ADDRESSING MITIGATION OF CLIMATE CHANGE THROUGH STRUCTURAL MATERIAL AND DESIGN

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ABSTRACT

Buildings are significant contributors to global carbon emissions throughout their life cycle,Makes up 21% of the planet's greenhouse gas pollution. This paper explores the carbon footprint of buildings, focusing on emissions from construction materials and potential mitigation strategies through design modifications and eco-friendly structural solutions. Cement and steel production, two major contributors to building emissions, are discussed in detail, along with the embodied carbon in different construction materials. Strategies such as bioclimatic design, natural ventilation, shading systems,integrating greenery is a multifaceted solution that tackles climate concerns and comfort needs simultaneously. Furthermore, eco-friendly materials like bamboo, hempcrete, and reclaimed wood are introduced as alternatives to conventional construction materials. The paper also advocates for a new design paradigm that integrates various disciplines and principles to create environmentally responsive buildings. Curbing the carbon footprint of buildings isn't optional in the climate crisis. Embracing sustainable solutions is key to building a greener future.

Keywords:*climate change, environment, construction industry, sustainable architecture, CO_2 emission.*

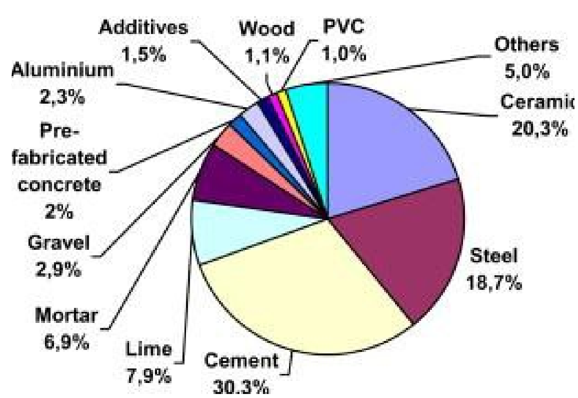
1. INTRODUCTION

The IPCC AR6 report highlights the building sector's substantial impact on climate change. In 2019, buildings generated a staggering 12 Gt CO2 equivalent of greenhouse gases, accounting for a full 21% of global emissions. 57% of GHG emissions from buildings were indirect CO2 emissions from the generation of electricity and heat off-site, 24% were direct CO2 emissions produced on-site, and 18% were from the production of cement and steel used for the construction and refurbishment of buildings.During the period of 1990 to 2019, global carbon dioxide emissions from the building sector exhibited a pronounced upward trend, increasing by 50%. This significant rise was accompanied by a parallel growth in final energy demand for buildings, which expanded by 38%. This growth was not evenly distributed, with non-residential buildings experiencing a more pronounced increase (54%) compared to residential buildings (32%).

According to the report, 50% of all emissions are embodied in buildings, which means they are caused by the manufacturing of materials and the process of construction. Just supercenters cause seventy percent of embodied emissions. (World Business Council for Sustainable Development, 2021). Although buildings have a strong potential to reduce their energy consumption and greenhouse gas emissions; the main challenge is achieving this objective without compromising thermal comfort needs. Curbing the environmental impact of construction necessitates a twofold approach: minimizing the carbon footprint of building materials and optimizing structural design elements. To align with the ambitious targets set forth by the 2015 Paris Agreement, a 50% reduction in embodied carbon from construction materials by 2030, followed by achieving complete carbon neutrality by 2050, is paramount for limiting global warming to 1.5 degrees Celsius above pre-industrial levels.

2. EMISSION FROM CONSTRUCTION MATERIALS AND MITIGATION

The construction industry is a diverse beast, devouring materials from nature's bounty like sand, wood, and water. However, it also feasts on manufactured goods, with cement, steel, and bricks being just a few examples. Among these, cement and steel are notorious polluters, belching out significant amounts of carbon dioxide (CO2) into the atmosphere. As Figure 1 illustrates, their CO2 emissions dwarf those of other construction materials, while ceramics, for example, leave a much smaller footprint.



Source: Bribian, et. al., 2011

Figure 1: CO_2 contribution from various construction materials.

