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Original Article

Multicriteria Decision Making Framework for Ranking Key Sustainability Parameters in Green Concrete Using SEM and FAHP

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Abstract **-** *Concrete is a crucial construction material due to its global consumption and environmental impact. Sustainable concrete construction trends and opportunities are essential due to global warming and environmental changes. Green concrete, additional cementitious materials, permeable concrete, cool concrete, and local materials are examples of sustainable materials and technologies. Self-healing concrete, geopolymer concrete, 3D-printed concrete, photocatalytic concrete, electrified equipment, and carbon capture, usage, and storage technologies are discussed as potential improvements to construction sustainability. Impacts on sustainable concrete construction are addressed from technical, economic, and sociological standpoints. Governments, businesses, and academia must work together to promote sustainable concrete construction through interdisciplinary collaboration and research. Digitation, data-driven methodologies, and circular economy principles are critical to the development of sustainable concrete structures. A questionnaire was sent to construction experts (academics, contractors, and engineers) to measure the importance of actual sustainability standards. A comprehensive literature analysis revealed 41 concrete sustainability variables, classified into three groups: Economic, Environmental, and social factors. Factor Analysis method was used to identify key factors among these variables. The Fuzzy Analytic Hierarchy Process (FAHP) was used to prioritize the weights for selected variables and establish a relationship between them. The sustainability of a concrete structure is typically assessed using various criteria and metrics, but there is no single sustainability index for concrete structures.*

Keywords **-** *Sustainability, Green Concrete, Sustainability Assessment, Life Cycle Cost Analysis.*

1. Introduction

In 2015, the European Union (EU) produced 215 million cubic meters of ready-mixed concrete [1]. Concrete is also growing more popular. People often recognize concrete as a significant building material, both in terms of quantity and environmental footprint. Cement manufacturing accounts for 5 to 8% of all human-caused CO_2 emissions [2]. The production of concrete releases chemicals into the atmosphere and water, which have demonstrated negative environmental impacts [3], including accelerated eutrophication, acidification, and global warmiFrom this perspective, buildings offer unique environmental advantages due to their longevity and ability to enhance environmental aspects through the optimization of materials and construction techniques.ion.When scientists first started exploring ways to lessen the environmental impact of concrete, they concentrated on developing new varieties of the material. Scientists created new varieties of concrete using Recycled Aggregates (RA) and other cementitious ingredients. Traditional concrete technology has a proven method of increasing the mechanical strength of concrete by increasing the quantity of Portland clinker in the mix. As a result, the environmental impact per cubic meter decreases, and industrial waste materials like fly ash may replace a portion of the cement. These waste materials replaced the original binder because they had a lesser environmental effect [4]. Using an alternative binder for cement in concrete mixes at different percentages (5%, 10%, and 20%) could potentially decrease Greenhouse Gas (GHG) emissions in the European Union (EU) by 0.06%, 0.12%, and 0.25%, respectively. A 20% exchange saves 11.3 million metric tons of CO_2 equivalent [5]. Using recycled aggregate instead of natural material reduces carbon emissions by 58% [6]. According to Life Cycle Assessment (LCA) statistics, using recycled aggregates made from Construction and Demolition (C&D) waste may lower net environmental effects (EI) by 49–51% compared to producing aggregates from crushed stone. However, recycled aggregate raises new concerns about aggregate purity [7-11], concrete mixture rheology, and hardened concrete strength and durability [12-14].

Current research suggests that the design process may make the majority of the final product modifications [15–17]. According to the findings, a thorough structural assessment, rather than only the concrete mix design, is necessary to properly evaluate the construction-material solution [4, 18]. Research has demonstrated that the use of higher concrete classes significantly reduces the amount of material in each component of a concrete building when calculating its environmental impact [5]. Research has demonstrated that High-Performance Concrete (HPC) can reduce greenhouse gas emissions by 10-20% while also mitigating eutrophication, acidification, and ozone depletion [5, 19]. A previous study [20] also demonstrated the impact of transportation on concrete. The results show that industrial activities (A1 and A3) produce significantly more environmental damage than transportation. Hossain et al. [21] conducted a sensitivity study to assess the effect of different transit durations on aggregate production from C&D trash. They find that variations in transit times of up to 20% have little to no effect on the results. They determined that this variation has a net impact of less than 12%. The findings seem to follow a consistent trend. However, keep in mind that the results may differ depending on the assumptions used. The paper [22] highlights the broad nature of Life Cycle Inventory (LCI) data in order to highlight the paucity of comprehensive examinations of actual industrial processes.

Because of the complexities of real-world processes, the diversity of evaluations, and the unavailability of databases, research may miss important aspects of unique projects. Life cycle engineering, on the other hand, attempts to educate specialists [23–26] about the costs and potential repercussions of enhancing a product's environmental effect. Multi-parametric models are required to accurately predict the lifespan of a concrete structure while accounting for all relevant components. The approach is unusual in that it examines and assesses the interdependencies between all of the many components involved in the optimization process. This is the only strategy that can provide real outcomes in terms of reducing negative environmental repercussions. Identify the aspects of the environmental impact assessment that are most likely to influence the outcomes before creating any such models.

The study's primary goal is to identify and assess the factors that influence the EI of concrete buildings over the course of their service lives. A better understanding of the standards, their importance, and the connections between them may help to limit the negative effects of physical components on the environment. This is true for both previously highlighted and recently neglected areas. This kind of requirement occurs in certification techniques like LEED, where every minor point counts toward an environmental indication. In contrast to the fundamental models often used in environmental assessments, the outcomes of this study demonstrate the complexities and diversity of analyzing the environmental consequences of concrete structures.

