brenna, A., Fumagalli, G., Goidanich, S., Lazzari, L., Ormellese, M., & Pedferri, M. P. (2014).	Experiences on Corrosion inhibitors for reinforced concrete.	The study reaffirms previous findings that nitrite-based inhibitors effectively reduce corrosion when the [NO-]/[Cl-] ratio surpasses 0.5-0.6. Yet, in carbonated concrete lacking sufficient inhibitor, there was no notable decrease in corrosion rate observed.
Reyes, J., San-José, J., Cuadrado, J., & Sancibrian, R. (2014).	Health and safety criteria for determining the sustainable value of construction projects.	- This research introduces a methodology for effectively integrating health and safety (H&S) concerns into management projects from the design stage. - This methodology utilizes a scoring system ranging from 0 to 1 that evaluates the project's sustainability level. Additionally, it presents the "Health and Safety Costs Index" (H&SC Index), a second tool based on economic criteria, that translates the initial score into quantifiable financial terms.
Barone, G., & Frangopol, D. (2014)	Lifecycle Maintenance of Deteriorating Structures by Multi-Objective Optimization Involving Reliability, Risk, Availability, Hazard and Cost.	This study addressed the challenge of optimizing maintenance plans for aging structures by comparing four bi-objective optimization methods. These methods aimed to balance optimal availability and minimal hazard risk, with cost minimization as a secondary objective.
Baltazar, L, Santana, J., Lopes, B., Rodrigues, M.P., & Correia, J.R. (2014)	Surface skin protection of concrete with silicate-based impregnations: influence of the substrate roughness and moisture.	Silicate impregnations provide robust protection against water and wear for concrete structures but may compromise impact resistance. Optimize results by considering surface texture and moisture levels when applying these treatments.
By Balali, V., Mottaghi, A., Shoghli, O., & Golabchi, M. (2014).	Selection of appropriate material, construction technique, and structural system of bridges by use of multi criteria decision-making method.	Sustainability was pivotal in material and method selection for the Kashkhan highway bridge. Engineers utilized the PROMETHEE method to choose a post-tensioned concrete box girder system, constructed using the balanced cantilever method.

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

Authors	Title of Papers	Discussion/Conclusions/Findings
De Schepper, M., Van den Heede, P., Van Driessche, I., & De Belie, N. (2014)	Life cycle assessment of completely recyclable concrete.	- High-Strength, Low-Clinker CRC: A champion in reducing greenhouse gas emissions! This combination can slash global warming potential by a staggering 66%-70% compared to standard concrete. - Normal-Strength CRC: While not as dramatic, even regular-strength CRC with higher clinker content can offer reductions of 7%-35%, provided it has a sufficient lifespan. Every bit counts in the fight against climate change.
Du, G., & Karourni, R. (2014)	Life cycle assessment framework for railway bridges: literature survey and critical issues	- This article introduces a user-friendly framework that revolutionizes LCA for railway bridges. - It provides a step-by-step process to measure emissions and energy consumption throughout the bridge lifecycle, addressing significant challenges in current LCA methods. - With this tool, optimizing projects for greener infrastructure and sustainability is made easier.
Du, G., Safi, M., Petterson, L. and Karoumi, R. (2014)	Life Cycle Assessment as a Decision Support Tool for Bridge Procurement: Environmental Impact Comparison among Five Bridge Design.	- While this thorough analysis of 20 environmental indicators across five bridge designs provides valuable insights, drawing universal conclusions is challenging. - Life Cycle Assessments are significantly influenced by subjective monetary weighting systems, uncertainties in variables like material recycling rates, and environmental contexts. - For future research and practice to offer meaningful comparisons and guide sustainable bridge design, specifying these influencing factors meticulously and transparently is essential.
Hu, M., Kleijn, R., Bozhilova-Kisheva, K. P., & Di Maio, F. (2013).	An approach to life cycle sustainability analysis (LCSA): the case of concrete recycling.	- The C2CA-LCSA study offers valuable insights into standardizing LCSA procedures, providing initial steps for implementation. - Its three-level sub-question categorization is beneficial, but additional case studies are required to solidify LCSA as a practical framework for complex sustainability analyses.
Thor, J., Ding, S., & Kamaruddin, S. (2013)	Comparison of Multi Criteria Decision Making methods from the Maintenance alternative selection perspective.	- Selecting the ideal maintenance strategy for complex infrastructure can be daunting. However, Multi-Criteria Decision Making (MCDM) methods serve as reliable guides, helping navigate toward the best solution. - This research explores four commonly used MCDM methods in maintenance decision-making: TOPSIS, VIKOR, PROMETHEE, and ELECTRE.
Gervásio, H. and da Silva, L. (2013)	A Design Approach for Sustainable Bridges – Part 1: Methodology.	- This paper introduces a fresh approach to bridge design, merging financial accounting with strategic decision-making. - This integration enables engineers to craft sustainable bridges that are both cost-effective and resilient.
Finnveden, G., Hakansson, C., & Noring, M. (2013).	A new set of valuation factors for LCA and LCC based on damage costs-Ecovalue 2012	- This study showcases an enhanced Ecovalue method, bridging the gap with the Recipe approach for most categories and leveraging Cumulative Exergy Demand for abiotic resources. - Analyzing an ICT product through this lens highlights the critical sustainability challenges of climate change, toxicity, and resource depletion, urging both manufacturers and consumers to prioritize these areas for improvement.