2.1 Cement

Cement production casts a long shadow on the world's climate, responsible for a staggering 5% of all CO2 emissions (Ma, 2016). This hidden cost becomes stark when you consider that crafting just one kilogram of Portland clinker, the heart of cement, releases nearly another kilogram of CO2 into the air (Ma, 2016). The culprit? The fiery calcination process within the cement kiln, spewing out 0.55 kg of CO2 per kilogram of clinker (Nielsen, 2008).

2.2 Steel

Steel's birth pangs leave a hefty environmental mark. Forged in the fiery crucible of blast furnaces, iron ore and a carbon-rich agent like coking coal dance a chemical waltz, releasing a torrent of CO2. This reaction, the heart of steel production, spews 70-80% of the industry's total CO2 emissions (Kittipongvises, 2017). Globally, the steel sector belches out a hefty 6% of all CO2 emissions (Stoke Orchard, 2000). Take, for instance, a recent project by Solis Guzmán: two four-story blocks of flats constructed with Steel B 500S. During their year-long construction, these seemingly ordinary buildings left a staggering 281,898.38 kg CO2 eq in their wake.

2.3 Carbon Emission from A Typical Building

Opting for prefabricated timber panels to build a 3-bedroom semi-detached house offers a substantial environmental advantage over traditional brick-and-mortar construction. Research indicates that the carbon footprint of such timber houses is roughly 35 tons, representing a 34% reduction compared to the 52 tons associated with a standard brick dwelling. This significant decrease primarily stems from the materials themselves, accounting for 82% of the difference. Transportation and waste generation play secondary roles, contributing 2% and 16% to the carbon footprint reduction, respectively.

As buildings age and their usefulness dwindles, their demolition becomes necessary. While this may seem straightforward, it comes with an environmental cost. Demolishing concrete structures, a common building material, releases CO2 into the atmosphere. The exact amount per unit of concrete varies between 0.004 and 0.01 kg, depending on several factors. These include the type of steel reinforcement used, the overall structure itself, and even the specific conditions present during the demolition process (as described by Monahan in 2011).

Demolishing an in-situ concrete building in Korea using diesel fuel resulted in substantial carbon dioxide (CO2) emissions. This method required a high energy consumption of 51.5 megajoules per square meter (MJ/m2), leading to CO2 emissions of 10.3 kilograms per 10 square meters (kg-CO2/10 m2). Waste transportation further amplified these emissions, varying with building type: single-family houses (24.4 kg-CO2/10 m2), flats (26.3 kg-CO2/10 m2), and multi-family houses (17.6 kg-CO2/10 m2). A separate study also highlighted the environmental impact of waste transportation during construction. Generating 530 tons of waste and consuming 527 L of diesel for its transport resulted in 1.4 tons of CO2 emissions solely from this phase. This data underscores the need for more sustainable demolition and waste management practices to minimize carbon footprint.

2.4 Construction and Manufacturing Waste Management

The construction industry generates various waste materials, including concrete rubble, timber, glass, plastics, and excavated soil. Fortunately, many of these can be recycled for alternative construction uses. Demolition interiors can even be reused or recycled. To minimize environmental impact and maximize reuse/recycling potential, careful waste management planning is crucial, involving volume and composition assessments.

For example, crushed concrete blocks can be landfilled or used for landscaping. Carpet fiber can be repurposed in fiber-reinforced concrete and soil, enhancing properties like toughness and crack resistance. Additionally, waste materials can even partially replace concrete components: plastics and glass up to 20% of fine aggregates, and waste concrete up to 20% of coarse aggregates. By embracing such recycling and reuse strategies, the construction industry can significantly reduce its environmental footprint while creating more sustainable structures.

3. MITIGATION THROUGH DESIGN MODIFICATION

Although buildings offer significant opportunities for reducing energy use and emissions, achieving these goals effectively necessitates maintaining occupant thermal comfort. This comfort depends on a complex interplay of environmental conditions, human characteristics, and even psychological factors, extending beyond solely managing temperature. Similarly, visual comfort deserves consideration, alongside its own set of influencing variables. Traditionally, occupants of homes managed CO2 levels by simply opening and closing windows. However, advancements in technology have brought forth tools like air purifiers, helping maintain comfortable air quality in more advanced smart homes. The figure below illustrates how these three comfort areas are shaped by various factors within the environmental, human, and physiological things.