1.1. Sustainability

Simply expressed, sustainability is the technique of addressing current needs without jeopardizing future generations' ability to do the same. This strategy considers environmental, social, and economic considerations in order to protect the planet's and its people's long-term well-being. Sustainable activities and policies, from a green perspective, are those that decrease negative environmental repercussions. Among them are boosting renewable energy sources, minimizing greenhouse gas emissions, and safeguarding biodiversity. Sustainable practices are ones that have a low environmental effect, such as preserving natural resources and reducing pollution. Because of its focus on social justice, sustainability creates a more egalitarian and inviting society. The objective is to ensure that everyone has access to the resources they need to live a healthy and productive life. Social cohesion, along with the abolition of inequality and poverty, is at the forefront of sustainable communities. They also promote cultural diversity and assist the most vulnerable members of society. Sustainability includes advocacy for ecologically and socially acceptable corporate practices. Circularity is an aim of sustainable economies in which resources are efficiently utilized, waste is minimized, and items and materials are reused several times before being discarded. Sustainability advocates for a balance between economic development, social fairness, and environmental conservation in order to leave future generations with a society that is both stable and successful.

1.2. Sustainability in Concrete

Environmentally friendly concrete is significantly used in modern construction and infrastructure projects. The production of concrete, one of the most commonly used construction materials globally, has significant environmental and social effects. Improving the durability of concrete is critical for lowering its environmental impact and creating structures that can survive natural calamities. Concrete's carbon footprint must be reduced in order for it to be fully sustainable. Carbon dioxide (CO_2) is produced in significant amounts during the manufacturing of conventional concrete, mostly due to the use of cement. Carbon emissions may be reduced by using sustainable concrete solutions as binders, such as fly ash and slag, using recycled materials, optimizing mix designs, and promoting carbon capture and utilization technologies. These approaches have the potential to significantly cut CO_2 emissions from concrete production, making it more sustainable. Concrete's durability and hardness also contribute to its environmental friendliness. Long-lasting concrete structures that need minimal maintenance and repair are the product of sustainable concrete mixes that prioritise the use of high-quality components and cutting-edge construction techniques. This reduces not just the environmental impact of the structure but also the financial cost of periodic maintenance and replacement. Improving the lifetime of concrete structures decreases energy consumption and aids in the preservation of infrastructure for future generations. Material stewardship is also considered in sustainable concrete. This involves promoting ethical and environmentally sound mining and extraction practices, as well as using locally available resources to reduce transportation-related emissions. Furthermore, sustainable concrete manufacturing strives to reduce waste and boost recycled concrete from demolition and construction sites, all while maintaining concrete's important role in today's building industry.

1.3. Advantages of Using Sustainability in Concrete

Adopting sustainable practices in the concrete construction business has environmental, social, and structural advantages. The following are some of the primary advantages of using sustainable concrete:

1.3.1. Environmental Benefits

- Sustainable concrete mixes commonly include non-Portland cementitious ingredients such as pozzolans, fly ash, or slag to reduce energy consumption and greenhouse gas emissions. As a result, less greenhouse gas is created during the concrete production process.
- Sustainable concrete architecture minimises the environmental impact of mining, quarrying, processing, and shipping raw materials by optimising their usage, reducing waste, and employing recycled or locally produced materials.
- Improved Energy Performance: Using more efficient energy for heating, cooling, and lighting is one way to minimise a building's environmental impact through the use of sustainable construction practices.

1.3.2. Longevity and Durability

- Because of the increased durability that may be integrated into sustainable concrete compositions, a longer usable life is conceivable. In the long term, this means less money and resources spent on repairs and maintenance.
- Sustainable concrete, which is more resistant to environmental forces like freeze-thaw cycles, chemical exposure, and seismic activity, provides improved structural resilience and reduces the need for rebuilding.

1.3.3. Social and Economic Benefits

- Green building, energy efficiency, and other environmentally friendly components of construction may all generate new job opportunities as a result of sustainable building practices.
- Improved health and happiness are unintended consequences of sustainable building designs, which often prioritise ventilation, natural lighting, and occupant ease.
- Owners and tenants may save money on utility costs during the life of the building if it is ecologically friendly and consumes less energy and water.

1.3.4. Regulatory and Market Advantages

- Many countries around the globe are implementing more demanding environmental regulations and building codes that promote sustainable construction practices. In order to achieve these expectations, building firms might employ sustainable concrete.
- Market Demand: Environmentally conscious consumers and businesses are becoming more interested in sustainable construction practices. Sustainable building practices may assist construction firms in gaining new clients and maintaining their competitive advantage.

Some of the numerous reasons to emphasize sustainability in concrete construction include environmental advantages, structural enhancements, social and economic rewards, and satisfying ever-changing regulatory and market expectations. Because of these advantages, sustainable concrete is fast becoming the material of choice for builders and developers who want to create long-lasting, environmentally responsible structures.

1.4. Types of Sustainable Concrete

Several varieties of sustainable concrete have been created to lessen the environmental effect of conventional concrete and encourage more environmentally friendly building practices. Here are some of the most important forms of sustainable concrete:

1.4.1. High-Performance Concrete (HPC)

High-performance concrete is designed to withstand environmental stresses such as chemical corrosion and freeze-thaw cycles, making it extremely robust and long-lasting. Reduced environmental and economic costs owing to concrete deterioration are the outcome of builders using HPC to design structures with longer lifespans and fewer repair and maintenance requirements over time.