Authors	Title of Papers	Discussion/Conclusions/Findings
Thiebault, V., Du, G., & K.aroumi, R. (2013,2010).	Design of railway bridges considering LCA	- This study explores a simplified quantitative Life Cycle Assessment (LCA) method for railway bridges, implemented in an easy-to-use Excel tool. - Using this tool to analyze two bridge designs from Sweden's Banafjäl Bridge project, the research meticulously examined various air and water pollutants throughout the entire life cycle.
Gjørsv, O. (2013)	Durability design and quality assurance of major concrete infrastructure.	- Neglecting to document compliance before accepting structures from contractors can compromise construction quality and future maintenance. - Inadequate service manuals deprive owners of crucial information for condition assessment and preventive maintenance, possibly resulting in decreased durability and shortened lifespan for concrete structures.
Kim, S. H., Choi, M. S., Mha, H. S., & Joung, J. Y. (2013).	Environmental impact assessment and eco-friendly decision-making in civil structures.	This research evaluated a bridge's environmental performance using two methods: a comprehensive life-cycle assessment (LCA) and a user-friendly, eco-friendly decision-making process based on the Analytical Hierarchy Process. While focusing on four key materials (steel, concrete, asphalt, and timber), the analysis considered the entire bridge lifecycle, providing a holistic view.
Du, G., & Karourni, R. (2013)	Life cycle assessment of a railway bridge: comparison of two superstructure designs	Unveiling a powerful new tool for assessing railway bridge sustainability: the Bridge LCA model. This model comprehensively analyzes environmental impacts from material extraction to end-of-life, empowering engineers to make informed design choices.
Safi, M. (2013).	Life-cycle costing: Applications and implementations in bridge investment and Management	- This research presents a thorough framework for implementing Life Cycle Cost Analysis (LCCA) across bridges' entire lifespan. - Through various case studies, it illustrates how Bridge Management Systems (BMS) can utilize LCCA to enhance decisions for both existing and new bridges.
Habert, G., Denarie, E., Sajna, A., & Rossi, P. (2013)	Lowering the global warming impact of bridge rehabilitations by using Ultra High Performance Fibre Reinforced Concretes.	- This study evaluated a new rehabilitation system featuring an innovative UHPFRC with high limestone content. - While its environmental impact comparable to traditional methods when not considering lifespan, the Eco-UHPFRC solution boasts a significantly lower Global Warming Potential (GWP) - even for a single rehabilitation cycle.
Akadiri, P. O., Olomolaiye, P. O., & Chintio, E. A. (2013)	Multi-criteria evaluation model for the selection of sustainable materials for building projects	This paper unveils a novel building material selection model powered by the Fuzzy Extended Analytical Hierarchy Process (FEAHP). This robust method overcomes the challenges of sustainability assessment and weighting by incorporating the triple bottom line framework and stakeholder priorities.
SBRI-2013	Sustainable Steel-Composite Bridges in Built Environment	This research breaks new ground by merging functional quality with both environmental and economic aspects through a comprehensive life-cycle perspective. Leveraging LCP, LCA, and LCC methodologies, it delivers a complete picture of bridge performance.