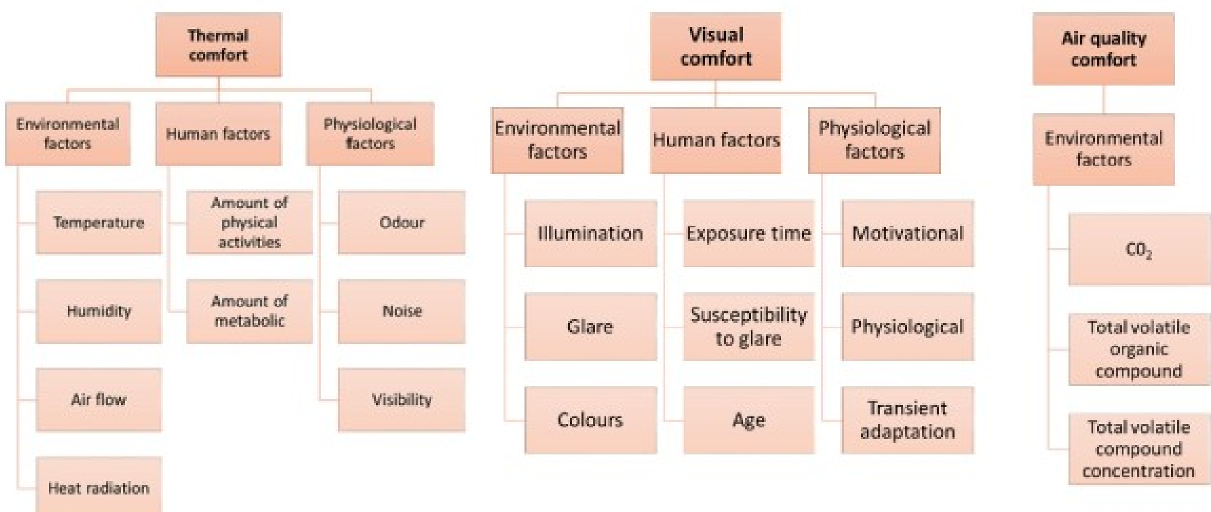


Figure 2: Factors influencing (a) thermal, (b) visual, (c) air quality comfort of building occupants

4. ADAPTATION OF DESIGN STRATEGIES

Bioclimatic strategies:

Bioclimatic architecture considers the microclimate of the site and site surrounding, climate conditions of the location and hence reduces the need for heating, cooling, lighting and ventilation increasing comfort in every season and climate.

A new concept of bioclimatic architecture is bionic green architecture. Bionic green architecture also known as biomimicry is a science that studies Nature's best ideas and implements the ideas to solve human problems. For example, the way termites drill holes in their mounds to cool down in the hot African Savannah has inspired architects to develop buildings that are more efficient.

Natural ventilation:

Natural ventilation increases daytime air speed and high night ventilation rates, providing good air quality and improving the thermal comfort in hot climates. Moreover, natural air ventilation provides high ventilation rates for cooling purposes without consuming too much energy. Natural ventilation is essential in bioclimatic design systems.

Shading System:

Passive and active shading systems are considered not only as thermal-lighting strategy, but also as cooling technique. Well-designed sun control and shading devices can improve the natural lighting quality of building interiors and dramatically reduce building peak heat gain and cooling requirements. The design of effective shading devices depends on the solar orientation of a particular building facade.

Building envelope:

Building envelope parameters and geometry configuration designed to separate the indoor environment from the outside one reduces energy consumption and greatly influences the living conditions of any structure. Using Sustainable Materials reduces buildings energy consumption.