1.4.2. Recycled Concrete Aggregate (RCA) Concrete

RCA concrete incorporates recycled concrete as a replacement for some or all of the natural aggregates (e.g., gravel and sand) in the mix. This reduces the demand for virgin materials, decreases waste going to landfills, and lowers the overall environmental impact of concrete production.

1.4.3. Fly Ash Concrete

Fly ash, a byproduct of coal combustion, adds cementitious properties to concrete. It makes the material easier to work with, reduces the amount of heat generated during curing, and improves its strength and durability over time. One technique to reduce the environmental impact of concrete production is to substitute fly ash for some of the Portland cement.

1.4.4. Slag Cement Concrete

Similar to fly ash, slag cement is a byproduct of industrial processes, typically from iron production. It can be used as a partial replacement for Portland cement, improving the sustainability of concrete while offering benefits like enhanced workability and durability.

1.4.5. Geopolymer Concrete

Geopolymer concrete is an innovative, sustainable alternative to traditional concrete. It utilizes aluminosilicate materials and an alkaline activator to form a binder. Geopolymer concrete has a lower carbon footprint, requires less energy for production, and exhibits excellent resistance to chemical corrosion.

1.4.6. Self-Healing Concrete

Self-healing concrete contains materials that can autonomously repair microcracks that form over time. This reduces maintenance needs, increases durability, and extends the service life of structures.

1.4.7. Bio Concrete

Bio concrete mixes microorganisms and nutrients into the mixture. When cracks emerge in the concrete, these bacteria can generate calcium carbonate, which seals the cracks and increases durability. Bio concrete can be used to reduce maintenance in infrastructure that is exposed to hostile environments.

1.4.8. Lightweight Concrete

Lightweight concrete employs lightweight aggregates (such as expanded clay or shale) to lower its total weight. This may lead to decreased transportation costs, reduced structural loads, and increased energy efficiency in buildings.

1.4.9. Low-Carbon Concrete

Low-carbon concrete focuses on minimizing carbon dioxide emissions during production. This can involve using alternative binders, carbon capture technologies, and optimized manufacturing processes.

1.4.10. Green Concrete

Green concrete is a general term that encompasses various sustainable concrete types and practices, including those mentioned above. It emphasizes reducing the environmental impact of concrete through material selection, energy-efficient production, and innovative construction methods.

These types of sustainable concrete represent diverse approaches to making the construction industry more environmentally responsible and reducing its carbon footprint. The choice of which type to use depends on the specific project requirements and sustainability goals.

1.5. Applications Using Sustainable Concrete

Sustainable concrete has a wide range of applications across the construction industry, offering eco-friendly alternatives for various types of structures and projects. Here are some common applications of sustainable concrete:

1.5.1. Residential Construction

Sustainable concrete can be used in the construction of residential buildings, including houses and apartment complexes. It is often employed for foundations, slabs, walls, and other structural elements, promoting energy efficiency, durability, and reduced maintenance costs for homeowners.

1.5.2. Commercial Buildings

Sustainable concrete is increasingly utilized in the construction of commercial properties such as offices, retail spaces, and hotels. These buildings benefit from the improved thermal performance, indoor air quality, and sustainability credentials of sustainable concrete.

1.5.3. Industrial Facilities

Industries use sustainable concrete for constructing factories, warehouses, and other industrial structures. Its durability and resistance to harsh conditions make it an ideal choice for facilities that require long-term reliability.

1.5.4. Transportation Infrastructure

Sustainable concrete is applied in various transportation projects, including highways, bridges, and tunnels. Its resistance to heavy traffic loads, de-icing chemicals, and environmental factors makes it a preferred choice for these critical infrastructure components.

1.5.5. Public Infrastructure

Sustainable concrete is used for public infrastructure projects like water treatment plants, sewage systems, and stormwater management structures. Its durability and resistance to corrosion make it suitable for these demanding applications.

1.5.6. Educational Facilities

Sustainable concrete can be found in the construction of schools, colleges, and universities. It contributes to a healthier indoor environment and supports sustainable building design principles.

1.5.7. Healthcare Facilities

Hospitals and medical centres benefit from the durability, fire resistance, and infection control properties of sustainable concrete, which are essential for ensuring the safety and well-being of patients and staff.

1.5.8. Cultural and Recreational Facilities

Sustainable concrete is used in the construction of museums, sports stadiums, and cultural centres. It helps create iconic structures while adhering to sustainable and energy-efficient design principles.

1.5.9. Resilience and Disaster Mitigation

Sustainable concrete plays a crucial role in the construction of disaster-resilient structures, including earthquake-resistant buildings, tsunami barriers, and flood control systems.

1.5.10. Infrastructure Rehabilitation

In addition to new construction, sustainable concrete is used for repairing and rehabilitating existing structures. Techniques like concrete overlays, retrofitting, and the use of self-healing concrete can extend the service life of ageing infrastructure.

1.5.11. Green Building Projects

Sustainable concrete is a key component of green building certifications like Leadership in Energy and Environmental Design (LEED) and BREEAM. These certifications promote the use of sustainable materials and construction processes in order to lessen the environmental effects of buildings.

1.5.12. Urban Development

Sustainable concrete is crucial in urban development projects like sustainable housing complexes, mixed-use developments, and urban revitalization efforts aimed at creating more livable and environmentally responsible cities.

These applications demonstrate the versatility and significance of sustainable concrete in modern construction, where its use can help reduce environmental impact, enhance durability, and support the development of more sustainable and resilient infrastructure and buildings.

