AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF ARCHITECTURE

A Framework for Integrating Low Carbon Materials in the Egyptian Building Industry

A Thesis submitted in partial fulfilment of the requirements of the degree of Master of Science in Architectural Engineering

By

Hadeer Abdelrahman Elmoslmany
Bachelor of Science in Architectural Engineering
Faculty of Engineering, Ain Shams University

Supervised By

Prof. Dr. Mostafa Rifat
Professor of Architecture, Department of Architecture
Faculty of Engineering, Ain Shams University

Dr. Weaam Mahmoud
Assistant professor, Department of Environmental Engineering
Faculty of Environmental Studies and Research Ain Shams University

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STATEMENT

This thesis is presented in partial completion of the Master of Science in Architectural Engineering requirement, Faculty of Engineering, Ain shams University.

The content included in this thesis was produced by the author, and no portion of it has been submitted for a certification or degree at another scientific institution.

Hadeer Abdelrahman Elmoslmany

Signature

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THESIS SUMMARY

In many countries around the world, Low Carbon Building Materials have received a growing amount of scrutiny in recent years. Numerous initiatives have been devoted to promoting the decrease of carbon dioxide emissions from buildings, to reduce greenhouse gas (GHG) in developed cities. Nevertheless, in the Middle East in specifically, Egypt, there has been insufficient thought devoted to this major problem. Since the built environment is fully responsible for approximately 50% of GHG, making it the largest emitter, and building construction is estimated to grow. In considering these findings, it is clear that following to a low-carbon growth path is the best option for the economy, the environment, and the future of our country. Accordingly, This Research's main objective is to study the practice of using low carbon materials in the Egyptian buildings to bridge the gap between the current practice locally and internationally, to know how to enhance the chances of using these materials within the Egyptian buildings, Furthermore, the study will provide a framework for integrating low carbon materials by using the construction bill of quantities (BOQ) and a carbon emission measuring model throughout the materialization process, as a platform to evaluate the embodied carbon. Posteriorly, this platform can inform users of the effect of applying a change in any of the building variables or building materials as to achieve lower carbon emissions.

Key words: Low carbon materials – Carbon emission measurement – Egyptian building industry

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LIST OF ABBREVIATIONS

GHG	:	Greenhouse Gas
BOQ	:	Bill of Quantities
S.G	:	Sustainable Growth
SD	:	Sustainable Development
UNEP	:	United Nations Environment Program
WCED	:	World Commission on Environment and Development
UN	:	United Nations
CSD	:	Commission on Sustainable Development
MDGs	:	Millennium Development Goals
SDGs	:	Sustainable Development Goals
OECD	:	Organization for Economic Co-operation and Development
HVAC	:	Heating, Ventilation, and Air Conditioning
UNESCO	:	United Nations Educational, Scientific, and Cultural Organization
GCAP	:	Greenest City Action Plan
CO_2	:	Carbon Dioxide
IPCC	:	Intergovernmental Panel on Climate Change
ppmv	:	Parts per Million by Volume
ppm	:	Parts per Million
UNFCCC	:	United Nations Framework Convention on Climate Change
INDCs	:	Intended Nationally Determined Contributions
PAS	:	Publicly Available Specification
LCA	:	Life Cycle Assessment
kg CO_2 /m^2	:	Kilo Grams of Carbon Dioxide per Meter Square
GWP100	:	100-year Global Warming Potential
CF	:	Carbon Footprint
ZCB	:	Zero Carbon Building
LETI	:	London Energy Transformation Initiative
ICE	:	The Inventory of Carbon and Energy
CCI	:	Construction Carbon Index
EU	:	Energy Efficiency
VOCs	:	Volatile Organic Compounds
PEEB	:	Programme For Energy Efficiency in Buildings
RTS	:	Reference Technology Scenario
CTS	:	Clean Technology Scenario
GDP	:	Gross Domestic Product
LEAs	:	Low Carbon Emission Approaches
CDW	:	Construction and Demolition Waste
CCS	:	Carbon Capture and Storage