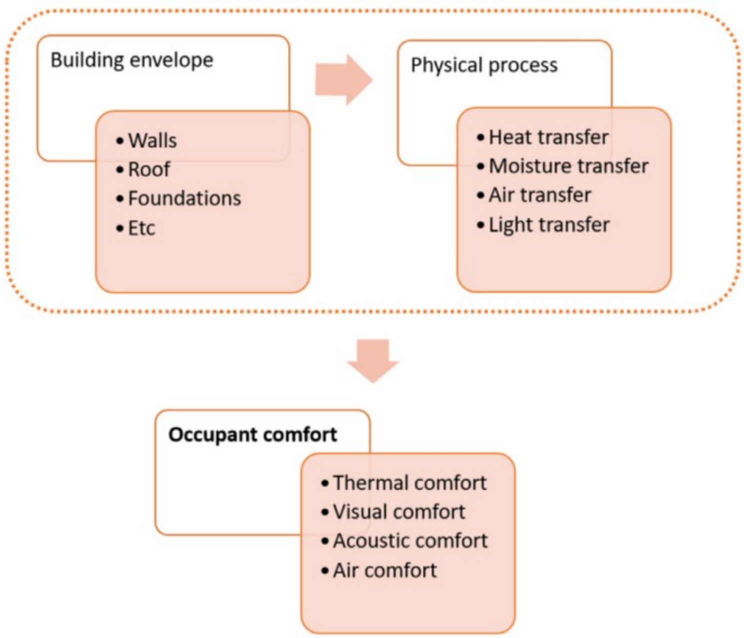


Figure 3: Major components of the building envelop and physical processes

Adaptive capacity of the building envelope

Adaptive Capacity can be supported by several devices and components that are:

a) Shield internal spaces from changes in solar radiation and minimize thermal losses
  - solar control / low-emissivity coatings,
  - multiple glazed units with gas fillings,
  - fixed or movable external shading devices,
  - vacuum glazing,
  - transparent insulating materials, aerogels, etc.

b) Maximize daylight transmission and distribution, whilst reducing glare and contrast
  - manually- or automatically controlled blind systems,

- reflective lamellae, prismatic screens,
- holographic optical elements,
- light shelves,
- laser cut panels,
- anidolic ceilings, etc.

c) Adaptive measures for peaks in temperature and moderate day-night and seasonal thermal variations.
- exposed thermal mass,
- vaulted ceilings,
- phase change materials,
- vacuum insulated panels

Integration of greenery in buildings

Using green roof and interior greenery efficiently improves building envelopes. Green roofs function as insulators for building and remove heat by evapotranspiration, lowering the energy required for cooling and heating, reducing urban heat island effect in the urban setting. Urban vegetation improves the air quality of the polluted cities by reducing air conditioning need, air pollution and GHG emissions from air through carbon sequestration and storage.

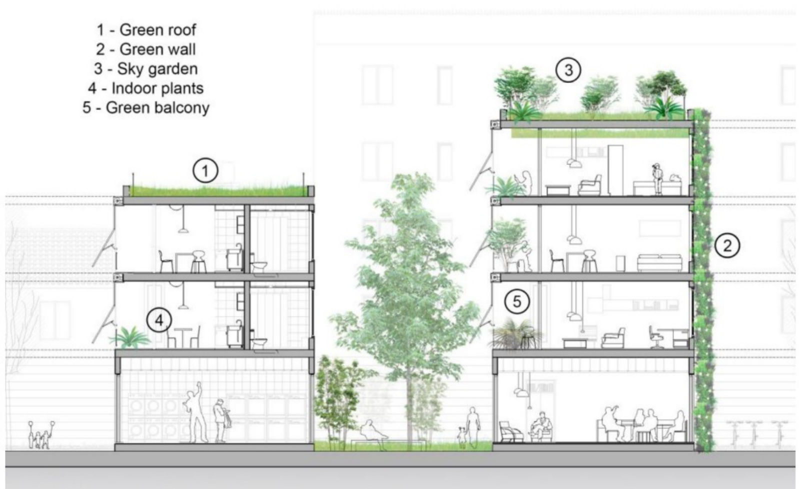


Figure 4: Integrating greenery in building.

Cool Roof System

Cool roofs are roofs coated externally with high albedo materials that provide a reduction of the solar heat gain in the building and increase the solar reflectance of the roof surface [A.L. Pisello,2017]. Using cool coatings, membranes, and tiles benefit by improving indoor and outdoor thermal conditions in summer and decreasing the building energy demand (between 7% and 57%, depending on the climate and the building type).

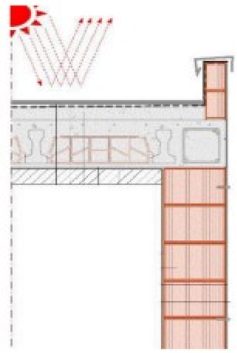


Figure 5: Cool roof system.