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

Authors	Title of Papers	Discussion/Conclusions/Findings
Padgett, J. E., & Tapia, C. (2013)	Sustainability of Natural Hazard Risk Mitigation: A Life-Cycle Analysis of Environmental Indicators for Bridge Infrastructure	Energy and emissions: The framework analyzes the embodied energy and greenhouse gas emissions associated with each design and retrofit option, guiding towards more sustainable choices.
Dequidt, T. (2012)	Life Cycle Assessment of a Norwegian Bridge	Understanding the breakdown of carbon footprint across different phases empowers targeted interventions for greener bridge design, construction, and maintenance.
Spencer, P., Hendy, C. and Petty, R. (2012)	Quantification of Sustainability Principles in Bridge Projects	Real-time monitoring: Use the index throughout the design process to track the effectiveness of your decisions and adjust accordingly. Future-proof planning: Set ambitious sustainability targets based on the index rating, ensuring your bridges meet the demands of a greener future.
Du, G. (2012).	Towards sustainable construction: life cycle assessment of railway bridges	This research dives deep into the complex world of bridge sustainability, offering valuable insights for engineers, architects, and anyone passionate about building greener infrastructure.
Habert, G., Arribe, D., Dehove, T., Espinasse, L., & LeRoy, R. (2012).	Reducing environmental impact by increasing the strength of concrete: quantification of the improvement to concrete bridges.	This research tackles the crucial question: can high-performance concrete (HPC) help us build more sustainable bridges? The answer is a resounding yes, with some fascinating caveats.
Mirzaei, Z., Adey B.T., Klatter, L., & Kong, J. (2012).	The IABMAS Bridge Management Committee Overview of Existing Bridge Management Systems	Report offers a comprehensive high-level view of bridge management systems, outlining their key components and functionalities.
Wilmers W. (2012)	Restoration of Masonry Arch Bridges: Proceedings of the Institute of Civil Engineers – Journal of Bridge Engineering.	This comprehensive report delves into the preservation of masonry arch bridges, analyzing over 30 structures and detailing best practices for their inspection, assessment, and repair. From scrutinizing foundations and masonry to optimizing hydraulics and pavements, the study offers a holistic approach to safeguarding these historical bridges.
Zhang, C., Amaduddin, M. and Canning, L. (2011)	Carbon dioxide Evaluation in a Typical Bridge Deck Replacement.	The paper tackles the vital question of reducing carbon footprint in bridge deck replacement. It comprehensively compares two options for a typical UK highway project, including a pioneering fiber-reinforced polymer (FRP) alternative.

