

TITLE: SHAPING A SUSTAINABLE FUTURE: STRUCTURAL ENGINEERING, CIRCULAR ECONOMY & PATH TO ZERO-CARBON FUTURE BY SUSTAINABLE CONSTRUCTION

INTRODUCTION:

In an era marked by a growing environmental consciousness, the need for sustainable and zero-carbon construction practices has reached unprecedented levels. Within the construction industry, structural engineering assumes a pivotal role in shaping a sustainable future. As the world confronts the formidable challenges of climate change and environmental degradation, the industry is actively embracing the principles of circular economy, sustainable design, and eco-friendly materials. The ultimate objective is to attain zero carbon emissions and foster the development of a built environment that prioritizes long-term sustainability. Through the incorporation of circular economy principles, the adoption of sustainable design strategies, and the utilization of environmentally friendly materials, structural engineers can make substantial contributions towards mitigating the carbon footprint associated with the built environment.



This article provides an exploration of various facets within the realm of structural engineering in the context of sustainability, circular economy, and zero-carbon construction. It delves into the key concepts and approaches that drive the transformative process within structural engineering. Furthermore, the article conducts a thorough examination of the environmental impact and zero-carbon potential inherent in reinforced concrete structures, steel structures, and timber structures, allowing for meaningful comparisons between them. Additionally, the article emphasizes the critical importance of circular buildings, the reuse of existing structures, and the adoption of a "build nothing, build less, build clever" approach that effectively curtails the necessity for new construction. It also sheds light on the indispensable role played by structural integrity and health assessment through the utilization of non-destructive testing techniques, along with retrofitting and strengthening methods employed for repurposing existing structures. Lastly, the article delves into the future of buildings and infrastructure structures within the purview of a zero-carbon framework, envisioning a sustainable built environment that aligns harmoniously with the overarching goals of global decarbonization.

ZERO-CARBON PHILOSOPHY

The zero-carbon philosophy represents a fundamental shift in our approach to addressing climate change and reducing greenhouse gas emissions. It centers around the ambitious goal of achieving a carbon-neutral society, where the amount of carbon dioxide released into the atmosphere is balanced by the amount removed or offset. This philosophy recognizes the urgent need to transition away from fossil fuels and high-carbon practices to more sustainable and renewable alternatives. It encompasses various sectors, including energy, transportation, and construction, with a focus on minimizing carbon emissions throughout the entire lifecycle of products and services. In the context of buildings and infrastructure, the zero-carbon philosophy calls for the adoption of energy-efficient design principles, the integration of renewable energy sources, and the use of low-carbon materials. It also emphasizes the importance of sustainable transportation, waste reduction, and carbon offsetting measures. The zero-carbon philosophy recognizes that our collective efforts are necessary to combat climate change and create a sustainable future for generations to come. World economic forum gives an integrated approach, program energy

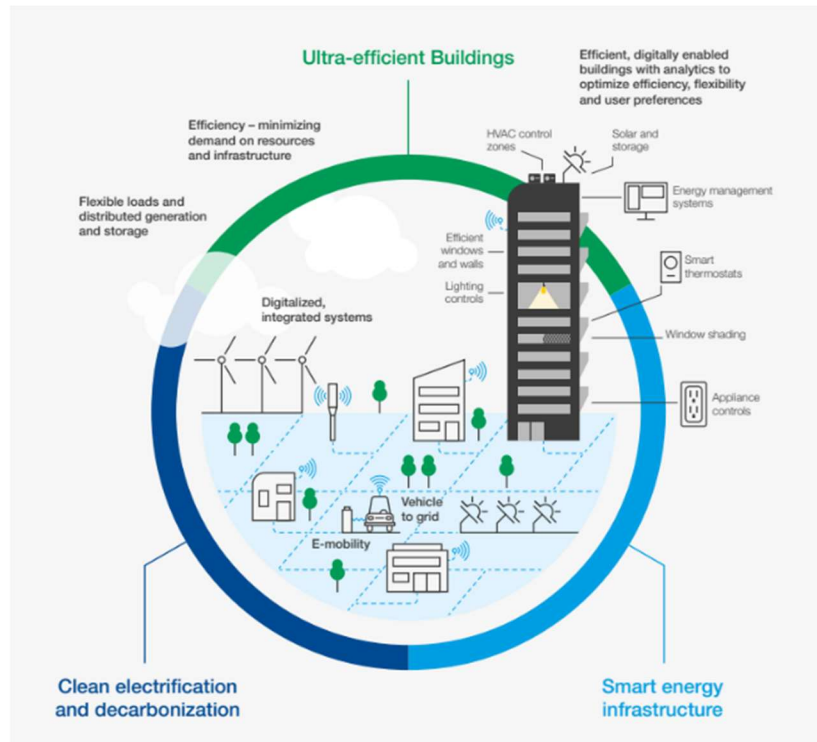
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system in net zero carbon cities. The Net Zero Carbon Cities program supports industry transformation through an Integrated Approach to help cities rethink urban ecosystems, ensuring that they are sustainable and resilient while bridging the gap across the energy, built environment and transport sectors.



