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Mitigation and Adaptation Strategies to Combat Climate Change in the Built Environment

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Abstract: ***The built environment with its high energy consumption and carbon emissions during the building life cycle has played a significant role in environmental degradation and global warming. Today the built environment accounts for more than half of global energy use and more than one-third of greenhouse gas emissions in the developed and developing world. New concepts of multidisciplinary design must be generated to develop a climate-responsive and energy-efficient built environment which adapts to the changing environmental conditions and mitigates the causes of the rapid change. By doing so, the building sector can drastically reduce its GHG emissions. Moreover, buildings can also adapt to the constant changes in the environment using emerging technologies such as the use of dynamic climate adaptive building envelopes. This paper presents an overview of climate change theory and its relationship to the built environment and novel methods of mitigation and adaptation.***

Keywords: ***Mitigation, Adaptation, Climate Change, Built Environment, Energy Efficiency, Adaptive Technology***

I. INTRODUCTION

The preceding few millennia in the Earth's climatic history have been an episode of climatic stability that provided favorable conditions for the advent of the agricultural revolution, growth of human civilizations and the advancement of human societies that are complex and layered in socio-economic structure. There was marginal variation in weather over the centuries and the changes took place over a long period of time giving all forms of life adequate time in which they could adapt, migrate or evolve. However, with the advent of the industrial age, there were chemical changes in the atmosphere due to the burning of fossil fuels that resulted in significant adverse changes in the global climate system and local weather patterns.

In the graph below (Figure 1.1) it is seen how the atmospheric carbon dioxide levels were stable for many centuries but have spiked since the Industrial revolution.

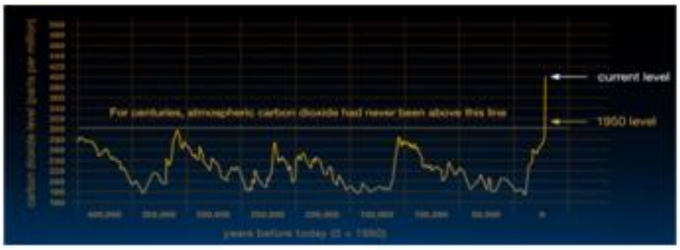

Fig. 1.1. Comparative graph of atmospheric carbon dioxide that shows that atmospheric CO2 has increased since the industrial revolution *(Source: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record (2016))*

The built environment with its high energy consumption and carbon emissions during the building life cycle has played a significant role in environmental degradation and global warming (Figure 1.2).

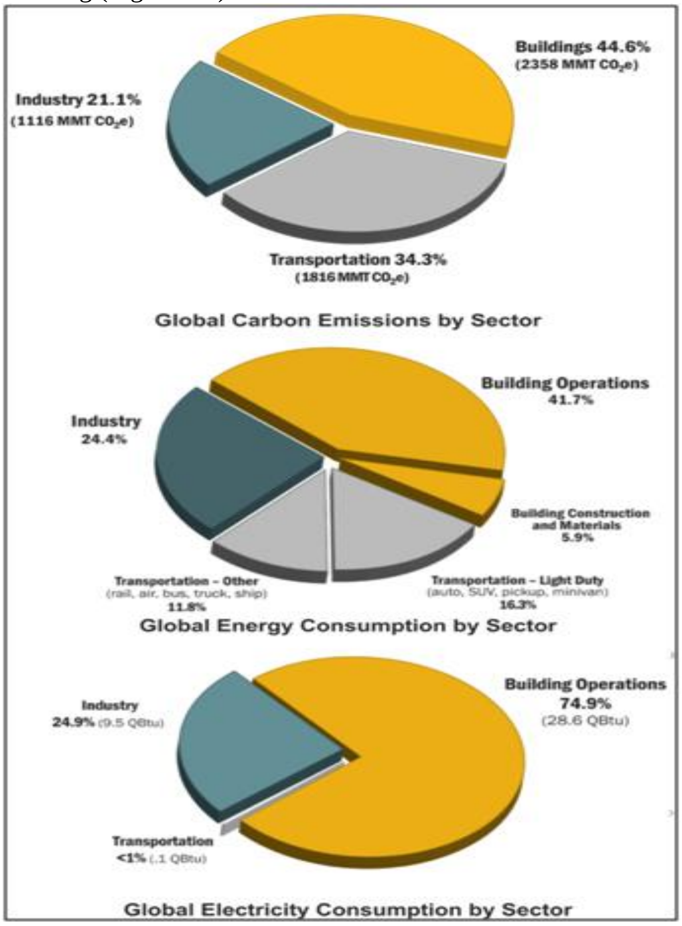

Fig. 1.2. Carbon emissions, Energy Consumption and Electricity Consumption By various sectors - the dominant sector being the Construction industry (Source: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record (2016))

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Today the built environment accounts for more than half of global energy use and more than one-third of greenhouse gas emissions in the developed and developing world (P Sudhakaran et al., 2017). The Fourth Assessment Report of the IPCC (Intergovernmental Panel on Climate Change) states that around 8.6 million metric tons of CO2 were emitted from construction-related activities (IPCC, 2007). Another disturbing reality is the rate at which emissions are growing. It has been estimated that CO2 emissions released through the energy use in buildings and direct emissions during the construction, maintenance and demolition of buildings grows at a rate of 2.5% per annum for the commercial sector and 1.7% per annum for the residential sector globally (Levine et al, 2007).