CCU	:	Carbon Capture and Utilization
BIM	:	Building Information Model
AR	:	Augmented Reality
EN	:	European Standards
ISO	:	International Standard
MOVES	:	Motor Vehicle Emission Simulator
EMFAC	:	Emission Factor
CEDST	:	Construction Environmental Decision-Support Tool
OEE	:	Operating Equipment Efficiency
EOL	:	End-of-Life
DFD	:	Designed for Disassembly
R&D	:	Research and Development
EGBC	:	Egyptian Green Building Council
GPRS	:	Green Pyramid Rating System
SDS	:	Sustainable Development Strategy
COP	:	Conference of Parties
CAHOSCC	:	Committee of Heads of States for Climate Change
UNSDG	:	United Nations Sustainable Development Goals
UNDP	:	United Nations Development Programme
$MTCO_2e$	:	Metric Tons of Carbon Dioxide Emissions
UBL	:	Unified Building Law
HBRC	:	Housing and Building Research Centre
IGCC	:	International Green Construction Code
ASHRAE	:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BSLP	:	Building Service Life Plan
ANSI	:	American National Standards Institute
USGBC	:	United States Green Building Council
IES	:	Illuminating Engineering Society
CEB	:	Compressed Earth Blocks
$BMCO_2$	:	Building materials CO_2
AEC	:	Architecture, Engineering, and Construction

BACKGROUND OF THE RESEARCH

In recent years, the global construction industry has witnessed a paradigm shift towards sustainable and environmentally conscious practices. With concerns over climate change, resource depletion, and the growing awareness of the environmental impact of construction, nations around the world are reevaluating traditional building methods and materials. Egypt, with its rich architectural heritage and burgeoning construction sector, stands at the intersection of this transformative journey.

This research endeavors to explore the paramount importance of integrating low-carbon building materials in the Egyptian building industry. As the nation grapples with the challenges of rapid urbanization, resource scarcity, and a commitment to sustainable development goals, the choice of construction materials becomes a pivotal factor in shaping the future of the built environment. This study aims to shed light on the multifaceted benefits, challenges, and opportunities associated with the adoption of low-carbon building materials in Egypt.

1. Background and Rationale:

1.1. Global Imperatives:

The construction industry is a major contributor to global carbon emissions, and the urgent need to mitigate climate change has spurred international efforts to embrace sustainable construction practices. Egypt, as a responsible global citizen, is compelled to align its building industry with these imperatives.

1.2. Local Context:

The Egyptian building industry faces a unique set of challenges, including a rapidly growing population, urbanization pressures, and concerns over resource availability. These challenges necessitate a reevaluation of traditional construction methods, making it imperative to explore alternative, low-carbon building materials that can offer both environmental and economic benefits.

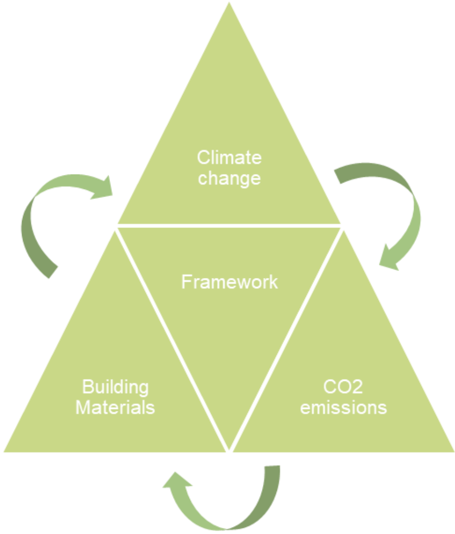
2. Objectives of the Research:

This research seeks to quantify and qualify the environmental impact of the Egyptian building industry, with a specific focus on carbon emissions. By understanding the sector's current carbon footprint, the study aims to emphasize the urgency of adopting low-carbon materials as a means to curb emissions and contribute to global sustainability goals.

Moreover, A comprehensive understanding of the existing regulatory framework related to construction materials is crucial. The research will examine current building codes, standards, strategies and government policies to identify the extent to which they incentivize or hinder the use of low-carbon materials.

