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Impact of building materials on carbon emission and possible remedy

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ABSTRACT

With the rapid urbanization process and rapid economic growth, the building industry has emerged as one of the largest carbon emitters in the world. The built environment is thought to play an important part in a country's carbon emissions. Operational carbon emissions, also known as operational period emissions from the built environment, include emissions from other phases, like those in building and materials production, are included in the built environment's associated carbon emissions. It is thought that the fraction of carbon emissions embedded in a building will rise in the future. This is due to the increased usage of energy-saving devices to cut back on operational energy and the emissions that go along with it. These energy-saving technologies may also increase the number of building renovations, which would lead to an increase in carbon pollution. In this paper, the reasons causing carbon emissions in the construction sector are further discussed, along with potential extenuation measures.

***Keywords*:** Emissions, CO_2, construction sector, impact, Extenuation

1. INTRODUCTION

Carbon emissions are rising, which is the primary cause of climate change and global warming [1]. More personnel are needed in metropolitan areas as a result of rapid urbanization and industrial expansion. Additionally, it improves peoples' quality of life. After the industrial revolution, electricity demand dramatically grew because of the rising energy requirements of

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industry and affluent lifestyles. Conventional, nonrenewable, and finite resources are used to produce energy. 90 percent of primary energy output worldwide comes from fossil fuels (coal, gas, and oil) [2]. Additionally, carbon dioxide (CO_2) is a key component of the greenhouse gasses (GHG) that are emitted during the production of electricity from non-renewable sources. Since employing renewable energy sources was initially more expensive than conventional energy sources, the concept of doing so is still unpopular in developing nations. In order to move toward a civilization without carbon emissions, energy generation needs to switch from conventional to renewable sources. A systematic method to raise public awareness is necessary because this process involves numerous work groups from society.

Energy use and greenhouse gas emissions are also largely attributable to the building sector. As of right now, CO_2 is thought to account for around 50% of anthropogenic GHG emissions [3]. Because of the global increase in greenhouse gas emissions brought on by the growth of the automotive and information technology industries, the earth's temperature is rising [4].

The construction and operation of both residential and non-residential buildings fall under the broad heading of the building sector. Which include the method for developing additional buildings on land parcels as well as operation of the building , upkeep, and repair. The building industry's enormous direct and indirect environmental impact has been observed due to revival in expansion of the building. It is one of the economic sectors that consumes and produces garbage most significantly [5]. Natural resources are affected by ecosystem changes, and impacts on the whole population can all be classed as this sector's environmental effects [6]. Approximately 39% of the annual worldwide CO_2 emissions are caused by buildings [7].