CIRCULAR ECONOMY AND SUSTAINABLE STRUCTURAL DESIGN:

The circular economy embodies a comprehensive approach to resource management and waste reduction, serving as a fundamental principle that advocates for the reduction, reuse, and recycling of resources within the built environment for the zero-carbon cities. When applied to the construction industry, circular building design endeavors to minimize waste generation, optimize resource efficiency, and encourage the reuse and recycling of materials. Circular buildings embody this philosophy by incorporating sustainable design strategies, including modular construction, adaptive reuse, and material recovery. These buildings strive to minimize waste, maximize resource utilization, and create flexible spaces capable of adapting to evolving needs.

The principles of the circular economy and sustainable structural designs are inherently interconnected, as they both share a common objective of minimizing waste, maximizing resource efficiency, and mitigating the environmental impact of the construction industry. In adopting a circular economy approach, the entire lifespan of a structure, from its design to eventual demolition, is taken into consideration. Sustainable structural designs embrace core principles such as adaptability, reusability, and the utilization of renewable and recyclable materials. They prioritize techniques like modular construction and prefabrication, along with other innovative methods that facilitate the straightforward disassembly and reassembly of structural components, thereby promoting the reuse and repurposing of buildings. By seamlessly integrating circular economy principles into the design process, sustainable structural designs effectively reduce the consumption of raw materials, minimize energy and water usage, and significantly contribute to the creation of a more sustainable and resilient built environment.

Numerous exemplary circular building projects, particularly in developed countries, serve as compelling demonstrations of successful integration of sustainable design principles. Given below are some examples of some of the Circular Building Projects in developed countries.

1. The CIRCL Pavilion, Amsterdam: The CIRCL Pavilion, located in Amsterdam
2. The Edge, Amsterdam: The Edge is a state-of-the-art office building in Amsterdam
3. The Circle, Zurich: The Circle is a sustainable building project in Zurich, Switzerland
4. The Bullitt Center, Seattle: The Bullitt Center, located in Seattle, Washington

These projects exemplify the benefits derived from enhanced energy efficiency, reduced environmental impact, and improved occupant well-being. By implementing innovative strategies and solutions that align with circular economy principles, these buildings showcase the immense potential for creating a built environment that fosters sustainability and promotes a healthier future for all.

SUSTAINABLE CONSTRUCTION, THE "BUILD NOTHING, BUILD LESS, BUILD CLEVER" APPROACH

To achieve zero carbon emissions, the construction industry must embrace the approaches of build nothing, build less, build clever. This mindset emphasizes optimizing resource utilization, reducing waste generation, and prioritizing renovation and refurbishment over new construction. Sustainable design principles, such as passive design strategies, energy-efficient systems, and the use of renewable energy sources, play a crucial role in achieving zero carbon buildings.

Sustainable construction and the "build nothing, build less, and build clever" approach are crucial elements in achieving a zero-carbon future through the principles of circular building. With the need to mitigate climate change and reduce carbon emissions, it is essential to rethink the way we design, construct, and use buildings. The principles of circular building revolve around reducing the overall environmental impact of construction by minimizing the need for new construction, optimizing the use of existing structures, and employing innovative design strategies.