XXEmissions of other GHGs such as halocarbons, chlorofluorocarbons, and hydrofluorocarbons are also accounted to the construction industry as they used in cooling, refrigeration and insulation materials.

The IPCC states that the emissions, if not controlled, could double up in the next decades to reach about 15.6 billion metric tons of CO2 equivalents which would be disastrous for civilization (ibid).

An innovative approach towards building sector is needed which addresses towards the requirements of the environment along with that of socio-economic aspects. New concepts of multidisciplinary design must be generated to develop a climate-responsive and energy-efficient built environment which adapts to the changing environmental conditions and mitigates the causes of the rapid change. By doing so, the building sector can drastically reduce its GHG emissions. Novel applications of technology can reduce emissions and energy consumption by 30 to 80% during the life cycle of the building (Architecture 2030, 2017). Moreover, buildings can also adapt to the constant changes in the environment using emerging technologies such as the use of dynamic climate adaptive building envelopes.

In pursuit of adaptation and mitigation strategies to climate change, motivation from the lessons found in nature is of key importance. Nearly all living organisms undergo a process of evolution to respond and adapt to altering environmental conditions. This natural process takes place without changing the balance of their immediate environment or significantly consuming natural resources. Taking a cue from nature, a bio-inspired 'adaptive' method of building can give a new direction to the way we build future buildings. If humans need to thrive as a race, then it is time we learn how to emulate nature and design the required technology for the most sustainable buildings yet to come.

II. MITIGATION AND ADAPTATION STRATEGIES IN THE BUILT ENVIRONMENT

Working Group III of the Fourth Assessment Report of the IPCC which deals with the contribution of Mitigation of Climate Change suggests vital short term and medium-term actions to be taken before 2030, and long term actions to be taken after 2030, thereby controlling human-induced effects on the environment.

Suggestions vary from the energy and building sector to transport industry, agriculture, forestry and waste management. It states that the incorporation of the mentioned strategies would help curb the carbon emissions from various sectors thereby improving social, ecological and economical parameters for the welfare of humanity (IPCC, 2007c).

The built environment in which we spend almost 90% of our day and forms the biggest part of social, cultural, business and private activities must not only mitigate the causes of climate change but also adapt to its effects. The figure below (Figure 2.3) shows the relationship between Climate change and the Built environment.

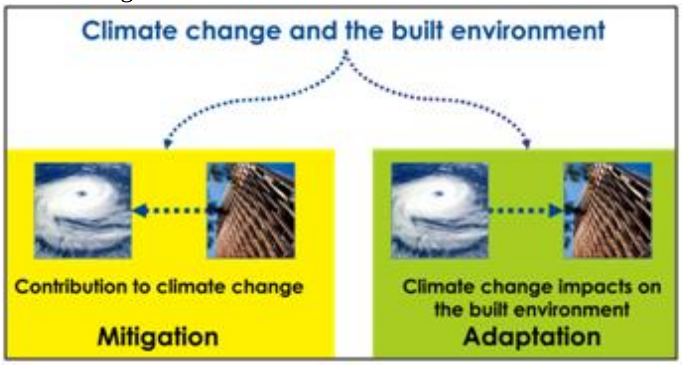

Fig. 1.3. Relationship between Climate Change and the Built Environment: Mitigation & Adaptation (Source: Author)

A. Technology at the cutting edge

It has been recorded that between the year 1970 and 1990, apart from electricity consumed direct carbon emissions from the building sector has increased by 26%. With its dependence on mechanical systems and services for heating and cooling, the total amount of direct and indirect emissions goes up as high as 75% (IPCC, 2007c).

Buildings consume an enormous amount of energy through its life cycle of construction, operation and demolition, depleting non-renewable resources and causing GHG emissions. More than half of the energy budget of the world, produced by the burning of oil, coal and natural gas is consumed by the building industry, significantly contributing to enormous carbon emissions which is the cause of anthropogenic climate change.