3. Research Hypothesis

Integrating low-carbon materials into construction projects and employing a construction Bill of Quantities (BOQ) along with a carbon emission measuring model can be a powerful strategy to evaluate and control embodied carbon in the built environment, so it can contribute significantly to mitigating climate change and promoting sustainable building practices.



4. Scope of the Research:

4.1. Materials Analysis:

The study will delve into various low-carbon building materials, including but not limited to recycled materials, locally sourced alternatives, and innovative technologies. Comparative analyses will be conducted to evaluate their environmental impact, durability, and overall suitability for the Egyptian context.

4.2. Case Study:

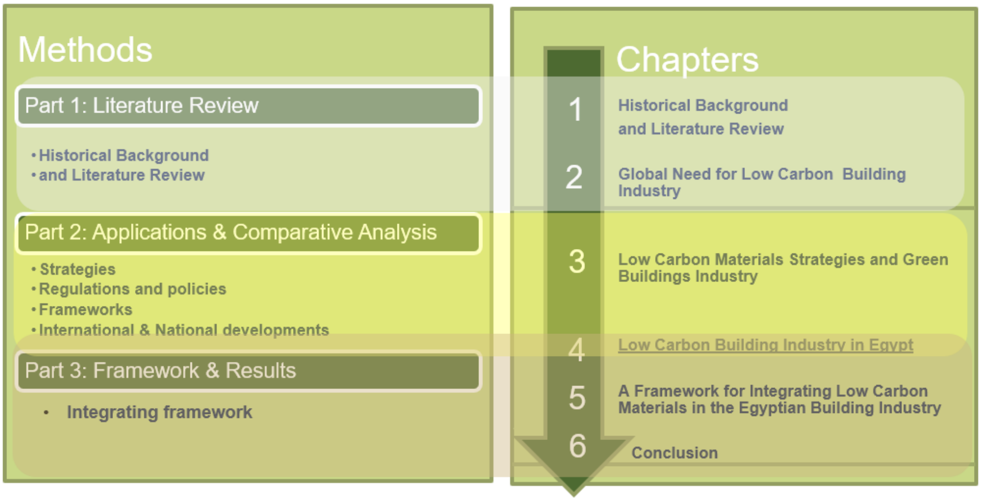
To contextualize the research, select case study from ongoing construction projects in Egypt will be examined. These case study will highlight practical applications, challenges faced, and lessons learned in incorporating low-carbon materials.

5. Significance of the Research:

This research holds significance not only for academia but also for industry stakeholders, policymakers, and the broader public. By elucidating the importance of low-carbon building materials, the findings aim to catalyze informed decision-making, inspire sustainable practices, and contribute to the resilience and longevity of the Egyptian building industry.

As we embark on this exploration, it is our hope that the insights gained will serve as a compass for a more sustainable and resilient future for Egyptian construction.

6. Conceptual Framework:



CHAPTER 1

HISTORICAL BACKGROUND AND LITERATURE REVIEWS

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1.1. Introduction

This chapter studies Sustainability is a way of thinking and acting that seeks to meet the needs of the present without compromising the ability of future generations to meet their own needs. It is based on the idea that economic growth, social development, and environmental protection are interdependent and must be addressed together to achieve a sustainable future. The philosophy of sustainability is grounded in the recognition that our planet has finite resources, and that we must use them wisely and responsibly to ensure a livable future for all.

Sustainable architecture is an approach to building design and construction that prioritizes environmental responsibility, social equity, and economic viability. Sustainable architecture paradigms are models or approaches to sustainable design that reflect different cultural, geographic, and technological contexts. Sustainable architecture can play a significant role in addressing environmental challenges like climate change problems. sustainable architecture can also help reduce the impact of buildings on the natural environment, by using sustainable materials.

Climate change is one of the greatest threats to global sustainability. It is caused by human activities, which releases greenhouse gases (GHG) like carbon dioxide into the atmosphere. These GHG trap heat and cause global temperatures to rise, leading to sea level rise, more frequent and severe weather events, and other negative impacts on the environment and human societies.