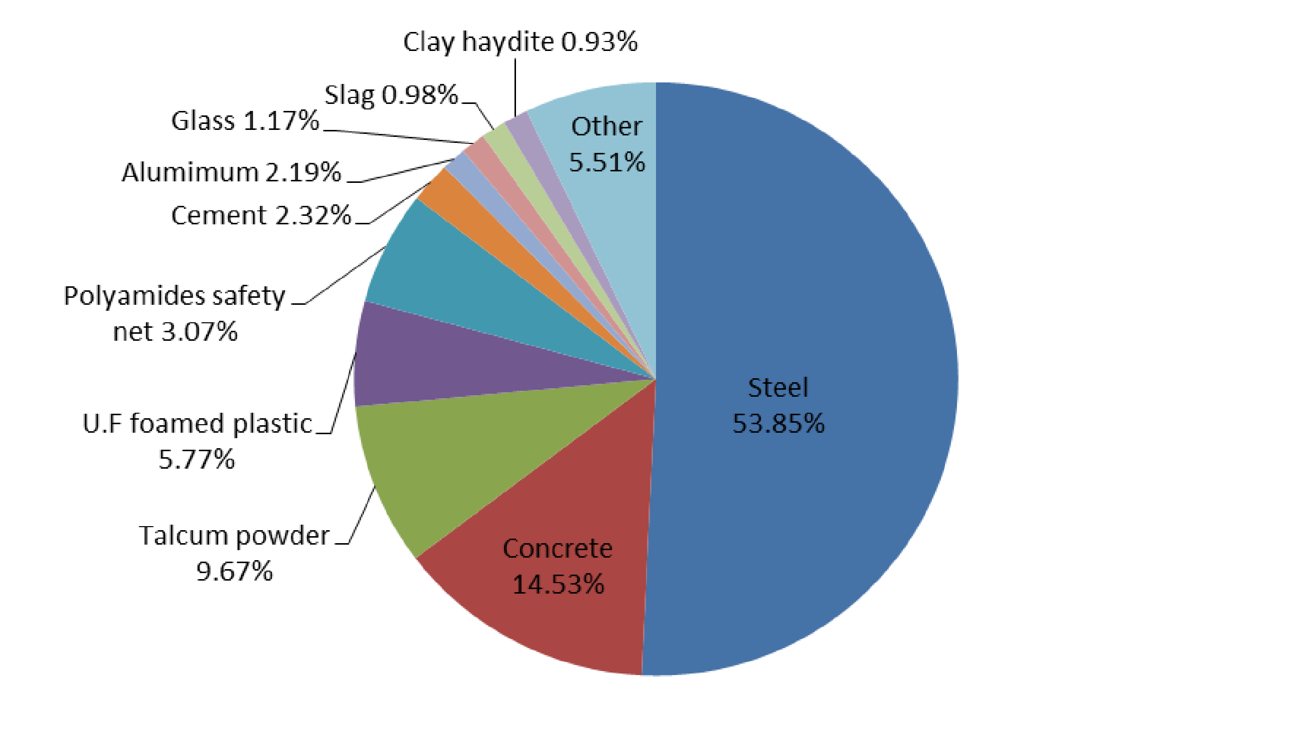

Figure 1. The different types of building materials' carbon emissions
(Source: Hong et al., 2015)

2. IMPACT OF CARBON EMISSIONS

An organized strategy is necessary to reduce carbon emissions from the energy industry globally. To make rapid development, it will be more effective to combine market processes with restrictions [8]. A barrier to the sustainable growth of the building industry is the use of non-sustainable energy sources throughout building planning, construction, and operation [9]. Using energy sources that aren't sustainable has an effect on the environment and is inversely correlated with the consumed volume. CO_2 is set free directly and indirectly throughout the construction course. Diesel, natural gas, fuel oil, and various products made from oil are burned to release their carbon dioxide (CO_2) into the atmosphere; whereas, electricity use releases their CO_2 indirectly. Only 14% of the CO_2 that is released directly worldwide, with the majority (85%) coming from indirect emissions. The well-known effect of CO_2 emissions on climate change and global warming, which have serious repercussions for both the environment and people, is well-known. Even if it contributes significantly to a country's economic growth, the building industry also plays a significant part in the release of greenhouse gases into the atmosphere, which has serious consequences like ozone depletion and global warming. Sea levels, weather patterns, and the availability of food and water would all be impacted by global warming. Image 2 depicts the effect of CO_2 emissions as a result of the increase in worldwide temperatures.