Authors	Title of Papers	Discussion/Conclusions/Findings
Detle, G., & Sigrist, V. (2011)	Performance indicators for concrete bridges.	Infrastructure management struggles with a crucial blind spot: the lack of well-defined performance indicators beyond technical aspects. This paper tackles this head-on, filling the void left by the Draft Model Code 2010.
Afshar, A., Marino, M., Saadatpour, M., & Afshar, A. (2011)	Fuzzy TOPSIS multi criteria decision analysis applied to Karun reservoirs system.	This research breaks new ground by proposing a multi-criteria decision-making approach for water management that goes beyond the water system itself.
Ahlorth, S., & Finnveden, G (2011)	A new valuation set for environmental systems analysis tools	Moving beyond subjective valuations, this research introduces a novel environmental weighting set grounded in real-world data.
Ahlorth, S., Nilsson, M., Finnveden, G., Hjelm, O., & Hochschoer, E. (2011).	Weighting and valuation in selected environmental systems analysis. tools-suggestions for further developments	This paper delves into the prevalence and potential of weighting methods in Environmental Systems Analysis Tools (ESATs).
Hammervold, J., Reenaas, M., & Brattebø, H. (2011, 2009).	Environmental Life Cycle Assessment of Bridges.	This research, through a detailed LCA, reveals the environmental trade-offs of three bridge designs: steel box girder, concrete box girder, and wooden arch.
Zhang, C. (2010)	Delivering Sustainable Bridges to help Tackle Climate Change	This research delves into the environmental impact of bridges, pinpointing major CO₂ emission sources throughout their life cycle. By analyzing these aspects, the paper identifies key areas for improvement, empowering bridge designers to adopt sustainable strategies and build eco-friendly bridges.
Botniabanan A.B. (2010)	Environmental product declaration for railway bridges on the Bothnia line.	This Environmental Product Declaration (EPD) offers a comprehensive, cradle-to-grave analysis of the environmental impact of railway bridges on the Bothnia Line.
Pacheco, P., Antonio, P., Fonseca, A., Resende, A. and Campos, R. (2010)	Sustainability in Bridge Construction Processes	This research goes beyond the technical prowess of Organic Prestressing System (OPS) technology in bridge construction, highlighting its remarkable contribution to increased sustainability.
Bouhaya, L., Le Roy, R., & Feraille-Fresnet, A. (2009).	Simplified environmental study on innovative bridge structure	This research explores the environmental footprint of an innovative bridge using wood and ultra-high-performance concrete. While it boasts superior strength, maximizing both low environmental impact and high performance proved elusive.
Hung, M. L., & Ma, H. (2009)	Quantifying system uncertainty of lifecycle assessment based on Monte Carlo simulation.	This municipal waste management case study sheds light on a crucial issue: different LCIA methods lead to different results! Choosing the right one, therefore, emerges as a major source of uncertainty in environmental impact assessment.

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

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Wang, Y., Liu, J., & Elhag, T. (2008).	An integrated AHP-DEA methodology for bridge risk assessment.	This paper breaks new ground with the AHP-DEA methodology, an integrated approach to efficiently evaluate risks in hundreds or thousands of bridge structures.
Gervasio, H., & Simoes da Silva, L.(2008).	Comparative life-cycle analysis of steel-concrete composite bridges.	This paper tackles two key objectives: (1) developing a comprehensive integrated methodology for life cycle and sustainability analysis (LCA and LCCA), and (2) showcasing its application through a case study of a composite bridge.
Dabous, S., & Alkass, S. (2008)	Decision support method for multi-criteria selection of bridge rehabilitation strategy.	To ensure the real-world effectiveness of our newly developed decision support method for bridge deck improvement projects, we applied it to a real case study.
Lim, S. R., Park, D., & Park, J. M. (2008).	Environmental and economic feasibility study of a total waste-water treatment network system.	This research breaks new ground by evaluating the feasibility of a comprehensive network (TWTNS) for handling wastewater in iron and steel plants.
Kendall, A., Keoleian, G. A., & Helfand, G. E. (2008).	Integrated life cycle assessment and lifecycle cost analysis model for concrete bridge deck applications.	While the initial cost and environmental impact per unit material might be higher, this study reveals that an engineered cementitious composite link slab design for bridge decks ultimately proves more sustainable and cost-effective over the entire life cycle compared to a conventional concrete deck.
Sleeswijk, A.W., van Oers, L. F., Guinee, J. B.,	Normalization in product life cycle assessment:	Analyzing 860 environmental interventions, this study reveals a surprising concentration of impact.
Struijs, J., & I Juijbregts, M. A.(2008).	LCA of the global and European economic systems in the year 2000.	This study provides a roadmap for efficient environmental action. By identifying the high-impact interventions and knowledge gaps, it emphasizes the need for targeted policies, emissions control measures, and improved data on toxic emissions to maximize our environmental impact reduction efforts.
Long, A., Basheer, P., Taylor, S., Rankin, B. and Kirkpatrick, J. (2008)	Sustainable Bridge Construction through Innovative Advances.	Enhanced in-situ tests guide us towards more durable designs, advanced understanding of arching action paves the way for virtually maintenance-free systems, and the innovative "flat pack" flexible concrete arch system offers efficiency and potential cost savings.
Melbourne, C., Tomor, A. and Wang, J. (2007)	A New Masonry Arch Bridge Assessment Method (SMART)	Using a practical example, it demonstrates how SMART pinpointed longitudinal shear stress as the key factor influencing ultimate load capacity and permissible axle loads, paving the way for informed decision-making.