Sustainable architecture can play an important role in mitigating climate change by reducing GHG emissions through energy-efficient design, the use of renewable energy sources and building with some alternative materials. It can also help communities adapt to the impacts of climate change through resilient design strategies that prioritize safety and the preservation of natural resources. By embracing sustainable architecture principles and paradigms, we can build a more sustainable and resilient future for ourselves and future generations.

1.2. The Philosophy of Sustainability

In the past few decades, human growth has resulted in increasing unfavorable climate change, natural disasters, wars, and socioeconomic and political insecurity. As a result of their actions, humans have negatively affected the ecosystem, risking the future of the planet and its inhabitants. All of the aforementioned factors, as well as many more, have resulted in behavioral adjustments aiming at a more sensible and effective utilization of existing resources, hence reducing environmental impact. The sustainable development concept, which developed in the 1980s, is regarded as a form of responsible behavior that ensures the long-term utilization of resources without endangering future generations. The approach of sustainable development is founded on the development concept (socioeconomic development consistent with ecological restrictions), a concept of demands (wealth distribution for natural resources to assure the quality of life), and a concept of coming generations (the potential for long-term utilization of natural resources to ensure future generations have the required standard of living).

The core of Sustainable Development originates from the Three bottom line idea, which entails the equilibrium within three pillars of sustainability (1). Environmental sustainability is focused with preserving the environmental quality, which is essential for conducting commercial transactions and enhancing the quality of life for individuals. Social sustainability that tries to preserve equality and Cultural identity restoration, cultural diversity, race, and religion respect. the economic sustainability needed to preserve the naturally, socially, and human capital required for income and standard of living.

1.2.1. The Meaning of Sustainability

Sustainability, as defined by the dictionary, actually indicates that a specific action or activity is potential of being sustained. "Sustainable" came to be used as an adjective to modify common words. It was inspired from the 'Sustained Yield' concept that is used to describe agriculture and forestry when these operations are regulated to sustain their yield indefinitely (2).

Sustainability as a basic idea has two meanings: The first is an undetermined period of time, particularly when compared to a human life. The second is that we should accept the mathematical fact that steady growth; whether for populations or resource rates; for a short period of time will result in a massive increase of these quantities to the point where this growth is actually impossible (3).

In 1713, the term "Sustainability" was mentioned for the first time in Europe. In Germany, it was written as "Nachhaltigkeit" in Sylvicultura Oeconomica the book by the German forester and Hans Carl von Carlowitz (4). Concern for the future preservation of natural resources is perennial. Undoubtedly, our Paleolithic ancestors were concerned regarding the demise of their prey, and earliest farmers were concerned about the maintenance of soil fertility. Traditional beliefs required attention and concerns for the coming generations, as represented by the words of a Nigerian tribal chief who viewed the community as consisting of "Many dead, few living and countless others unborn" (5). Apparently, there have always existed two different views of humanity's relationship with nature: one that focuses adaptation and harmonization, and the other that views nature as something to be controlled. Despite the fact that this last view might have quite prevalent in Western civilization in past decades, its antithesis has always existed (6).

During the 17th century, concerns about Population Expansion and its effects on Resource Consumption began to surface. In 1798 Thomas Malthus in his book described his philosophy of **looming mass starvation** because of the unavailability of cultivated land to feed a rapidly growing population. In 1931, the American economic expert Harold Hoteling created a philosophy on The Ideal Rate of utilization of Nonrenewable Resources that is still applicable today. (7).

During Industrial Revolution occurred on the global stage in the **18th century**, unalterably reshaping human communities, human development was likewise associated to economic prosperity and material development. Donald Worster in (1993) identifies industrialization as the *"Greatest Revolution that has ever taken place "*. By making people believe that it would be appropriate to control the natural balance and completely change it into end user products, it became essential and reasonable to devastate the landscape in order to pursue of optimum economic activity, and only things with value and manufactured by industry were available on the market.