The "**Build Nothing**" aspect of the approach emphasizes the importance of considering alternatives to new construction whenever possible. Rather than constructing new buildings, the focus is on repurposing and adapting existing structures to meet evolving needs. This approach not only minimizes the consumption of resources but also reduces waste generation and the carbon emissions associated with the production of new materials.

The "**Build Less**" aspect promotes the idea of constructing fewer new buildings by optimizing the utilization of existing infrastructure. By reusing and retrofitting buildings, we can extend their lifespan and maximize their functionality. This reduces the demand for new construction and preserves valuable resources, such as energy, water, and raw materials. Additionally, it minimizes the environmental impact associated with the demolition of existing structures.

The "**Build Clever**" approach encourages innovative and sustainable design strategies that prioritize resource efficiency, energy conservation, and the use of environmentally friendly materials. This includes incorporating renewable energy systems, employing passive design techniques to optimize natural lighting and ventilation, and utilizing recycled or sustainable materials in construction. By adopting these strategies, sustainable construction not only minimizes the environmental footprint but also creates healthier and more livable spaces for occupants. Adoption of these approaches and principles, can significantly reduce the environmental impact of the built environment, promote resource efficiency, and pave the way for a sustainable and resilient future.

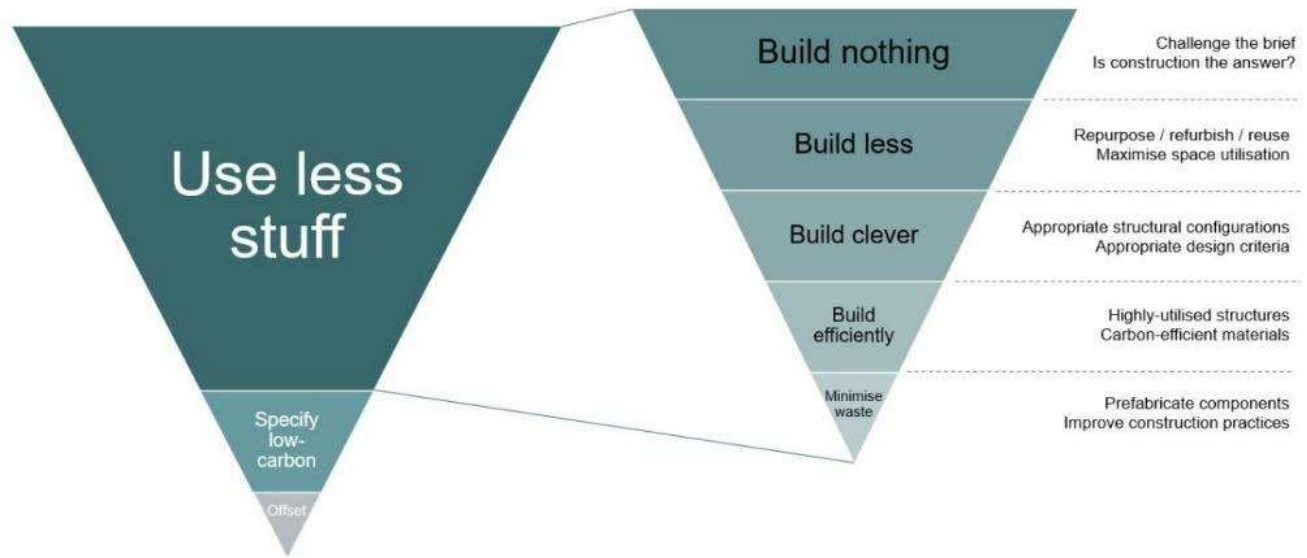


Image caption: The most sustainable building is the one already built. As consultants, we need to have the courage to challenge clients’ briefs and give them viable alternatives with lower carbon impacts (Source: Institution of Structural Engineers, IStructE)

SUSTAINABLE MATERIALS: A COMPARATIVE ANALYSIS:

The environmental performance of a structure is heavily influenced by the materials chosen for construction. When comparing reinforced concrete structures, steel structures, and timber structures in terms of their carbon footprint, resource depletion, and life cycle impacts, it becomes apparent that each material has its own unique characteristics. Reinforced concrete structures, although known for their strength and durability, have a significant carbon footprint and contribute to resource depletion. On the other hand, steel structures offer better recyclability and reduced material consumption, but they still have environmental implications. Timber structures, however, stand out as a renewable and carbon-sequestering alternative. They have the potential to store carbon and reduce embodied energy, making them a promising choice for zero-carbon buildings. Below is a comprehensive comparative analysis of these materials.