5. ECO-FRIENDLY STRUCTURAL STRATEGIES

Eco-friendly buildings are more than just bricks and mortar; they're designed to tread lightly on the planet throughout their entire existence. From the drawing board to demolition, every phase – design, construction, operation, maintenance, and even renovation – prioritizes resource efficiency. Minimizing environmental impact and safeguarding human health are core principles, achieved through smart resource management, particularly of energy, water, and other precious materials.

Buildings designed with environmental sustainability in mind, particularly those recognized by the LEED standard, are potent tools for minimizing the ecological footprint of both the structure and its residents. A study conducted by UC Berkeley in 2014 demonstrated that LEED-certified buildings, in contrast to traditionally constructed ones, emit 50% less greenhouse gases through water usage, 48% less through waste generation, and 5% less through transportation choices. This evidence underscores that pursuing environmentally conscious construction methods is not simply a fad, but rather a critical action for securing a future characterized by ecological responsibility.

Zero Energy Building

If consider zero energy building (ZEB) which is defined as a reference to achieve the balance between need and self-sufficiency for a building under service conditions. The ZEB concept focus on the active building appliances to assess the amount of minimum energy need, build energy recoveries that increase energy effectiveness and use of solar air conditioner that is the consumption of renewable energy.

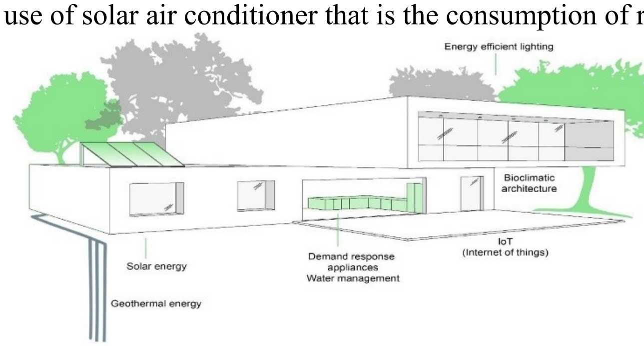


Figure 6: Ideal Zero Energy Building

To achieve ZEBs, a combination of passive and active strategies needs to incorporate. Four things need to consider for implementation strategies. Firstly, need to do passive sustainable design which includes building geometry, natural lighting and natural ventilation. Secondly, energy savings techniques and components need to introduce. Next is about incorporating renewable energy like solar thermal, geothermal system and finally make provision of the storage or back-up system for renewable energy.

Energy efficient and Eco-friendly Technologies

There are some of the many ways the construction industry is incorporating energy-efficient and eco-friendly technologies into their structures:

a) Solar energy panels – Can be use as the alternate of the electricity with multipurpose usage.
b) Drainage systems and water filtration – The system has to design in most innovative way that the water within a building can reuse, and biological waste is treated safely which can then be recycled. Furthermore, drains can be manufactured so that they lead to gardens. This is to collect rainwater for plants, rather than wastefully using water from a tap.
c) Low-energy lighting, which is typically IP 6 rated, can save you 100 percent on energy because they last twice as long as ordinary bulbs.
d) Heat proofing slab casting: That reduces more than 30% temperature reduction inside the structure which conserves electricity.

Sustainable Building materials

A. Bamboo:

Bamboo is a completely natural, biodegradable, eco-friendly, sustainable material that is renewable also as it grows back quickly. Though it is trendy now, in many parts of the world including Bangladesh bamboo has been used for centuries as construction material.

B. Alternatives of Concrete

i. **Hempcrete:**
Hempcrete is a concrete like material where hemp fibers are bound with lime to create blocks that are super light weight and strong, which is significantly less than construction cost of concrete. Moreover, Hemp plat is fast growing and acts as renewable resource.

ii. **Ashcrete:**
Ashcretea alternative to concrete that is composed of 97% recycled materials such as fly ash (a by-product of burning coal) and borate.

iii. **Timbercrete:**
Timbercrete is a building material made from a mix of saw dust and concrete. Sawdust, a waste product is reused and also replaces some energy intensivecomponents of concrete.
Its lighter than clay or concrete blocks and can be produced in forms of blocks, bricks and pavers.

iv. **Recycled Plastic:**
Recycled plastic and trash are used to make concrete like blocks and polymeric timber. This reduces GHG emission and gives plastic waste a new use.