In the **19th century**, coal became the most significant source of power, and there were concerns that coal reserves could be depleted. In 1866 W. Stanley Jevons' published his book "The Coal Question". It was the most significant publication in this area, predicting that English coal deposits would be exhausted within centuries. If England's wasteful consumption of coal keeps happening, the country will lose its dominant industrial position. As a result, it was important to apply "*Every means of sparing the fuel which makes our welfare"* (8). Rudolf Clausius and others in Germany maintained that non-renewable Coal and other natural resources shouldn't be wasted. (9).

Kenneth Boulding coined the term "Earth Spaceship" **in 1965** to reflect the material limitations humankind faces on Earth. Humanity, he argued, must recognize that the earth is *"A single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution"* (10). In such a "Spaceman Economy," sources and sinks are both sides of a single coin, limitless growth is not possible, and materials must circulate, if available, within the socio - economic system.

As a result, the term **Sustainable Growth (S.G)** was emerged, which means an infinite increase and growth of quantities; with the fact of having a finite size of resources verses an infinite growth; would result in the impossible achievement of sustainable growth. This is known as **The First Low of Sustainability**, which is *"Population growth and / or growth in the rates of consumption of resources cannot be sustained"*

The first law is that "Sustainable Growth" is an oxymoron, a term that combines two opposing things. Therefore, it would be acceptable to use the term 'Sustainable Consumption' because it tries to resolve the imbalance between social and environmental issues through a more responsible behavior. The main goal is to ensure that the entire global community's needs are met while reducing excess use of technology, avoiding, and minimizing environmental damage. According to this, the following are the primary principles of sustainability was introduced:

- The protection of nature
- Long-term planning and thinking
- Understanding the nature of the system we live in
- The recognition of resources and limits
- The practice of fairness
- Embracing creativity

1.2.2. Sustainable Development

The Club of Rome published "The Limits to Growth" in the **1970s**, a theoretical framework emerged. (11). In the same year, Stockholm hosted the United Nations Conference on the Natural Ecosystem as the first worldwide conference to address global sustainability. It generated significant momentum and numerous recommendations, leading to the formation of the United Nations Environment Program (UNEP). Just few years after, the (UNEP) hosted a conference on definition of sustainable development, emphasizing the importance of future generations needs and a long-term vision (12). The World Commission on Environment and Development (WCED) wish established in **1983** with the intention of uniting nations in their pursuit of sustainable development goals. However, The Brundtland Commission (13) coined definition of **Sustainable Development (SD),** which said that *"Sustainable Development: is development which meets the needs of the prese without compromising the ability of future generations to meet their own needs"*. But it was criticized because of being confusing, generic, and ignoring the growing population issue.

Later, **Agenda 21 (1992)** clarifies distinct socially, environmentally, and the economic dimensions of' sustainable development,' which may have been couched in the Brundtland Report (1987). However cultural and institutional aspects are also presented (14), However neither a conceptual reason nor a framework is provided (15).

After the 1992 Summit in Rio, the UN established the Commission on Sustainable Development (CSD) to provide guidance and track the progress on Agenda 21 and Rio Declaration’s implementation. In 1995, a workshop comprised of policymakers, officials of international organizations, and scientists was conducted to evaluate indications of the *“Three Principal Aspects of Sustainability”* which are the environmental, social and economic aspects (16).

The most well-known models represented as a **Venn diagram**, where sustainable development represents the point of intersection of the three pillars. The most problem of such diagram when it was designed, that it did not take in consideration the human quality of life as a social aspect. The three pillars here are equivalent. Some other interpretation to the same model was to treat them as a set of nesting concentric circles having the economy within the society and within the environment Some others re-designed the concentric circles to make the social subsystems just equivalent to the economic subsystem.