Authors	Title of Papers	Discussion/Conclusions/Findings
Lundie, S., Huijbregts, M. A., Rowley, H. V., Mohr, N. J., & Peitz, A. J. (2007).	Australian characterization factors and normalization figures for humantoxicity and ecotoxicity	This study tailors the existing USES-LCA 2.0 model to calculate impact factors for toxic chemicals released in Australia.
Hallberg, D., & Racutaru, G. (2007).	Development of the Swedish bridge management system by introducing a LMS concept	While the current system excels in operational, tactical, and strategic management, it lacks the functionality for optimizing and planning long-term MR&R actions based on service life performance.
Lounis Z., & Daigle L. (2007).	Environmental benefits of life cycle design of concrete bridges.	Not only does this lead to high-performance bridges, but it also minimizes environmental impact. By embracing innovative practices and materials, we can build future-proof infrastructure that endures, reduces costs, and protects our planet.
Ugwu, O., & Haupt, T. (2007)	Key performance indicators and assessment methods for infrastructure sustainability – a South African construction industry perspective.	This research tackles the challenge of efficient infrastructure development in developing countries. By identifying key performance indicators (KPIs) for timely delivery and mapping computational methods for achieving sustainable objectives, it provides a practical framework for evaluating and optimizing infrastructure design proposals.
Frischknecht, R.; Jungbluth, N.; Althaus, H. J.; Doka, G.; Dones, R.; Hellweg, S.; Hirschler, R.; Humbert, S.; Margni, M., & Nemecek, T. (2007).	Implementation of Life Cycle Impact Assessment Methods.	The report unveils a treasure trove of diverse impact assessment methods, from Cumulative exergy demand to IPCC 2001 for climate change.
Saparauskas, J. (2007)	The main aspects of sustainability evaluation in construction.	Recognizing the multi-faceted nature of sustainability, this research employs both TOPSIS and SAW multi-criteria decision-making methods.
Collings, D. (2006).	An environmental comparison of bridge forms.	Analyzing the variability of embodied energy and CO2 emissions in different materials and forms, it provides valuable insights for optimizing bridge design.
Guettala, A. and Abibsi, A. (2006)	Corrosion Degradation and Repair of a Concrete Bridge.	This study sheds light on the insidious threat posed by chloride ion infiltration in reinforced concrete bridges. By examining the degradation of bandages and piers on a specific bridge, the research reveals how this chemical attack leads to reinforcement corrosion and ultimately concrete bursting.