1.6. Factors for Economic, Environmental and Social Sustainability

1.6.1. Economic Sustainability

Economic sustainability in concrete construction involves factors that ensure the cost-effectiveness and long-term financial viability of concrete projects. Here are some key economic sustainability factors to consider:

Lifecycle Cost Analysis

Conducting a comprehensive lifecycle cost analysis is crucial for economic sustainability. This analysis evaluates not only the initial construction costs but also the long-term costs associated with maintaining, repairing, and eventually demolishing a concrete structure. It helps in making informed decisions about materials, design, and construction methods that minimize overall costs over the life of the project.

Optimized Mix Designs

Developing concrete mix designs that use materials efficiently and meet performance requirements is essential for economic sustainability. Optimized mix designs can reduce the need for expensive additives and minimize material waste.

Alternative Cementitious Materials

Using alternative cementitious materials, such as fly ash, slag, or silica fume, can reduce the reliance on traditional Portland cement, which is often costly and energy-intensive to produce. These alternatives can offer cost savings while also reducing the carbon footprint of concrete.

Energy Efficiency

Implementing energy-efficient practices in concrete production and transportation can lead to cost savings. Efficient kiln operation in cement manufacturing, for example, can reduce energy consumption and lower production costs.

Resource Efficiency

Maximizing the efficient use of resources, including aggregates and water, can reduce material costs. Reusing and recycling materials on-site or sourcing locally can also lead to economic sustainability by reducing transportation costs.

Durability and Maintenance

Designing concrete structures for durability and ease of maintenance can minimize the need for frequent repairs and replacements. Investing in high-quality materials and construction methods upfront can save money in the long run.

Innovative Technologies

Embracing innovative technologies, such as 3D printing, automated construction equipment, and digital modelling, can lead to cost savings through increased efficiency and reduced labour requirements.

Sustainable Procurement

Sustainable procurement strategies entail choosing suppliers and products based on environmental, social, and financial considerations. This might involve obtaining products from vendors that follow responsible environmental policies and ethical labor standards.

Financial Incentives

Taking advantage of government incentives, tax credits, or grants for sustainable construction practices can reduce the financial burden of implementing environmentally friendly and energy-efficient technologies in concrete projects.

Risk Management

Addressing potential risks, such as project delays or unforeseen expenses, is essential for economic sustainability. Having contingency plans and risk management strategies in place can help prevent financial setbacks.

Long-Term Value

Assessing the long-term value of a concrete structure beyond its initial cost is a fundamental economic sustainability factor. Investing in quality construction and materials that provide lasting benefits can be more financially advantageous in the long term.

By considering these economic sustainability factors, concrete construction projects can be planned, designed, and executed in a way that not only meets budgetary constraints but also delivers long-term financial benefits and minimizes lifecycle costs. This approach ensures that concrete structures are economically sustainable over their entire lifespan.

1.6.2. Environmental Sustainability

Environmental sustainability in concrete construction focuses on reducing the environmental impact associated with the production, use, and disposal of concrete materials and structures. Here are key factors to consider for environmental sustainability in concrete:

Alternative Cementitious Materials

Reduce the carbon footprint of concrete by using alternative cementitious materials such as fly ash, slag, silica fume, or calcined clays. These materials often have lower embodied carbon emissions than ordinary Portland cement.

Low-Carbon Concrete Mixes

Optimize concrete mix designs to minimize the cement content, which is a major source of CO_2 emissions in concrete production. Using supplementary cementitious materials and pozzolans can help achieve this while maintaining performance.

Recycled Aggregates

Use recycled aggregates, such as crushed concrete or recovered asphalt pavement, to minimize the need for virgin materials, save energy, and reduce landfill trash.

Energy-Efficient Production

Implement energy-efficient practices in cement manufacturing, including the use of more energy-efficient kilns, alternative fuels like biomass or waste-derived fuels, and waste heat recovery systems.

Carbon Capture and Utilization (CCU)

Invest in technology that captures CO_2 emissions from cement manufacturing and converts them into lucrative goods or securely stores them underground.

Sustainable Sourcing

Choose responsibly sourced materials, including aggregates, water, and admixtures, to reduce the environmental impact associated with resource extraction and transportation.

Reduced Water Usage

Implement water-efficient practices in concrete production and construction, such as using recycled water or optimizing batching processes to minimize water waste.

Waste Reduction and Recycling

Minimize waste during construction and demolition by reusing and recycling concrete materials. Crushed concrete can be used as aggregate in new concrete mixes, reducing the need for fresh materials.

Design for Durability

Design concrete structures with durability in mind to extend their lifespan and reduce the need for repairs and replacements, which can be resource-intensive and environmentally taxing.

Sustainable Transport

Minimize the carbon footprint associated with transporting concrete by sourcing materials locally and optimizing delivery routes.

Green Building Certifications

Concrete is one of the sustainable construction materials recognized by green building certifications like Leadership in Energy and Environmental Design (LEED).

Biodiversity Considerations

Incorporate environmentally friendly landscaping and green infrastructure into concrete projects to promote biodiversity and reduce the heat island effect in urban areas.

Construction Waste Management

Implement effective waste management plans to reduce construction site waste, recycle materials, and responsibly dispose of hazardous waste.

Environmental Impact Assessments

Conduct comprehensive environmental impact evaluations to better understand and reduce the possible environmental consequences of concrete projects, particularly in sensitive locations.

Lifecycle Assessment (LCA)

Use lifecycle assessment techniques to examine the environmental effect of concrete buildings at all phases, from raw material extraction to destruction and disposal. By addressing these environmental sustainability factors, concrete construction can contribute to reducing carbon emissions, conserving resources, and minimizing its overall environmental footprint, making it a more environmentally responsible and sustainable building material.