Parameters for Comparison	Reinforced Concrete Structures	Steel Structures	Timber Structures
Design	Reinforced concrete structures offer a wide range of design possibilities due to the versatility of concrete. It can be molded into various shapes and sizes, allowing for innovative and complex architectural designs.	Steel structures offer flexibility in design, allowing for large open spaces and creative architectural expressions. The strength-to-weight ratio of steel enables long-span structures and tall buildings.	Timber structures offer a natural and aesthetically pleasing design, providing warmth and a connection to nature. Timber can be easily shaped and manipulated, allowing for versatile architectural designs.

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Sustainability	Concrete production is resource-intensive and contributes to carbon emissions. However, the durability and long lifespan of reinforced concrete structures can offset their initial environmental impact. Additionally, advancements in concrete technology, such as the use of recycled aggregates and supplementary cementitious materials, can enhance the sustainability of these structures.	Steel is a highly sustainable material as it is recyclable and can be reused without loss of quality. The use of recycled steel reduces the environmental impact of steel structures. However, the energy-intensive production of steel contributes to carbon emissions.	Timber is a renewable and low-carbon material, as it sequesters carbon dioxide during its growth. Proper forest management and certification ensure responsible sourcing. Timber structures contribute to reducing greenhouse gas emissions.
Strength	Concrete has excellent compressive strength, making it suitable for supporting large loads. However, its tensile strength is relatively low, which is why reinforcement with steel bars or fibers is necessary.	Steel has excellent strength properties, providing high tensile and compressive strength. It can resist deformation under heavy loads, making it suitable for long-span structures and tall buildings.	Timber has good strength-to-weight ratio, with high strength in tension and compression parallel to the grain. Cross-laminated timber (CLT) and engineered wood products further enhance the structural properties of timber.
Constructability	Constructing reinforced concrete structures requires skilled labor and careful attention to detail. The process involves formwork, pouring, and curing, which can be time-consuming. However, advancements in precast and prefabricated concrete elements have improved the efficiency and ease of construction.	Steel structures can be prefabricated off-site, allowing for faster and more efficient construction compared to other materials. The lightweight nature of steel components makes transportation and assembly easier.	Timber structures can be prefabricated off-site, enabling faster construction with reduced site disruptions. Timber components are lightweight and easily handled, reducing the need for heavy machinery.
Durability	Reinforced concrete structures have a long lifespan and can withstand harsh environmental conditions, including exposure to moisture and chemicals. Proper maintenance and corrosion protection of	Steel structures have good durability when properly protected against corrosion. Various coatings and galvanizing techniques can enhance	Timber structures can have a long lifespan if properly maintained and protected from moisture and pests. Wood treatments and coatings can enhance their durability.

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	reinforcement are essential to ensure their durability.	the longevity of steel elements.	
Relocation	Due to their heavy weight and complex construction techniques, relocating reinforced concrete structures is challenging and often not feasible.	Steel structures can be disassembled, relocated, and reused, making them suitable for temporary and relocatable structures.	Timber structures can be deconstructed and rebuilt in new locations. Their lightweight nature and ease of handling facilitate relocation.
Reutilization / Reuse	Reutilizing or reusing reinforced concrete structures can be challenging due to the properties of concrete. Demolition and reconstruction are often the primary options for repurposing. Some components can be salvaged for use in new construction projects.	Steel structures offer excellent reutilization and reuse opportunities. Steel components can be easily disassembled and repurposed. Steel beams, columns, and other elements can be recycled and used in new steel structures, reducing the demand for new steel production.	Timber structures provide good opportunities for reutilization and reuse. Timber components can be deconstructed, and the wood can be salvaged for various purposes. Reclaimed timber can be used in new timber buildings or repurposed for furniture, flooring, or decorative elements.
Reliability	Reinforced concrete structures are known for their high strength and durability, making them reliable for withstanding heavy loads, earthquakes, and fire incidents.	Steel structures are known for their high strength and resilience, making them reliable in withstanding dynamic loads, such as wind and seismic forces.	Timber structures can provide reliable performance when designed and constructed following appropriate engineering principles and techniques. Proper detailing and treatment against moisture and pests are crucial for long-term reliability.