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

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Bare, J. C., & Gloria, T. P. (2006).	Critical analysis of the mathematical relationships and Comprehensiveness of life cycle impact assessment approaches.	By providing insightful comparisons across midpoint, endpoint, damage, and weighting levels, it empowers practitioners to make informed choices when selecting the right tool for their needs.
CIRIA Guide (2006)	Masonry Arch Bridges: Condition Appraisal and Remedial Treatment	Masonry arch bridges demand special care. While these grand structures may stand resilient, ensuring their continued service requires more than just routine maintenance.
Shen, L. Y., Lu, W. S., Yao, H., & Wu, D. H. (2005)	A computer-based scoring method for measuring the environmental performance of construction activities	The EPS system goes beyond calculating a score; it delves deeper, helping contractors diagnose the root causes of potential environmental issues and guiding them towards greener practices. This research not only conceptualizes the EPS system but also brings it to life through a simulated case study.
Kiker, G., Bridges, T., Varghese, A., Seager, P. and Linkov, I. (2005)	Application of Multicriteria Decision Analysis in Environmental Decision Making.	This paper serves as a comprehensive guide to using multi-criteria decision analysis (MCDA) methods in environmental contexts. It not only showcases existing applications but also equips you with the tools to tailor your own MCDA framework.
Jin, N., Chryssanthopoulos, M. and Parke, G. (2005)	Bridge Management Using Principles of Whole Life Cost and Life Cycle Assessment Subject to Uncertainty.	This study tackles the challenge of managing bridges by considering both financial and environmental consequences throughout their lifespan.
Itoh, Y., Wada, M., & Liu, C., (2005).	Lifecycle environmental impact and cost analyses of steel bridge piers with seismic risk.	This paper expands current life cycle analysis (LCA) methods for the construction and maintenance of buildings, taking the critical factor of seismic recovery after earthquakes into account.
Keoleian, G. A., Kendall, A., Dettling, J. E., Smith, V. M., Chandler, R. F., Lepech, M. D., & Li, V. C., (2005).	Life Cycle Modelling of Concrete Bridge Design: Comparison of Engineered Cementitious Composite Link Slabs and Conventional Steel Expansion Joints	This study proves that ECC link slabs significantly reduce environmental impact compared to traditional steel expansion joints over a 60-year lifespan.
Stewart, M. G., Estes, A. C., & Frangopol, D. M. (2004).	Bridge deck replacement for minimum expected cost under multiple reliability constraints.	- This analysis delves into the hidden complexities of bridge performance, considering not just design specifications but also the variability of materials, loads, dimensions, modeling errors, and even environmental factors like chloride penetration and corrosion. - By accounting for these uncertainties across both ultimate strength and serviceability criteria, it reveals the potential hidden costs inherent in a simplified, single-limit-state approach.

Authors	Title of Papers	Discussion/Conclusions/Findings
Martin, A. J. (2004).	Concrete bridges in sustainable development	This paper unveils the intricacies of sustainable concrete bridge construction, offering valuable insights for bridge owners, designers, builders, maintainers, and even users.
Sustainable bridges (2004)	European Railway Bridge Demography	Our expansive survey, covering nearly all of Europe and its distinct climatic zones, reveals a fascinating picture of the continent's railway bridge stock. Despite a general trend towards aged structures, a surprising variety of bridge types still stands strong.
Arskog, V., Fossdal, S., & Gjorv, O. E. (2004).	Life-cycle assessment of repair and maintenance systems for concrete structures.	This paper unveils a tool for choosing sustainable repair methods for concrete structures. By analyzing the environmental impact of different repair materials and systems, it empowers engineers to minimize their ecological footprint.
Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., Norris G., Rydberg T., Schmidt W. P., Suh S., Weidema B.P., Pennington D.W.(2004).	Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications.	This research lays the groundwork for any LCA study with its robust framework: a crystal-clear goal and scope definition followed by a meticulous inventory analysis.
Pennington D., Potting J., Finnveden G" Lindeijer E., Jolliet O., Rydberg T. and Rebitzer G. (2004)	Life Cycle Assessment part 2: Current impact assessment practice.	Examining the intricacies of the Life Cycle Impact Assessment (LCIA) phase, this research highlights the diverse modeling options and methodologies available for transforming life cycle inventory data into impactful environmental indicators.
Baumann, H. & Tillman, A-M. (2004).	The hitchhiker's guide to LCA	Environmental professionals will gain not only the skills to interpret LCA results but also the in-depth knowledge to apply them in real-world situations. Dive into practical exercises designed to prepare you for tackling complex LCA projects with confidence.
Steele, K., Cole, G., Parke, G., Clarke, B., & Harding, J. (2003)	Highway bridges and environment sustainable perspectives.	The proposed life-cycle assessment method offers a tool for making informed decisions that account for both direct and indirect environmental impacts.
Itoh, Y., & Kitagawa, T. (2003).	Using CO2 emission quantities in bridge lifecycle analysis	By employing a modified life cycle assessment methodology, we found that minimized girder bridges produce significantly lower CO2 emissions and are more cost-effective throughout their lifespan.
Steele, K. N. P., Cole, G., Parke, G., Clarke, B., & Harding, J. (2002).	The Application of Life Cycle assessment Technique in the Investigation of Brick Arch Highway Bridges.	This paper comprehensively examines all stages of a bridge's life cycle, from initial construction to years of service, culminating in the eventual need for either strengthening or replacement due to obsolescence.

Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region: A Critical Review

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Godart, B. and Vassie, P. (2001)	Bridge Management Systems Extendedreview of Existing Systems and outline Frameworkfor a European System.	This survey reveals that computerized bridge management systems (BMS) are widely used across the continent, with 11 out of 16 responding countries employing them.
Worrell, E., Price, L., Martin, N., Hendriks, C., & Meida, L. O. (2001).	Carbon dioxide emissions from the global cement industry.	In 1994, the world's hungry appetite for cement generated a staggering 307 million metric tons of carbon emissions, constituting a significant 5% of all human-caused CO2 emissions that year.
Fowler, D.W. (1999)	Polymers in concrete: a vision for the 21st century.	PIC, PC, and PMC have been taking the construction world by storm for the past 25 years. These versatile materials, used for repairs, overlays, and precast elements, offer enhanced performance compared to traditional concrete.
Widman, J. (1998).	Environmental impact assessmentof steel bridges.	Swedish Institute of Steel Construction studies shows that steel bridges reduces their environmental footprints as compared to concrete bridges because they require less construction material.
M.A. Issa, A.K. El-Shakour, and M.C. Chiew (2023)	Durability of Ultra-High-Performance Concrete (UHPC) in Prestressed Concrete Bridge Decks.	UHPC's remarkable resilience against freeze-thaw cycles and chloride attack paves the way for a revolution in bridge deck construction. Its dense microstructure, exceptional strength, and optimized pore structure create an impenetrable barrier against environmental threats, promising longer lifespans, reduced maintenance costs, and ultimately, superior bridge performance.
S.Y. Hong, Y. Liu, and Y.C. Teng (2023)	Long-Term Monitoring of Prestress Losses in a Segmental Concrete Bridge	Contrary to expectations, a long-term study shows much lower prestress losses in a segmental concrete bridge than traditional calculations predict.
Horvath, A. & Hendrickson, C. T(1998)	Steel vs Steel-Reinforced Concrete Bridges: Environmental Assessment	The growing prevalence of mini mills, which primarily use recycled steel scrap, could significantly reduce the resource inputs and environmental impact of steel production compared to traditional integrated mills.
Thompson, P., Small, P., Johnson,M. and Marshall,A. (1998)	The Pontis Bridge ManagementSystem.	This advanced bridge management system leverages the power of Markov decision processes and linear solutions to tackle complex network optimization challenges.
Page, J. (1996)	A Guide to Repair and Strengtheningof Masonry Arch Highway Bridges	This in-depth guide delves into the challenges faced by arch bridges, presenting a plethora of repair and strengthening options tailored to diverse issues.
Mikawi, M. (1996).	A methodology for the evaluation of the use of advanced composites in structural civil engineering applications	This research unveils a new tool for evaluating advanced materials in civil engineering, specifically targeting their potential for repairing and strengthening aging bridge columns.