1.6.3. Social Sustainability

Social sustainability in concrete construction focuses on creating positive social impacts and ensuring the well-being of people throughout the lifecycle of a project. Here are key factors to consider for social sustainability in concrete:

Worker Safety and Health

Prioritize the safety and well-being of construction workers by providing safe working conditions, appropriate training, and Personal Protective Equipment (PPE). Implementing strict safety protocols and practices is essential.

Local Employment

Foster local employment opportunities by hiring skilled and unskilled labour from the local community. This can contribute to economic development and reduce the need for long-distance commuting.

Fair Labor Practices

Ensure fair wages, benefits, and working conditions for all workers involved in the concrete construction process, including labourers, contractors, and subcontractors.

Community Engagement

Engage with the local community and stakeholders to seek their input and address concerns related to concrete construction projects. Open and transparent communication can build trust and support.

Minimizing Disruption

Minimize disruptions to the surrounding community during construction, such as noise, dust, and traffic congestion, by implementing best practices in construction management and scheduling.

Accessibility and Inclusivity

Design concrete structures to be accessible to all individuals, including those with disabilities. Incorporate universal design principles to ensure usability by people of all abilities.

Cultural Sensitivity

Respect and protect cultural heritage and sensitive sites when planning and executing concrete projects. This includes preserving historical structures and landscapes.

Local Material Sourcing

Whenever possible, source construction materials, including aggregates and reinforcement, locally to support the local economy and reduce transportation-related environmental impacts.

Social Equity

Promote social equity by ensuring that concrete projects benefit all segments of the population, particularly marginalized or disadvantaged communities.

Education and Training

Invest in education and training programs to develop the skills and knowledge of workers in the concrete industry, supporting their career development and long-term employability.

Apprenticeships and Internships

Provide opportunities for apprenticeships and internships to promote workforce development and facilitate the entry of new talent into the concrete construction industry.

Social Impact Assessments

Conduct social impact assessments to understand the potential effects of concrete projects on the local community and take measures to mitigate negative impacts.

Community Benefits

Explore opportunities for Community Benefits Agreements (CBAs) that outline specific benefits, such as job opportunities, affordable housing, or infrastructure improvements, for the local community in exchange for support of the project.

Public Space Enhancement

Enhance public spaces and amenities in the vicinity of concrete projects to improve the overall quality of life for residents and users of the area.

Ethical Procurement

Promote ethical procurement practices by sourcing materials and products from suppliers that adhere to fair labour practices and environmental standards.

By addressing these social sustainability factors, concrete construction projects can contribute to stronger and more inclusive communities, promote social well-being, and enhance the overall quality of life for the people affected by these projects. Social sustainability ensures that concrete construction benefits society as a whole, not just economically and environmentally, but also by fostering positive social impacts.

2. Methodology

An online poll was used to assess the impact of eco-friendly elements on concrete buildings in the construction sector. We created a simple yet thorough survey. The questionnaire is divided into two sections. The first section introduces us to the respondents; the second examines the implications of sustainable concrete buildings on the construction sector. Anything may be ranked from 1 to 5 in significance. Owners, designers, builders, cost estimators, and building site managers all shared their thoughts. The poll was addressed to a variety of NGOs, enterprises, and government bodies. Some others couldn't react at all, and those who did gave inadequate reasons. After deleting the 18 incomplete surveys, there were 195 valid responses left. We arrived at these findings after considering all the remarks. Nine hundred and fifty-five individuals voted in the survey. These data were examined using structural equation modelling. PLS employs structural equations as well as evaluation functions. The internal model defines the connections between the parts. A factor analysis was performed using SPSS. PLS-SEM was used in this work to evaluate the relationships between the components that impacted coronavirus development. The PLS-SEM model was chosen as the preferred relapse approach because of its capacity to tolerate dependent and free component multi-collinearity. The multivariate PLS-SEM model investigates numerous underlying linked connections using direct relapse and factor reduction.

3. Data Analysis Using SPSS and SEM

In comparison, covariance-based approaches assess four or more constructs, while the PLS method assesses just one. The PLS approach works effectively when analyzing survey data that does not have a normal distribution. PLS considers interaction effects and corrects measurement errors. After determining dependability, the quality of the study's internal consistency may be assessed. The Cronbach's alpha value was determined to be 0.818. This result is much higher than the average threshold of 0.7. After that, since credibility has been established, it is safe to continue with the analysis. Table 1, this page compiles all available impact measurements. Finally, the survey findings' dependability is confirmed.

Table 1. Impact of sustainability factors of concrete structures with factor loadings and cronbach's alpha

Code	Causes	Factor Loading	α
A1	Lifecycle Cost Analysis	0.6861	0.8320
A2	Optimized Mix Designs	0.7996	0.8603
A3	Alternative Cementitious Materials	0.7554	0.8295
A4	Energy Efficiency	0.5632	0.9111
A5	Resource Efficiency	0.5683	0.9117
A6	Durability and Maintenance	0.7532	0.9227
A7	Innovative Technologies	0.5494	0.8211
A8	Sustainable Procurement	0.6551	0.9192
A9	Financial Incentives	0.7331	0.9189
A10	Risk Management	0.8296	0.8189
A11	Long-Term Value	0.7591	0.9194

3.1. Model Construction

The many reasons for the impact of sustainability factors on concrete structures in the construction industry are shown in Figure 1. As a result, the SEM model developed serves as a framework for analyzing study-variable interactions.