The comparative analysis highlights the sustainable attributes and drawbacks of each material, providing insights into selecting the most suitable option for zero-carbon construction.

SUSTAINABLE & SMART CONSTRUCTION FOR ZERO CARBON – GREEN BUILDINGS:

Green buildings or energy efficient buildings are a crucial component of zero-carbon construction. This section explores the principles of green buildings, including energy-efficient systems, renewable energy integration, and sustainable material choices. It also examines the role of smart technologies in optimizing energy management, improving occupant comfort, and reducing environmental impact. Sustainable and smart construction, exemplified by green buildings, has emerged as a crucial approach in achieving zero carbon emissions and promoting environmental stewardship.

Green buildings are designed and constructed with the aim of minimizing their environmental impact throughout their entire life cycle. They incorporate various sustainable design strategies, such as energy-

efficient systems, renewable energy sources, efficient water management, and the use of environmentally friendly materials. These buildings prioritize energy conservation, reduce greenhouse gas emissions, and promote occupant health and well-being. Smart technologies and innovative systems are integrated into the construction process to enhance the building's performance and efficiency. These may include advanced building automation systems, intelligent lighting and HVAC systems, and the use of data analytics for optimized operations. Sustainable and smart construction practices not only contribute to the mitigation of climate change but also create healthier, more comfortable, and more productive environments for occupants. By adopting green building principles, the construction industry can lead the way in achieving a zero-carbon future and sustainable development.

In case of Structural Engineering and its role in Green Building. Structural engineers can contribute to the reduction of carbon footprints in the construction industry by employing innovative design techniques and incorporating sustainable materials. They work closely with architects, builders, and other stakeholders to develop energy-efficient structural systems that optimize the use of resources, minimize waste, and promote sustainable practices. Additionally, structural engineers play a crucial role in ensuring the structural integrity of green buildings, taking into consideration factors such as load-bearing capacities, seismic resilience, and the incorporation of renewable energy systems.

DESIGNS AND CONSTRUCTION FOR EASY ERECTION AND RELOCATION:

The ability to erect and relocate structures with ease offers numerous advantages in terms of sustainability and adaptability. This section explores design strategies that prioritize flexibility, modularity, and efficient assembly processes. Designs and construction techniques that prioritize easy erection and relocation have gained significance in the construction industry. With the need for flexibility and adaptability in the built environment, these approaches offer numerous benefits. Such designs typically involve modular construction, prefabrication, and the use of lightweight materials. Modular construction allows for the assembly of standardized modules that can be easily transported and interconnected on-site, reducing construction time and labor. Prefabrication involves the manufacturing of building components off-site, enabling faster assembly and reducing disruption to the surrounding environment. Lightweight materials, such as steel and timber, facilitate easier handling and transportation. Structures designed for easy relocation can be disassembled and reconstructed at new locations, promoting sustainability by minimizing waste and extending the lifespan of the building. This approach is particularly valuable for temporary structures, such as event venues or disaster relief shelters. By embracing designs and construction methods that prioritize easy erection and relocation, the construction industry can achieve greater efficiency, flexibility, and sustainability in the built environment. Examples of structures designed for easy erection and relocation, such as construction of temporary stadiums used in the FIFA World Cup 2022 in Qatar, illustrate the practical implementation of sustainable and adaptable designs.