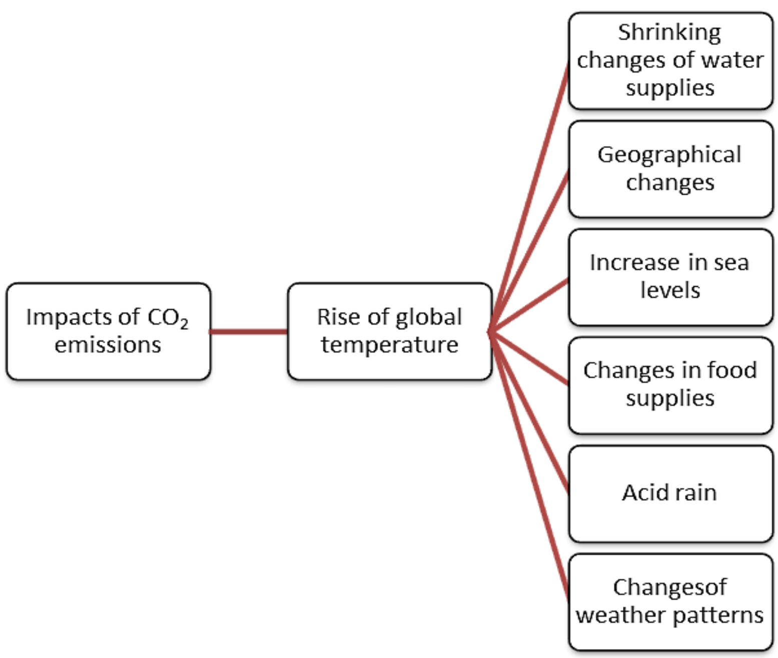

Figure 2. Impacts of carbon emissions on the ecosystem.

Building is one of the economic sectors that consumes and produces trash the most, according to research [5]. The itemization of the construction and operating processes is one way to allow for thorough evaluations. Because the majority of the building materials are made from fossil fuels, the country's construction sector is responsible for 24 percent of the nation's carbon emissions [10]. Actually, buildings account for over one-third of societal energy use in both industrialized and developing nations. The major sources of carbon emissions can be extrapolated to be energy use, on-site transportation, cement manufacturing, the manufacture of building materials, followed by the burning of fossil fuels, and the removal of construction debris. However, there are other sources of carbon emissions, including mining, plant machinery, off-site transportation, construction projects, and employee and staff activities.

2. 1. Combustion of Fossil Fuel

When fossil fuels are burned with oxygen or in the presence of air, they produce energy that can either be utilized as fuel or used to generate electricity. Fossil fuel usage has expanded significantly as a result of the Industrial Revolution, to the point where rates are generally considered to be unsustainable. The nine types of energy sources that are typically employed while constructing are crude oil, gasoline, kerosene, diesel, fuel oil, electricity, natural gas, and pulverized coal. Coal combustion produces more carbon emissions when compared to other forms of energy; hence, a greater reliance on coal causes higher carbon generation and consequent environmental harm [11] [12].

2. 2. Energy Consumption

Concerns regarding production challenges, resource depletion, and severe environmental effects including ozone layer thinning, global warming, and climate change have already been raised by the world's rapidly expanding energy use [13]. The Inter-National Energy Agency has learned ominous details about changes in energy consumption. Beyond 67% of global energy usage and above 70% of its CO_2 emissions are created in urban areas, according to recent estimates [14]. Buildings use a significant amount of the energy produced by the burning of fuels to produce electricity, which produces carbon dioxide.

The majority of these emissions result from the burning of fossil fuels for power and electrical equipment, as well as for heating, cooling, and lighting.