3.2. Structural Equation Modelling for Impact of Sustainability Factors of Concrete Structures Analysis

Latent variable values from Table 2 and SEM Model A-Impact of Concrete Structure Sustainability Factors on the Construction Industry are shown in Figures 2, 3, and 4.

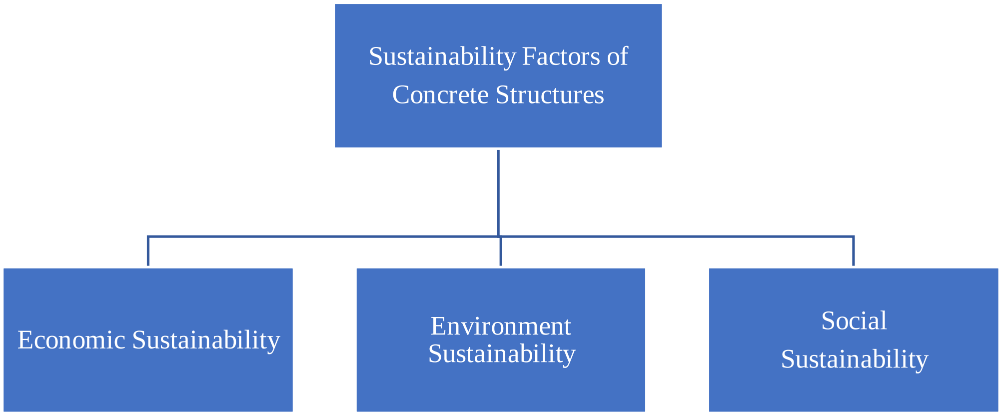

Fig. 1 Sustainability factors of concrete structures

Fig. 2 SEM model A- economic sustainability factors

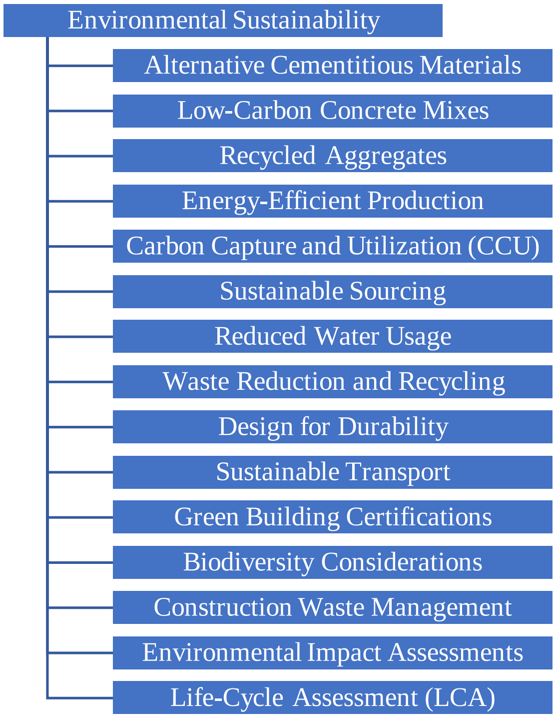

Fig. 3 SEM model B- environment sustainability factors

Fig. 4 SEM model C- social sustainability factors

Table 2. Latent variable coefficient

Model A	
R-squared	0.384
Adj. R-squared	0.205
Composite Reliability	0.915
Cronbach's alpha	0.766
Average Variance Extraction	0.799
Full collinear VIF	1.191
Q-Squared	
Min	-3.685
Max	2.568
Median	0.399
Mode	0.43
Skewness	0.699
Exc. Kurtosis	1.337

3.3. Model Fit and Quality Indices

- Currently, the APC is 0.941. A route coefficient greater than 0.90 indicates a fair and accurate match.
- The coefficient of determination is 0.938. R2, a statistical indicator, always has a value between 0 and 100%. A response variable with a value of 0% implies that any variation around the model's means is ignored. The mean of the dependent variable is used to predict regression models and dependent variables. A model is considered to have a 100% fit when it accurately explains all of the variation in the response variable around its average value. A higher R2 value often suggests that the regression model and data are more closely aligned.
- It employs a Goodness-of-Fit index (GoF) of 0.124. The Goodness-of-Fit (GOF) metric is used to ensure that the model accurately describes the experimental data. The GOF values, which vary from 0.25 to 0.36 and are both inside the 0–1 range, indicate that the model has widespread acceptance. A successful model fit suggests that the model is practical and realistic.
- Descriptive statistics may be used to examine the skewness and kurtosis.

3.4. Relative Importance Index

The 195 survey answers were extensively examined using the Statistic Package for the Social Sciences (SPSS) as a research instrument to get a better understanding. Table 3 shows the results of analyzing the effect of the coronavirus on the construction sector and ranking the variables according to their predicted criticality using the Relative Importance Index (RII) created by condition (2).

The variable W means "weight," and N, the total number of respondents, was obtained by ranking it on a 5-point scale, with 1 denoting "strongly disagree" and 5 denoting "strongly agree".