C. Clay Bricks:

Clay brick is made from a mix of clay and water. It is recyclable, eco-friendly and doesn't release any toxic chemicals.

D. Reclaimed or Recycled Wood:

While wood is an excellent material, using virgin wood harms the environment more than it aids. Using reclaimed, recycled wood saves trees and has less environmental impact than harvesting new timber. It can be used in cabinetry, flooring and framing but integrity assessment and appropriate selection is absolutely required.

6. DEVELOPING NEW DESIGN PARADIGM

To address the critical need for buildings that prioritize resident comfort, health, and environmental sustainability, a revolutionary design approach is essential. This new paradigm demands breaking down traditional disciplinary silos and fostering knowledge exchange across seemingly disparate fields like architecture, physics, engineering, climatology, physiology, psychology, and biosciences.

As Altomonte and Luther (2006) proposed, an integrated building design process could pave the way. Built on iterative analysis and interconnected systems, this approach considers the following key aspects:

a) **Site & Climate Analysis:**
Analyzing the site, exposure, climate, orientation, topographical factors, local constraints of the site and evaluating the availability of natural resources and ecologically sustainable forms of energy considered in relation to the duration and intensity of their use (genius loci, Olgyay, 1963).

b) Flexible & Adaptive Structural Systems:
Exploring and researching structure characteristics, be it permanent or temporary, integrating with other elements of the building such as interior, envelope or mechanical systems to get the desired aesthetics and maximize comfort for the occupants.

c) Renewable & Environmental Building Materials:
Concerning material or product efficiency, available size, standardization, structural effectiveness, intricacy, regularity, adequacy, cost, labor involved, plantation origin, method of growth (especially for natural materials), embodied energy (i.e. combined energy needed to design, produce, transport, use, maintain and discard a product), recycled and reused content (deconstruction, adaptability), toxicity level (wastes, pollution), etc.

d) Modular Building Systems:
To isolate different single construction elements and or substitute them without detrimental complication to the whole system, the construction and assembling methods of building components must be studied. This allows for shorter construction time, reduction of energy consumption and waste. Also, maintenance and/or replacements, flexibility and interchangeability is enabled by perfecting modular building systems.

e) Integrating Building Components:
Researching and exploring the role and the design of building elements, device, systems and mechanisms acting as an interface, internal and external environments and the dynamic filter between them, in order to control the energy that flows directly or indirectly, enters (or leaves) an enclosed volume, considering orientation, seasonal variations, surrounding environment, function of the building, user requirements and type.

f) Renewable & Non-conventional Energy Systems:

Researching sources of energy that can be exploited without depleting or draining and exhausting their point of origin and collecting that directly on site or in centralized areas with little or no ecological impact.

g) Innovative Heating, Ventilation & Air Conditioning Systems:
Exploring mechanically-regulated, hybrid, or, preferably, totally passive techniques,
to offer comfortable interior ambience for the occupants in terms of thermo-hygrometric and air quality comfort.

h) Water Collection & Storage Systems:
Inventing and analyzing the methods and strategies to collect, store, distribute, use, recycle and re-use water, a primary resource in all occupied buildings.

7. CONCLUSION

The past 200 years have seen our unrelenting pursuit of industrial advancement weave the fragile tapestry of the natural world into the rich fabric of our constructed environment. However, because of this mutually beneficial relationship, the climate crisis has become more urgent and demanding, requiring a comprehensive and multifaceted approach for a successful settlement. Given the urgency of the issue, proactive mitigation techniques to prevent future adversities must be implemented in conjunction with a robust adaptation framework to help people navigate and survive the ongoing changes.
This combined approach represents a significant change toward adopting the concepts of sustainable development, going beyond the simple act of protecting against future uncertainty. It calls on us to reconsider the way we now do things, to think outside the box, and to come up with and put into action solutions that not only lessen our influence on the environment but also bring harmony to our coexistence with it. The pursuit of these tactics becomes morally required as we negotiate this pivotal point in human history, influencing the course of our planet's future and ensuring the welfare of future generations.

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