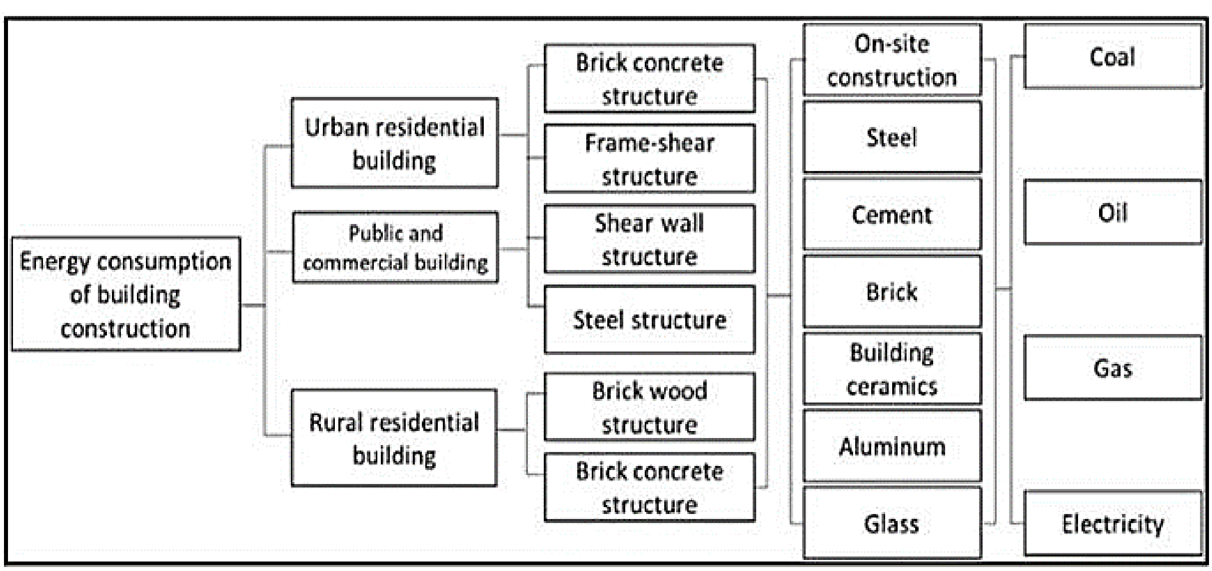

Figure 3. Typical energy usage framework (Zhang et al., 2019)

Buildings are responsible for 70% of the electricity used in the United States and 39% of the carbon emissions. Building CO_2 emissions are anticipated to increase quicker than other sectors 25 years from now , rising by 1.8% annually by 2030. Buildings which typically last between 50-100 years, use energy continuously, which produces carbon emissions, which have an impact on the climate and contribute to global warming.

The construction industry's energy usage and emissions have been discovered to be influenced by the building type, structure, product, and fuel source [15]. Due to this, the construction sector, which includes both commercial and public structures, contains a variety of building types, including hotels, hospitals, schools, museums, etc. Having numerous uses and energy-related features, including hot water (DHW, cooling, HVAC and lighting. The framework shown in Figure 3 illustrates how the many above-mentioned elements affect energy usage. Factors governing energy use and related carbon emissions in the building industry are graphically depicted in Figure 3. The highest intensity of greenhouse gas emissions to date can be attributed to electricity use.

2. 3. Manufacturing Of Cement

Quantity and the most common and basic building material used in civil engineering, which is cement , has dramatically expanded as a result of widespread and quick urbanization. Cement production is another major source of carbon emissions [16]. This industry contributed roughly 1.8 Gt of Carbon emissions, or nearly 7 percent of the total anthropogenic carbon emissions worldwide occurred in 2006 [17]. The Carbon emissions across all processes of cement manufacture include raw material processing, clinker production, fuel combustion in kiln, and creation of finished produced cements [18]. According to research, clinker production accounted for 90% of the carbon emissions from cement manufacturers, while raw material processing and the last phases of production produced the remaining 10%. [17][19]. In the global cement business, In the cement industry, China is the world's largest producer and carbon emitter. Production of cement makes up for 14.8 percent of China's overall carbon emissions, which makes it a crucial industry for the country to develop in order to fulfill its national carbon reduction goal of 40–45 percent [19].

2. 4. Construction Waste Disposal

According to the definition given by the construction industry, construction waste is a mixture of surplus materials left over after building, renovating, and demolishing new and existing structures [20]. Construction wastes are typically produced by activities including site cleanup, demolition trash, unexcavated objects(such as polluted sediments), discarded concrete, discarded timber, discarded chemicals, sewage, and garbage from homes. Concrete shards, metal, glass, surface asphalt, polymers, and wood will all be left over after temporary buildings and homes are demolished. Concrete/masonry is reportedly the most wasteful material during the stages of structural concrete construction, which account for 88 percent of all waste streams.

Wood is discovered to be the main component at roughly 54 percent throughout the Masonry Work and Finishing Stage. As a result, the disposal of garbage on site results in the emission of toxic, such as methane, into the air, soil, and waterways, which contribute to the carbon effect. It is widely known that the global construction industry uses enormous amounts of natural resources, energy, and, as previously indicated, C&D waste [21]. C&D garbage makes up 30-40 percent of all urban solid waste produced in China due to the country's rapid urbanization, making it a significant source of solid urban waste. Additionally, demolition debris in the range of 200 million tonnes (DW) are produced in China annually, 90 percent of which is C&D waste, which amounts to C&D waste [22]. Large building materials that are disposed of as a result of demolition activities often have a high residual value but are not recycled, which raises the energy demand for landfilling and transportation and contributes to carbon emissions [23]. Because of the various ways that garbage disposal causes greenhouse gas emissions, The environmental effects of the demolition process could be negative due to the equipment utilised for dumping and transporting garbage. [24].