Table 3. Relative importance index for sustainability factors

Code	Causes	RII	Rank
A1	Lifecycle Cost Analysis	0.932	1
A2	Optimized Mix Designs	0.930	2
A6	Alternative Cementitious Materials	0.928	3
A3	Energy Efficiency	0.925	4
A4	Resource Efficiency	0.924	5
A5	Durability and Maintenance	0.920	6
A9	Innovative Technologies	0.817	7
A7	Sustainable Procurement	0.812	8
A11	Financial Incentives	0.810	9
A8	Risk Management	0.807	10
A10	Long-Term Value	0.801	11

3.5. The Key Factors that have been Most Impacted by Economic Sustainability Factors of Concrete Structures Using Factor Analysis

1. Lifecycle Cost Analysis
2. Alternative Cementitious Materials
3. Energy Efficiency
4. Long-Term Value

3.6. The Key Factors that have been Most Impacted by Environmental Sustainability Factors of Concrete Structures Using Factor Analysis

1. Low-Carbon Concrete Mixes
2. Energy-Efficient Production
3. Waste Reduction and Recycling
4. Green Building Certifications
5. Environmental Impact Assessments

3.7. The Key Factors that have been Most Impacted by Social Sustainability Factors of Concrete Structures Using Factor Analysis

1. Education and Training
2. Social Impact Assessments
3. Minimizing Disruption
4. Worker Safety and Health
5. Local Material Sourcing
6. Community Engagement

3.8. Reliability Statistics

Using SPSS, an assessment of the reliability of the sample size was performed. Table 4 indicates the value of "Cronbach's Alpha" as calculated by SPSS. Maybe expect a value between 0 and 1. In this case, the "Cronbach's alpha" value is 0.882, which is more than 0.6 and extremely close to 1, indicating that there is enough data in the sample and the questionnaire is reliable enough to conclude.

Table 4. Statistics on reliability

Cronbach's Alpha	Cronbach's alpha is based on Standardized Items	Number of Items
0.882	0.689	11

3.9. Feasibility of Factor Analysis Data

Table 5 shows the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test findings, which were used to assess if factor analysis was sufficient. Because the extended questionnaire survey passes Bartlett's Test of Sphericity, factor analysis may be performed.

Table 5. (SPSS output) KMO and Bartlett's test

Kaiser-Meyer-Olkin Sampling Adequacy Measure	0.753
Approx. Chi-Square Bartlett's Test of Sphericity	1670.647
df	284
Sig.	.000

The KMO statistic value is usually 0.753, which means that 0 KMO 1 is greater than 0.5. As a consequence, factor analysis is regarded as a valid approach. Assuring variable homogeneity helps with both factor analysis and data usability. Significantly (p-value). Given the number of variables ($p < 0.05$), factor analysis is a viable choice.

4. Fuzzy Analytic Hierarchy Process (FAHP)

The Saaty-designed Analytic Hierarchy Method (AHP) combines fuzzy theory with a clear analytical hierarchy approach. Fuzzy logic has been utilized to improve standard AHP since it removes the requirement for hazy, subjective assessments.

The FAHP technique of comparing criteria and alternatives uses triangular numbers to reflect linguistic aspects. Applying the FAHP approach to the supplied criteria and possibilities assists in the creation of more efficient, adaptable, and realistic judgements. The FAHP approach is chosen as the most effective self-healing alternative.

The following are the fundamentals of filling out an FAHP application.

1. Splitting the problem into manageable parts by using a hierarchical structure with the goals at the top, standards or assessment criteria in the middle, and alternative solutions for accomplishing the goals at the bottom.
2. At the conclusion of the iterative process, the issue is refined from an unstructured to a manageable state by further breaking down each branch into suitable degrees of detail. The challenge is then ranked horizontally and vertically based on a weighted factor hierarchy.
3. A matrix detailing the properties of the selections and the values that correlate to them.
4. Each survey characteristic is given a numerical weight after the verbal scale is converted into a fuzzy triangle scale with a range of 1 to 9.

Table 6. Linguistic scale and associated fuzzy numbers

Satty Scale	Definition	Fuzzy Triangular Scale
1	Equal Importance	(1,1,1)
3	Moderate Importance	(2,3,4)
5	Strong Importance	(4,5,6)
7	Very Strong Importance	(6,7,8)
9	Extreme Importance	(9,9,9)
2	The Intermittent Values between Two Adjacent Scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

1. A pairwise comparison with all other attributes in a matrix is used to determine the relevance of each feature.
2. We compute the geometric mean for each condition when comparing fuzzy values.
3. The consistency of the matrix is evaluated after obtaining the fuzzy weight (attribute weightage).
4. In order to identify the priority vectors, we do a thorough evaluation of each technology, analysing all aspects.
5. The weights produced in step VII are used to calculate the overall weight of each option by normalising the attribute weights and priority vectors.
6. The order is determined by weighing the importance of each choice. The allocation of weight determines the ranking's supremacy.

4.1. Methodology

A detailed literature survey is done to identify the various criteria that affect the sustainability of the structures. After identifying the criteria affecting the sustainability of concrete structures, the most important factors are selected using the FAHP tool. A questionnaire survey is conducted to determine the relative importance of the criteria. The relative weights are calculated from a normalized weighted matrix using the geometric mean method, and then the ranks are allocated to the shortlisted criteria. A Multicriteria Decision Making (MCDM) tool is used to rank technologies so that the user may choose the best solution for the issue at hand. The Fuzzy Analytical Hierarchy Process (FAHP) tool of MCDM is extensively used in this work. Using the FAHP results, the important factors of the sustainability of concrete structures are evaluated and ranked.

4.2. Criteria Weightage

The judgement weights were based on the results of a survey conducted among experts in the same field. Tables 8, 9, and 10 depicts the network utilized to calculate the primary rule loads, which serves as a representation of the decision makers' options. Fuzzification, or the translation of linguistic notions into membership functions, is achieved by utilizing the Saaty scale to convert matrix values into fuzzy numbers. Finding the reciprocal values and using geometric approaches are the next steps in calculating the weights.