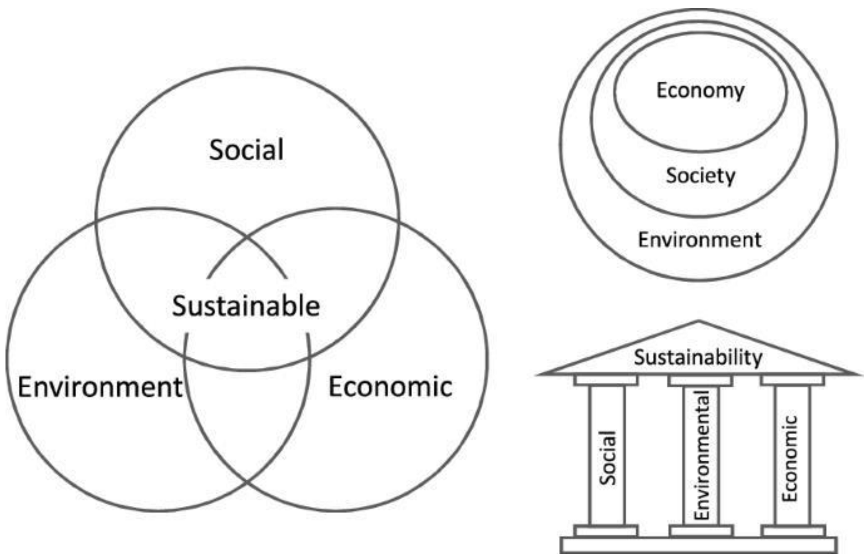

Figure (1): Venn diagram

<u>Source</u>: Boroń, S. (2018). *Will The Real Sustainable Development Please Stand Up-An Introduction*.

The CSD introduced a testbed choice of 130 indicators the following year, with the goal of achieving a "Good set of indicators" by the year 2000. These indicators were classified according to the four aspects provided at a workshop in 1995. (17). Regardless of this, the CSD does not globally employ these 4 dimensions. the 1997 report is written Since Rio is organized on 3 "mutually reinforcing components" of SD "economic growth, social development, and environmental sustainability" (18), but without any analysis of the conflicts for these objectives. In the sixth session report of the CSD, the presence of the three elements was highlighted once again (19).

In 2001, the CSD produced the 2nd version of its signifier framework, which preserves the classification of SD's economic, environmental, institutional, and social "dimensions." (20). The objectives of *"social and institutional progress, environmental integrity, and economic success"* are also mentioned. to emphasize the "multidimensional aspect" of sustainable development, the third edition did not elaborate on the four dimensions explicitly (21).

In 2000 with Parallel to the CSD's efforts, the UN launched **8 millennium development goals (MDGs)** as a new milestone, to be done by the global community by 2015 (22). The MDGs contain eight goals, which are; environmental devastation, poverty, hunger, gender inequality and school issues. During this period, some nations have made substantial progress toward the MDGs, and others have not.

Later, the situation regarding these nations, the objective, and the locations changed. But, for almost fifteen years, the aforementioned aims have been the primary focus of global policymakers' minds (22). Therefore, a new set of aims known as the **Sustainable Development Goals (SDGs)** was introduced, which will be the focus of attention for the upcoming fifteen years.

Figure (2): Sustainable Development Goals (SDGs)

Source: Hák, T., Janoušková, S., & Moldan, B. (2016). Sustainable Development Goals: A need for relevant indicators. *Ecological Indicators*, *60*, 565–573. https://doi.org/10.1016/j.ecolind.2015.08.003.

1.2.3. Sustainability and Sustainable development goals (SDGS)

Member States of the UN adopted "Agenda 2030" in 2015, which is based on the 17 SDGs, with the goal of eradicating poverty, conserving Earth, and ensuring that all humans enjoy peace and security in the present and the future. The 17 goals of the SDGs, of which goals 1–6 correspond to the earlier-introduced Millennium Development Goals (MDGs), while goals 7–17 reflect the brand-new goals that highlight the new sustainability challenges. Each goal contains between 5 - 12 targets, and around 303 indicators are supplied to assess achievement and progress in connection to the goals and targets (23).

The 17 SDGs contain 169 goals that are bigger in scope and more ambitious than the (MDGs) In confronting the origins of poverty and the global need for development that benefits all people. The new global goals seek to address inequalities, economic expansion, good jobs, towns and human settlements, industries, oceans, ecosystems, electricity, climate change, peace, and justice, based on the achievements and momentum of the MDGs.