2. 5. Manufacture of Building Materials

Buildings are the largest single industry in the world for energy consumption, and the construction industry is the largest consumer of raw materials [25]. Approximately two-thirds of carbon emissions are caused by steel and concrete created during the production of building materials. These materials are produced in conjunction with upstream activities that use fossil fuels, such as the production of steel and cement. Even if they are relatively light (0.1%), other materials like aluminum and polyamide safety nets generate a lot of greenhouse gasses (GHG) during manufacturing (between 2 and 3 percent).

2. 6. On-Site Transportation

When building materials are transported to the sites, fuel and energy are used, which results in carbon generation and greenhouse gas emissions. Transporting workers about the construction site causes carbon pollution to be released into the atmosphere, which contributes to global warming. Moving the building supplies to the construction site is accomplished by the diesel utilized to power the machinery during construction. Transporting building supplies to the construction site includes moving things like precast concrete, tiles, and cement [26]. The transportation of materials during an ongoing building project results in a 6–8% carbon emission. Plant emissions have the largest carbon emissions when compared to other activities due to the use of diesel by plant machinery, as well as the use of fuels and lubricants for excavators, trucks, and cranes on site. It was discovered by statistical and scientific study conducted by IPCC that different types of gear and equipment, such as off-road, mobile, and stationary combustion, can produce different amounts of nitrous oxide and methane. [27]. As a result, The combustion of fuels and exhaust gases from the nearby automobiles are what generate air pollution.

3. SYSTEM APPROACH TOWARDS CARBON EXTENUATION

All technologies were created with the sole purpose of reducing human effort in demanding jobs and enhancing precision in high-quality work at the beginning of the industrial revolution. Over time, standards for new technologies were developed, but they were unable to address the impact of cutting-edge technology on the environment and society. All of this caused society to grow in a lopsided way. A great need to link development and sustainability was felt as the threat of climate change became apparent. Thus, the notion of a green and carbon-free civilization developed. Around the world, a number of policies and rules were established to reduce the impact on the environment (Figure 4). As explained below, these methods can be used to reduce CO_2 emissions at different sizes.

Figure 4. Methods to reduce CO_2 emissions in the building sector.

3. 1. Restriction Strategy

Shutting down operations and turning off associated equipment are easy ways to reduce carbon emissions and energy usage in buildings. The most practicable technique is to keep the doors locked and turn off the lights and electrical appliances in empty rooms. When utilized in open-air spaces, it is known as the limitation(restriction) technique. The majority of public structures, including classroom buildings, libraries, and fitness centers, have been divided into a number of categories based on their level of usage. A restriction strategy is possible within these public structures if empty spaces are shut down and users must assemble in predetermined, permitted locations in order to share the services. Consequently, energy use is decreased. According to a study, there is a connection between building occupancy rates and energy usage [28]. With an increase in occupancy rate, there has been a noticeable decrease in the amount of energy used for heating and lighting per person.

However, as the occupant rate rises, it may cause occupants to become dissatisfied. High occupancy rates typically result in lower air quality, which eventually affects the occupants' ability to perform their daily tasks. Energy saving thus poses the biggest challenge to the restriction strategy by undermining occupant happiness.

3. 2. Adopting Low Carbon Technology

Low carbon technology is one of the technical strategies that may be applied in buildings to reduce carbon dioxide emissions. Low carbon technology is defined as the technology that releases the fewest greenhouse gases (GHGs), particularly carbon emissions, into the environment [29]. A few examples of renewable and sustainable energy technologies are evaporative cooling, passive ventilation and cooling, solar photovoltaic, dehumidification, and energy recovery systems. These technologies have been shown to greatly help in lowering emissions and promoting energy conservation in buildings. Low carbon technologies can also be used to determine the essential strategic requirements for innovation-driven development in the building [30]. The disadvantage of using low carbon technology is that they could result in increased running costs for buildings. It is important to pay careful, methodical attention in order to maintain harmony between the reduction of carbon emissions and investments in technology.