The IPCC suggests that developed economies and emerging nations should reduce the pressure of human habitats on the environment to avoid extreme consequences. In this context, it is believed that advances in technology could play a crucial role in the incorporation of cleaner renewable sources of energy, thereby reducing the building industry's dependence on the carbon budget of the planet and ecologically enhancing building design (Smith 2005 and 2007).

Recent advances in technology have developed a range of 'sustainable' ways to curb the stress of the construction industry on the climate system.

But innovations in the production and management of energy in buildings must be coupled with more responsive and adaptive strategies for both existing and new infrastructure. Thus to effectively mitigate the long term impacts of climate change and additionally adapt to the short term effects of climate alterations, the need of the hour is to develop sustainable design methodologies by which technology and design can be integrated, to limit the use of energy, and effectively reducing carbon emissions.

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The structure, envelope, interiors and services of a building play a key role in determining the delicate balance between internal and external conditions of built spaces. It is through strategic integrated design and the thorough implementation of knowledge–both existing and forthcoming–that the built environment can integrate functions and requirements with dynamic environmental forces thereby providing comfort for users with efficient use of energy and reducing waste and emissions.

B. Integrated Building Design

'Integrated Building Design' uses advances in technology and incorporates active and passive strategies and is suggested as one of the primary conclusions of the Fourth Assessment Report of the IPCC as amongst the many mitigation strategies and adaptive practices to be achieved by built environments before 2030 (IPCC, 2007c).

There have been several attempts to provide recommendations, guidelines and design strategies that are either too specific or vague to a circumstance towards sustainable design. But it is to be understood that thermal performances of buildings, ventilation, and light and humidity regulation are parameters that require to be designed as per specific requests, in varied climatic zones and varied technical scenarios. Additionally, architecture is also meant to provide necessary functional services to its user's apart from being a climatic filter (Hawken et al; 1999). This would give rise to a question of how the built environment can satisfy contemporary comfort and aesthetic needs and at the same time be energy efficient with reduced environmental impact. To meet these demands, it is the need of the hour to incorporate an integrated design methodology that could lead to an innovative as well as progressive architecture that could adapt to current as well as predicted climatic alterations and contextual conditions.

C. Adaptive Building Envelope

Adaptation strategies became more prevalent during the 1970s after new demands for comfort emerged in buildings. 'Adaptation' within architecture is a term used to describe processes performed by systems to manipulate changing environmental parameters to meet user demands within a specific time frame. The environment is in a state of constant change and hence it is important to manage these constant changes towards the needs, comfort and satisfaction of the occupants. For example, "an ideal cladding system would have quite different thermal and optical properties at different times of the day and night, at different outdoor temperature conditions, and in summer and winter" (Gregory, 1986).

Adaptive performance in buildings can either be flexible, transformable or responsive which aims to reduce the confusion caused due to various definitions of adaptation found in the literature. Moreover, it also emphasizes the degree of adaptation.

a) Flexible: Change in surface orientation/configuration
b) Transformable: Change in the spatial structure of the building
c) Responsive: Change in 2 dimensional and 3-dimensional parameters in time

The physical interface between the external environmental parameters and the internal conditions of the building is termed as the building envelope. The interface that adapts to changing external environmental conditions, at the same time managing internal conditions is termed as an adaptive building envelope. It aims at reduction in energy consumption and improvement of occupant thermal comfort.

Innovative adaptive building envelopes have been emerging considerably over the last few decades. Some are still in their theoretical stage, but potentially applicable. For example, 'Polyvalent Wall' proposed by Davies (1981) consisted of multiple layers that could absorb, reflect, filter and transfer energy from the environment. Le Corbusier's 'House of Exact Breathing' introduced the wall that managed the internal conditions through cavities as an adaptation strategy. (Le Corbusier, 1991). However, this futuristic strategy was not implemented due to lack of technology.

III. CURRENT ADAPTIVE SOLUTIONS

Various emerging technologies like information technology now allow the built environment to adapt to changing environmental conditions. (Wigginton & Harris, 2002). Current methods of climate adaptation in buildings include the incorporation of mechanical services and the implementation of responsive building materials and construction techniques, both active and passive.

D. Mechanical systems

Most of our built environment today is dependent on mechanical systems for heating, ventilation, cooling and control of internal environmental parameters (P Sudhakaran at al., 2018). These systems are either integrated or attached to the building envelope and technology. Use and maintenance are important factors for the efficient functioning of these systems. These systems could also be part of the overall design concept (part of the building skin) or could be an isolated solution (like an air-conditioning unit). Circulation, communication among occupants, information and products in buildings are influenced by the degree of separation between the structure of the buildings and its mechanical systems (Banham 1984). Banham states that "history ignored the technological art of creating a habitable environment" and focused on "external forms of habitable volumes as revealed by the structures that enclose them" (Banham, 1984).