Table 7. Criterion and strategies selected for FAHP

Sr. No.	Main Criteria	Sub-Criteria	Criterion Code
1.	Economic Factors	Life Cycle Cost Analysis	EC1
2.		Alternative Cementitious Materials	EC2
3.		Energy Efficiency	EC3
4.		Long Term Value	EC4
1.	Environmental Factors	Low-Carbon Concrete Mixes	EN1
2.		Energy-Efficient Production	EN2
3.		Waste Reduction and Recycling	EN3
4.		Green Building Certifications	EN4
5.		Environmental Impact Assessments	EN5
1.	Social Factors	Education and Training	S1
2.		Social Impact Assessments	S2
3.		Minimizing Disruption	S3
4.		Worker Safety and Health	S4
5.		Local Material Sourcing	S5
6.		Community Engagement	S6

Table 8. Pairwise comparison matrix for economic factors

	EC1	EC2	EC3	EC4
EC1	(1,1,1)	(4,5,6)	(2,3,4)	(6,7,8)
EC2	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	(1,1,1)	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	(4,5,6)
EC3	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(4,5,6)	(1,1,1)	(5,6,7)
EC4	$(\frac{1}{8},\frac{1}{7},\frac{1}{6})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{7},\frac{1}{6},\frac{1}{5})$	(1,1,1)

Table 9. Pairwise comparison matrix for environmental factors

	EN1	EN2	EN3	EN4	EN5
EN1	(1,1,1)	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	(4,5,6)	(6,7,8)	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$
EN2	(1,2,3)	(1,1,1)	(2,3,4)	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$
EN3	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$
EN4	$(\frac{1}{8},\frac{1}{7},\frac{1}{6})$	(1,2,3)	(1,2,3)	(1,1,1)	(4,5,6)
EN5	(4,5,6)	(3,4,5)	(3,4,5)	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	(1,1,1)

Table 10. Pairwise comparison matrix for social factors

	S1	S2	S3	S4	S5	S6
S1	(1,1,1)	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	(4,5,6)	(2,3,4)	(1,2,3)	(3,4,5)
S2	(3,4,5)	(1,1,1)	(6,7,8)	(3,4,5)	(2,3,4)	(4,5,6)
S3	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{8},\frac{1}{7},\frac{1}{6})$	(1,1,1)	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	(2,3,4)
S4	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	(4,5,6)	(1,1,1)	(2,3,4)	(3,4,5)
S5	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,2,3)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	(2,3,4)
S6	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)

4.3. Ranking of Criteria

A comparison of the qualities at each level resulted in priority values, with the Life Cycle Cost Analysis, Environmental Impact Assessments, and Social Impact Assessments getting the maximum weights. Long Term Value, Waste Reduction and Recycling, and Community Engagement got the least weight in the decision-making tool evaluation.

Table 11. Weighted matrix and ranking of criterion for economic factor

Criterion Number	Name of Criteria	Normalize Weight	Ranks
EC1	Life Cycle Cost Analysis	0.540	I
EC3	Energy Efficiency	0.305	II
EC2	Alternative Cementitious Materials	0.109	III
EC4	Long Term Value	0.044	IV

Table 12. Weighted matrix and ranking of criterion for environmental factor

Criterion Number	Name of Criteria	Normalize Weight	Ranks
EN5	Environmental Impact Assessments	0.301	I
EN1	Low-Carbon Concrete Mixes	0.230	II
EN4	Green Building Certifications	0.227	III
EN2	Energy-Efficient Production	0.171	IV
EN3	Waste Reduction and Recycling	0.070	V

Table 13. Weighted matrix and ranking of criterion for social factor

Criterion Number	Name of Criteria	Normalize Weight	Ranks
S2	Social Impact Assessments	0.416	I
S1	Education and Training	0.215	II
S4	Worker Safety and Health	0.162	III
S5	Local Material Sourcing	0.108	IV
S3	Minimizing Disruption	0.056	V
S6	Community Engagement	0.041	VI

5. Conclusion

The research looked at the trends and prospects in sustainable concrete building, emphasizing the necessity for environmentally friendly techniques to reduce the industry's environmental effects. The purpose of this research was to identify and assess the main aspects that may influence the lifespan of concrete buildings. A survey was sent to construction specialists (academics, contractors, and engineers). The relevance of real sustainability criteria was assessed in the survey. A thorough literature review discovered 41 specific sustainability factors. These variables were divided into three categories: economic, environmental, and social. To find the essential elements among the numerous sustainability criteria, the factor analysis approach is utilized. As a result of the factor analysis, the lifecycle cost analysis, alternative cementitious materials, energy efficiency, and long-term value were identified as the primary elements most influenced by the economic sustainability elements of concrete structures.

The factor analysis thus determined the main factors that environmental sustainability factors of concrete structures, such as low-carbon concrete mixes, energy-efficient production, waste reduction and recycling, green building certifications, and environmental impact assessment, have the most impacted. The component analysis, therefore, indicated the primary aspects that have been most influenced by the social sustainability aspects of concrete structures, such as education and training, social impact assessments, minimizing disruption, worker safety and health, local material sourcing, and community engagement.To priorities the weights for the chosen variables and develop a link between them, the Fuzzy Analytic Hierarchy Process (FAHP) is utilized. FAHP made the following observations:

1. Life Cycle Cost Analysis gained maximum weightage for Economic Factors followed by Energy Efficiency. Long Term Value factor got the minimum weightage.
2. For the Environmental Factor, Environmental Impact Assessments gained the maximum weightage and Waste Reduction and Recycling got the least weightage.
3. In Social Factor, Social Impact Assessments got the maximum weightage, and Community Engagement got the least weightage. The sustainability of a concrete structure is typically assessed using various criteria and metrics that consider the above factors. There isn't a single sustainability index for concrete structures.

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