3. 3. Impact Assessment of Building Process and Materials

In order to reduce CO_2 emissions, it is crucial to understand the entire construction process. These procedures involve gathering resources, producing goods, moving them, building things, keeping them up, and disposing of them. Buildings throughout their lifetime use a variety of materials, which use energy and release CO_2 collectively known as "embodied energy" and "embodied carbon.". The evaluation of the embodied carbon in building materials is one key factor that can minimize carbon footprint as part of extenuation measures. Using the correct sustainable building materials can reduce embodied CO2 emissions during the structure's lifetime by about 30% [31, 32].

According to this assessment, reinforced concrete and clay bricks emit the most carbon, making up between 60 and 70 percent of the total quantity of embodied carbon [33, 34]. Hammond and Jones [35, 36] give a detailed breakdown of the building materials and embodied carbon. Additionally, materials that are environmentally friendly or low-carbon can be considered during the production process to lower CO_2 emissions or satisfy emissions targets. Some excellent substitutes for traditional building materials are compressed earth, low-carbon concrete, wood, straw, and low-carbon cement.

The main building materials that clearly have an impact on the environment must be identified in order to be included in the sustainability assessment scope. A rapid environmental impact assessment might be achieved thanks to this discovery, which would simplify the review process. In Table 1 [37], Building materials' CO_2 emissions, weight, cost, and energy usage are all examined. (kg CO_2 e/m^2), a useful unit, is used to assess the carbon emission of construction materials during the embodied stage. The carbon emission figures for buildings of various sizes can be compared and are consistent thanks to the benchmark value provided by this functional unit [38]. Equation (1) was used to calculate CO_2 emissions using the quota technique:

$$QC_{Mg} = \sum_{i=1}^{n} CM_{ri} \times m_i$$

where,

QC_{Mg} is the amount of CO_2 that is emitted as a result of manufacturing construction materials. Without taking recycling into account, CMri is the part of the building material manufacturing process that produces carbon emissions. *mi* ; the quantity of construction supplies.

Regarding energy usage, the method (Equation (2)) for determining the value is as follows:

$$QE_{Me} = \sum_{i=1}^{n} EM_{ri} \times m_i$$

where,

QE_{Me} is the amount of energy used to produce the building materials.
EM_{ri} is the construction material's energy needed during manufacture, ignoring recycling.

Using the following equation (Equation (3)), the price of the construction supplies at the embodied phase is finally determined:

$$QTC_{Mc} = \sum_{i=1}^{n} UCM_{ri} \times m_i$$

where,

QTC_{Mc} is the entire cost of the building materials used in construction.
UCM_{ri} is the cost per unit of a building material without taking recycling into account.

The earlier research [39–42] documented the energy factors, carbon emission elements, as well as the building materials' unit costs. Approximately 80% of carbon emissions, according to this study, are caused by mortar, commercial concrete, wall components, steel, doors, and windows. Therefore, it is crucial to recognise and research the CO_2 emissions of buildings based on their necessary building shapes. Because of this, steel, wall appliances, industrial concrete, and mortar should be given more consideration when implementing CO_2 emission reduction methods.

Table 1. Building materials' prices, weights, and energy usage, as well as their CO_2 emissions [37]

Material	CO_2 Emissions ($kgCO_2e/m^2$)	Cost (RMB/m^2; USD/m^2; EUR/m^2)	Weight (kg/m^2)	Energy Usage (MJ/m^2)
Steel	142.23	279.54; 40.72;34.20	64.86	1415.80
Commercial concrete	123.94	440.06;64.10;53.84	905.3	209.37
Wall materials	68.19	37.88;5.52;4.63	334.13	260.29
Mortar	58.1	29.61;4.31;3.62	372.76	223.69
PVC pipes	33.44	7.56;1.10;0.92	5.89	16.96