Technology integrated into the design process can provide better innovative and sustainable solutions (Watson 1997). In integrated building services, the building envelope is a functional entity, where services are embedded in the structural system. The level of adaptation to environmental conditions is influenced by the inter-relationship of various elements of the building envelope.

E. Building materials

The molecular structure of building materials allows them to have a great influence on the adaptive performance of a building. The use of advanced responsive building materials in real-time proves to perform better. Various smart materials are being used throughout the construction industry today with high potential (Addington & Schodek, 2005). For example, improved thermal distribution, cost and space effectiveness is observed when phase change materials are

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applied in buildings for improved energy conservation purpose. A new range of materials is being developed through research for potential use in the construction industry such as shape memory alloys (SMA) and shape memory polymers (SMP) to be used in form for adaptive architecture for various conditions (Lelieveld and Vourbij 2009).

IV. ADAPTIVE SOLUTIONS IN NATURE

As the adaptive stability between internal environment of the built environment and external climatic conditions is tried to be achieved through technological solutions, there is much we can learn from how organisms try and achieve 'homoeostasis' in nature. Nature achieves homeostasis through thermoregulation, osmoregulation and gas regulation. Evolution has managed to develop various mechanisms and strategies enabling organisms to achieve homeostasis. Adaptation could occur at various time scales: either through the day, through seasons or throughout their lifetime.

For example:

a) Adaptation through the day: solar tracking abilities of the sunflower
b) Adaptation through seasons: shedding of leaves by trees during winter due to lack of sunlight
c) Adaptation throughout life: change of color of human skin caused by tanning

And yet living organisms in nature can adapt efficiently to extreme environmental conditions through behavioral, morphological, physiological and structural adaptations (Louw and Seely 1982).

V. RESULTS

The study shows that there are various possibilities for mitigation and adaptation strategies that need to be pursued for the built environment to adapt towards climate change.

Various strategies such as the use of 'technology at the cutting edge', integrated building design, advanced mechanical systems, innovative building systems and materials and most importantly emulating the various strategies and mechanisms available in nature and translating them to useful adaptive concepts in the design of the built environment. The paper results proposed the use of the advanced integrated concepts on the building skin as it is the interface between the external environmental factors and the internal conditions of the building.

New concepts of multidisciplinary design must be generated to develop a climate-responsive and energy-efficient built environment which adapts to the changing environmental conditions and mitigates the causes of the rapid change. By doing so, the building sector can drastically reduce its GHG emissions. Moreover, buildings can also adapt to the constant changes in the environment using emerging technologies such as the use of dynamic climate adaptive building envelopes. This paper presents an overview of climate change theory and its relationship to the built environment and novel methods of mitigation and adaptation.

VI. CONCLUSION

The building envelope acts as the interface between external and internal conditions of the built environment. Bio-inspired building envelope could prove to be an adaptive solution to altering environmental conditions in contrast to static building facades. It could also be a solution for thermal comfort and various activities of the occupants within a built environment.

Nature provides us with a catalogue of adaptive strategies to suit varying environmental conditions and the exploration of these strategies could be dominating principles to design Bioinspired climate adaptive building skins/shells/envelopes.

How does one convert this extensive source of natural strategies, mechanisms, processes and behavior to be integrated into a design methodology for architectural envelopes is scope for future research which could lead to an establishment of Design methodology to be incorporated by Architects & Designers?

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Dr Pratheek Sudhakaran is an internationally recognized Building Scientist and expert in the field of High-Performance Buildings, Envelope Information Modelling and Bioinspired Architecture. As a visiting research fellow at the High-Performance Building Lab, Georgia Tech, USA he worked on Building Energy Efficiency through the application of Bioinspired Dynamic/Kinetic Building Envelopes in an effort to reach conclusions that will curb, mitigate or adapt to the challenges of climate change with regard to clean and efficient energy and environmental protections. He graduated from the University of Mumbai and is a registered architect with the Council of Architecture, New Delhi, India.

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Ar. Nishant Saxena is a Jaipur (India) based architect and academician, also holds specialization in construction management is being practicing from over a decade now. He has been involved in design, project management & execution of numerous urban planning, housings, commercial and conservation related projects. He is a green building strategist, a GRIHA certified professional and IGBC accredited professional. Currently he is serving Amity School of Architecture And Planning, Amity University, Jaipur in the capacity of Associate Professor.

Ar. Rakesh Kumar is a Jaipur(India) based architect and academician, also holds specialization in urban and regional planning is working as academician from the last eight years involved in housing design, urban planning, and rural planning, disaster mitigation, and BIM modelling. Presently he is serving as an assistant professor in Amity School of Architecture and Planning, Amity University Jaipur.