REUTILIZATION / REUSE OF EXISTING STRUCTURES:

The reutilization or reuse of buildings and structures aligns perfectly with the principles of circular buildings and the circular economy. As discussed, circular buildings promote the idea of extending the lifespan of existing structures, minimizing waste, and maximizing resource efficiency. Instead of demolishing and constructing new buildings, reutilization focuses on repurposing and adapting existing structures to meet changing needs and demands. This approach not only reduces the environmental impact associated with new construction but also preserves the embodied energy and materials already invested in the building. Through careful assessment and renovation, buildings can be transformed into new functional spaces while retaining their inherent value and character. The concept of circular buildings encourages creative and innovative strategies for reuse, such as adaptive reuse, where buildings are repurposed for different functions, and modular construction, where components can be easily disassembled and reconfigured.

STRUCTURAL INTEGRITY ASSESSMENT OF BUILDINGS AND STRUCTURES:

Reusing existing structures is a sustainable and environmentally responsible strategy that offers numerous advantages, including waste reduction, preservation of embodied energy, and a reduced need for new construction. However, before repurposing a structure, it is essential to assess its structural integrity and overall health to ensure its suitability for reuse. Structural integrity assessment involves a comprehensive evaluation of the building's structural elements, including the foundation, columns, beams, slabs and connections. This assessment is typically conducted using visual inspection by qualified structural engineers, non-destructive testing techniques, such as rebound hammer, ultrasonic pulse velocity analyzer, ferro-scanning, corrosion analyzer, forensic studies based on chemical testing, hardness test, torquing by torque meter, weld joint assessment, infrared thermography, radiography and ground-penetrating radar. These methods allow for thorough inspections without causing damage to the structure. Rebound hammer & LEEB hardness tester used for surface hardness & strength of concrete and steel material. Ultrasound testing can detect flaws or discontinuities in materials by sending high-frequency sound waves through them and analyzing the reflected signals. Ferro scanner used to identify the patten of rebars and concrete covers. Corrosion analyzer used for the corrosion assessment o rebars. Chemical testing include chloride and carbonation test for remaining life assessment of concrete structures. Magnetic particle induction, dye penetration tests & ultrasonic flaw detection test for weld joint assessment. Ultrasonic thickness gauging for thickness measurement of steel sections. Infrared thermography measures surface temperature variations to identify potential defects, such as moisture or insulation gaps. Ground-penetrating radar utilizes electromagnetic waves to detect variations in material density and locate hidden anomalies. These non-destructive testing techniques provide valuable information about the condition of the structure, identifying any areas of concern or deterioration that need attention. Core extraction from concrete and compressive loads testing is little bit destructive technique but more reliable to get the in-site strength of concrete.