Polystyrene extrusion board	21.25	15.06;2.19;1.84	1.08	15.81
Architectural Ceramics	12.12	3.19;0.46;0.39	3.13	22.91
Doors and Windows	9.54	70.5;10.27;8.63	5.41	112.12
Water paints	5.03	7.76;1.13;0.95	0.68	19.82
Copper core conductor table	2.58	14.07;2.05;1.75	0.27	12.21
Wood	1.40	6.61;0.96;0.81	5.03	5.88
Waterproof roll	0.62	4.25;0.62;0.52	0.51	0.02
Stone	0.47	5.43;0.79;0.66	17.12	3.63
Total	478.91	921.51;134.23; 112.75	1716.16	2318.50

Proposed CO_2 reduction strategies should incorporate renewable energy sources like solar, wind, and biofuels into building operations through life cycle analysis. By utilizing less energy during the stages of planning, construction, and operation by raising construction standards and efficiency, the building sector has a lot of potential to lower CO2 emissions throughout its operating stage. Reducing environmental costs and consequences is the aim of the life cycle assessment.

Regarding this, a global assessment methodology known as EN 15978:2011 was produced in 2011 and provides the mathematical methods and analytical principles for evaluating the environmental performance of new and existing structures [43]. All phases of the structure's lifespan can be included in this plan. Hong Kong, for instance, has studied the life cycle of the structures that fall within its purview. By 2030, they aim to reduce energy use by 25% from 2005 levels [44]. The life cycle evaluation can differentiate between the structure's lifecycle and the building's operational lifecycle [45]. The building's operation and integrated carbon footprint are taken into account during construction and upkeep. CO_2 emissions from the production, advancement, upkeep, and replacement of services and supplies for construction are a part of the construction process [45]. For a specific fuel blend, Maintenance energy requirements are equal to operational carbon footprints. Measures taken to reduce the operational carbon footprint may have a negative impact on the carbon footprint hidden within.

Contrarily, impact evaluations of historic or existing structures should be taken into account in addition to new construction, since they can be a suitable alternative to lower CO_2 emissions. Buildings typically last between 60 to 120 years, according to the literature, which is an incredibly lengthy lifespan. In light of this longevity, buildings that date back in time or are older are still in operation, and it is projected that by 2050, 80 percent of those that are currently occupied will still be so [46].

By examining the building materials and components, it is possible to determine the concepts, materials, methods, dangers, and technologies that are necessary for decarbonizing these structures. A thorough life cycle analysis can be performed by considering Operational energy efficiency, reuse, sustainable renovation, retrofitting options, thermal performance enhancements to the building's exterior, its HVAC, lighting, and ventilation systems, and adoption of passive measures are all variables that help reduce CO_2 emissions [47, 48].

3. 4. Standards and Policy

To increase building energy efficiency and lower CO_2 emissions around the world, several countries have developed a variety of sustainable building standards, guidelines, laws, and suggestions. In order to fulfil the Paris Agreement Commitment and the UN Sustainable Development Goals, Nationally Determined Contribution (NDC) was formed in 2015.

The NDC saw participation from 184 nations in total. Governments have made efforts to decarbonize the construction sector by creating regulations and rules. Following this approach, chosen countries have committed to several standards and regulations, which are listed in Table 1 and which include a decrease in CO_2 emissions as one of its goals and objectives. As buildings move toward becoming zero or low carbon, these packages provide minimal standards for energy performance and efficiency. More than 60 nations throughout the world have started plans to put them into place, either on a required or voluntary basis [49, 50].

Table 2. Shows existing criteria for limiting CO_2 emissions in buildings as part of prioritizing taking measures to fulfill its obligation under the Paris Agreement and achieve the UN Sustainable Development Goals which were set up in 2015.