Authors	Title of Papers	Discussion/Conclusions/Findings
Bertolini, L., Bolzoni, F., Pastore, T., & Pedferri, P. (1996).	Behaviour of stainless steel in simulated concrete pore solution.	This study analyses the performance of various stainless steel rebars in highly aggressive concrete settings. By subjecting them to a range of pH levels, chloride concentrations, and temperatures, researchers explored the impact of these factors on the critical chloride content, highlighting the influence of composition and temperature.
Heijungs, R. and Guinée, J. (1994)	Software as a Bridge between Theory and Practice in Life Cycle Assessment.	This study emphasizes the pitfalls of relying on implicit knowledge within computers or even among computer specialists. Only through meticulous and open communication of LCA methods and everyday practices can we ensure the development of computer models that truly fulfill their potential.
Ashurst, D. (1993)	An Assessment of Repair and Strengthening Techniques for Brick and Stone Masonry Arch Bridges	This report analyzes an extensive sample of 180 repair and strengthening techniques, meticulously selecting the 50 most promising candidates for in-depth exploration.

4. LIMITATIONS

In the reviewed papers, it is observed that the majority of the study have been carried out in the phase of early 20th century without the fusion of new technologies in the field of construction of bridges, however in today's respect with growing demand for earliest and fast bringing of the project considered parameters are limited to prioritized on economic aspect and somewhat limited to environmental parameters considering a huge drive worldwide for preservation of nature, resources and environment. In this context the social aspects somehow lag behind as a gray patch considering the fact that the influence of such projects with speedy work can only influence the society of the place as a whole for a limited time during the construction phase, while this concentration further diminishes when the project is fully complete in practical aspects. Hence, a further study in this area is required to carefully study the social aspect also.

5. CONCLUSION

The sustainability of the construction cannot be assessed merely by accounting the performance of individual key indicators rather the design that provide desired result balanced in between economic of environmental field may be considered for holistic design perspective.

It is observed from the review that cost of aggregate counts for major chunk of economic impact, also construction cost initially may seem on a higher side however in contrary to this maintenance cost is more than the construction cost. Low repair cost directly refers to performance of the bridge. It was further noted that difference between preventive maintenance and reactive/ capital maintenance is also very low. However, cost of construction is quite relevant, the cost associated with the complexity of maintenance in Himalayan region cannot be neglected. Cost data considered in the journals review are greatly related to place and time. The inference drawn from review of literature is that the preferred designs are based on surface treatment, thus accounting for significant frequency of maintenance operation throughout the bridge life cycle. Less preferred is the baseline design alternative, as the performance is greatly affected by the tough and volatile environmental conditions in Himalayan region hence the maintenance thus associated are also cost driven when compared to surface treatments. It may also be noted that less maintenance cost is not an indicator of design alternative as the need may

be different in different cases, it may be possible that installation cost may be on a higher side. However, if we consider optimization, the impacts of life cycle economics are less as compared to impact on environment.

Environment aspect is the most relevant parameter while sustainability assessment as damage / alteration to the ecosystem and exploitation of resources is considered as major parameter amid concern of world community for environment. The major contributor in this aspect is the increase use of water and contamination of water ecosystem. Also, the sustainability of structure greatly depends on how aggressive / impactful the exposed environment is to the structure. In specific cases, it was analysed that use of steel rebars were the worst performer as far as environmentally sustainable materials are considered.

Social impact symbolizes damage/ effect to health of human, damage to the ecology of that place, and the available resources thereon. Further, labours/ workers are one of the major stakeholders. The indicator related to labours/ workers are related to sustainable achievement of desired result. Social impact counts on generation of quantity and duration for which work/ employment considering the overall life span of the infrastructure inclusive of construction phase and the maintenance phase. Further, case it was observed that fair salary for work, safety of workers/ labours, gender considerations, local laws, employment statistics of the region is chief contributors of social impact that it draws. Sustainability of project are greatly dependent on the social and regional context where the project is to be executed under the consideration of tough environmental terrain of the Himalayan region.

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