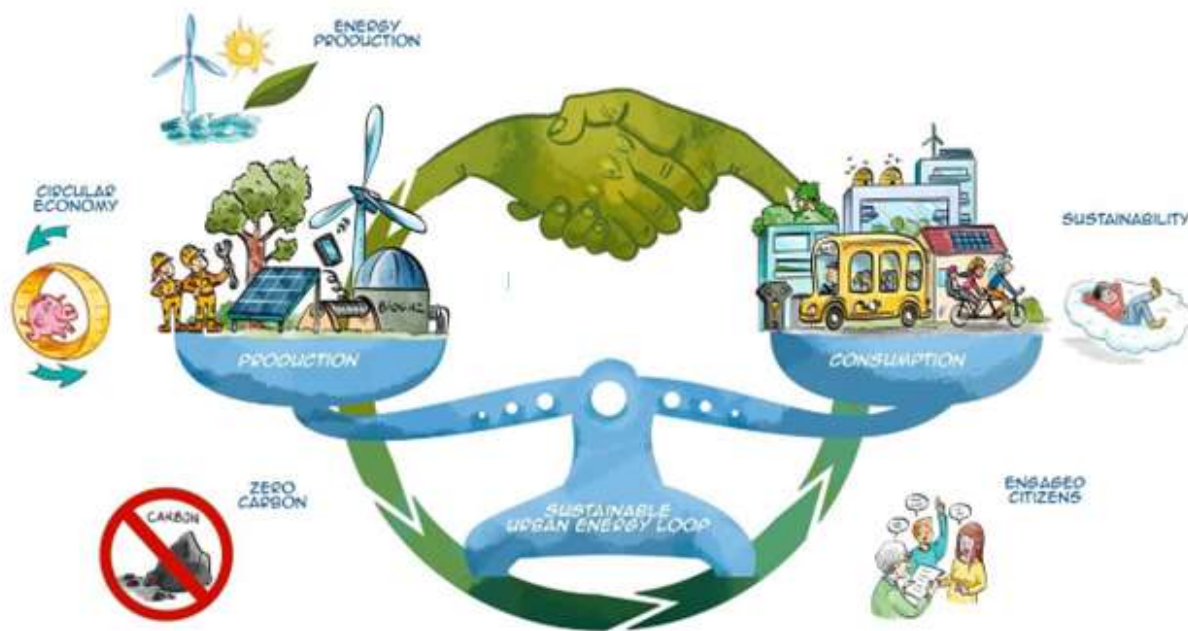
RETROFITTING AND STRENGTHENING OF EXISTING STRUCTURES

Once the structural integrity assessment is complete, retrofitting and strengthening methods can be employed to upgrade and enhance the existing structure. Retrofitting involves the modification or addition of structural components to improve performance and meet modern design requirements. This can include adding supplemental supports, such as steel braces or concrete walls, to enhance load-carrying capacity and resistance to seismic forces. Upgrading materials, such as replacing outdated or deteriorated elements with high-strength materials, can also improve structural integrity. Strengthening methods, such as carbon fiber reinforcement or steel plate bonding, can be employed to increase the strength and stiffness of existing members.

These retrofitting and strengthening measures aim to extend the lifespan of the structure and ensure its ability to meet current safety standards and functional requirements. By repurposing and upgrading existing structures, we can minimize waste, reduce carbon emissions associated with new construction, and optimize the use of resources. Additionally, the reuse of existing buildings contributes to the preservation of cultural heritage and the conservation of embodied energy, which is the energy consumed during the original construction process. Through thorough structural integrity assessment and strategic retrofitting and strengthening methods, existing structures can be revitalized and repurposed for sustainable and long-lasting use in the built environment.

FUTURE OF BUILDINGS AND INFRASTRUCTURE STRUCTURES IN A ZERO-CARBON ERA:

The future of buildings and infrastructure structures rests on the shoulders of sustainable practices and groundbreaking technologies. As we strive for a zero-carbon future, it is the field of structural engineering that will lead the way in developing and adopting innovative construction techniques. The utilization of advanced materials holds great potential in achieving sustainability objectives. Carbon-neutral concrete and high-performance timber products are examples of such materials that can significantly reduce carbon emissions and environmental impact. These materials offer strength, durability, and energy efficiency, making them valuable components in the construction industry. Moreover, the integration of smart technologies, such as sensors and automation systems, coupled with building information modeling, can enhance the performance and efficiency of buildings. By harnessing renewable energy sources, such as solar and wind power, structures can become self-sufficient and reduce their reliance on traditional energy grids. The collective implementation of these sustainable practices and innovative technologies will pave the way for the creation of buildings that are not only visually striking but also energy-efficient, resilient to climate change, and environmentally friendly. The structural engineering field will play a pivotal role in shaping this future by designing and constructing structures that embody sustainable principles and embrace the latest advancements in technology.

**CONCLUSION:**

As the world transitions towards a zero-carbon future, the role of structural engineering in sustainable construction becomes increasingly vital. By embracing circular economy principles, sustainable design strategies, and material choices, the industry can significantly reduce its environmental impact. Reusing existing structures, applying non-destructive testing for structural integrity assessment, and retrofitting for repurposing enable the transformation of the built environment. The "build less" approach minimizes new construction, optimizing resource utilization. Looking ahead, the future of buildings and infrastructure structures will be shaped by innovative technologies, sustainable materials, and a commitment to achieving zero carbon emissions. Structural engineering will continue to play a pivotal role in creating a sustainable and resilient built environment.

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SGS: By embracing circularity, sustainable design, and the reuse of existing structures, structural engineering can be at the forefront of the global efforts to combat climate change. The future of buildings and infrastructure structures lies in the application of sustainable practices, with the guidance of inspection companies such as SGS, driving the industry towards a greener and more sustainable future. Together, through collaboration and innovation, we can create a built environment that minimizes environmental impact, promotes circularity, and enables a zero-carbon future for generations to come.

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