Country	Standards or Policies
China	The Energy Consumption of Buildings standard was established in 2016 by the Ministry of Housing and Urban-Rural Development. The indicators of energy use for different building types are covered by this standard. It makes an effort to control overall CO_2 emissions as well as the nation's building sector's energy consumption.
Australia	The National Carbon Offset Standard for Buildings was introduced by the Australian Federal Government in 2017. It was founded in partnership with the Green Building Council of Australia. The standard's major goal is to provide for the measurement, reduction, offset, reporting, and auditing of CO_2 emissions from building operations.
India	The Energy Conservation Act of 2001 included a policy that was approved in 2016 under the Perform, Achieve, and Trade (PAT) programme. It has preserved almost 9 million tonnes of final energy (Mtoe) comparable to oil, lowering yearly CO_2 emissions by almost 23 MtCO2. In order to recognise progress made toward decarbonization, the Energy Conservation Building Code (ECBC) for commercial buildings was modified in 2017. With easy thermal comfort and passive system upgrade enforcement, the Energy Conservation Building Code for Residential Buildings—the first national model building energy code—was released in 2018.

European Union	Through recommendations on energy efficiency, energy market, and renewable energy programmes as part of the Clean Energy for All European Policy Package, which was developed in 2016, the European Commission wants to combat climate change caused by GHGs, mainly CO2 emissions. The Energy Performance of Buildings Directive (EPBD) was updated in 2018 in order to achieve high energy efficiency and carbon decarbonization by 2050.
Sweden	To promote energy-saving renovations and the use of environmentally friendly products, which could reduce CO_2 emissions, the Swedish Government established the Center for Sustainable Construction in 2016. An environmental effect certification program for new buildings was implemented in 2019.
Japan	The Building Energy Efficiency Act, which contains regulations requiring non-residential structures to meet minimum energy efficiency requirements, was introduced in 2017. Its goal is to improve the energy consumption performance of buildings. This plan of action fits into the Japanese government's effort to attain zero-energy buildings and homes by the year 2030.
Canada	2016 saw the implementation of tighter energy performance standards for certain types of energy-consuming building products. To improve the energy efficiency of existing buildings, new building energy rules are expected to be implemented in 2022 as part of the Pan-Canadian Framework on Clean Growth and Climate Change. To assist the goal of establishing building energy use labeling, the Canadian government was attempting to create a building code that is net-zero energy ready in 2019.
Germany	The German government created a set of emission reduction measures in 2019 to comply with Agenda 2030's requirements for the building industry.
USA	The first code in the USA was introduced in 2018 with the California 2019 Building Energy Efficiency Standards. The New York State Energy Research and Development Authority was founded in 2018 with the goal of enhancing the general sustainability and efficiency of buildings.

Nigeria	The German Development Agency (GIZ) and the Nigerian Energy Support Program worked together to create a set of minimum standards for energy-efficient building construction in Nigeria to produce the first building energy code in 2017
Singapore	The Code on Environmental Sustainability Measures for Existing Buildings was introduced in 2016 and applies to existing non-residential structures covered by Singapore's building control laws.
Switzerland	To accelerate the de-carbonization of buildings, Switzerland's new Energy Act was implemented in 2018 using a charge on stationary fuels for carbon dioxide (heating and industry). Geothermal energy subsidies and a CO_2 tax have been implemented under the Act. To apply NDC in the construction industry, 2019 saw a modification to a Federal Act on Reducing CO_2 Emissions.

4. CONCLUSIONS

Global CO_2 emissions are significantly influenced by the building industry. The massive production and emission of CO_2 have had significant effects that have exacerbated climate change. The unfavorable effects on people as well as the environment have been impacted by the non-sustainable built environment. This study covered the general causes of CO_2 emissions as well as a mitigation plan for reducing and controlling CO_2 emissions in the building industry. The use of fossil fuels cannot be sustained, while accounting for a sizable amount of the energy usage in the operation and construction stages. Putting laws and policies into practice, doing impact studies, implementing low-carbon technologies, and limiting energy consumption are the methods to be used to reduce CO_2 in the building industry. By then, it will be too late to correct the earlier errors, if we keep constructing things while failing to take the required steps to lower or limit CO_2 emissions. We might not succeed in achieving the global sustainable development goals if we don't make sustainable cities and communities a reality. To slow down CO_2 emissions, the building industry has to receive necessary attention. To address the problem, international organizations must provide a thorough structure, and a complete analysis is required to examine CO_2 emission mitigation techniques in the building sector. To fight climate change and secure a more sustainable future, drastic measures must be taken to reduce CO_2 emissions.

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