The SDGs provide an internationally road map for the creation of widespread Economic, social, and environmental principles. The 17 SDGs of the UN target international development concerns and provide a road map for achieving a more equitable and sustainable future. Sustainable development requires providing healthy life and supporting human at all ages (SDG3), making communities inclusive, secure, resilient, and sustainable (SDG 11), combating climate change and its repercussions (SDG13), and putting strain on ecosystems and biodiversity (SDG 15). These goals and objectives also represent the particular concentration.

1.3. Sustainability and Architecture

In 1960s and 1970s, at the beginning of the environmental revolution, deterioration to the natural ecosystem was a great concern. However, according to scientific proof that unsustainable Utilization of natural assets and ever-increasing polluting agents will result in permanent environmental degradation, terms such as sustainable architecture have attracted significant interest.

Approximately around the same time as the phrase sustainable development developed, the term sustainable architecture emerged(24). Sustainable architecture refers to architectural design strategies that are environmentally responsible. In addition, it aims to limit the harmful environmental print of buildings through the moderate and efficient usage of materials, energy, and developing space. The term sustainable architecture is defined as *"The* architecture *that seeks to minimize the negative environmental impact of buildings by efficiency and moderation in the use of materials, energy, and development space. Sustainable architecture uses a conscious approach to energy and ecological conservation in the design of the built environment"* (25). Moreover, architect Norman Robert Foster defines sustainable architecture as *"doing the most with the least means "* (26).

In general, sustainability considers the long-term relationships between human and natural systems. According to Hassan Fathy, a building's shape is influenced by its surroundings, including the local climate and the buildings around it, as well as other factors like social, cultural, and economic factors. Modern architects, according to Fathy, produce innovative and unusual architecture since they are followed to new innovation and ignore about the environment in which their buildings are placed, so failing to accomplish the purpose of 'functionality' in architecture.' In addition, they lose to understand that the form of buildings has meaning apart from in the context of its surroundings (27).

According to Guy and Farmer (2001), sustainable architecture is an approach and an attitude rather than a "prescription". Sustainable architecture in general is now dominated by energy efficiency and climate change techniques that can enhance the economic performance of buildings. The development of sustainable architecture has surged over the past four decades, with significant steps toward a better future for the earth (28).

1.3.1. Principles of the sustainable architecture

Park (1998) hypothesized that the sustainable architecture promotes the use of renewable and natural resources, innovative inventions for energy control, recyclable products and materials and which can be efficiently maintained and regenerated materials. The following are Park's outlines of four key sustainable building design principles:

- By providing sufficient ventilation, you can create a healthy working environment.
- Select "green" building means and techniques, such as the use of local materials.
- Use less energy than the industry guideline for new building systems.
- Have a waste and water recycling plan.
- Besides this, Reynolds (2000) introduces the new architectural principles required for sustainability, as illustrated by the "Hannover Principles," which were created for EXPO 2000 at Hannover, Germany, and include:
- Humanity's and nature's right existing in a healthy and sustainable state;
- Identify the interrelationship between humanity and the natural environment;
- Developing relationships between material and spiritual awareness;

- Take responsibility for design decisions that affect the well-being of human and eco systems;
- Produce secure items with lasting value; ignore the waste concept.
- Depending on the flow of natural energy;
- Identify design boundaries.
- Support architects and local users to communicate directly with each other.

Furthermore, in a study on sustainable building alternatives, (29) added certain points that were quoted from the OECD (Organization for Economic Co-operation and Development) and published in his work. The five principles for sustainable buildings, according to him, are:

1- Resource conservation.
2- Energy conservation (including GHG).
3- Prevention of pollution (considering quality of indoor air and noise reduction).
4- Environmental harmony
5- Systemic and integrative strategies

Numerous further research on sustainable architecture have been done, one of them is AL Mansuri et al. (2008) which provided the following summary of the fundamental concepts of sustainable architecture (30):

- Respecting of the sociocultural values of the user.
- Having to adapt to the climatic variables.
- Energy efficiency.
- Utilization of local materials
- Respect the site location.
- Water Conservation.
- Natural illumination and ventilation.
- The planned use of color.
- Solutions for environmental issues such as noise pollution.

The sustainable movement has seen a significant increase in all fields, especially architecture. This occurred in various aspects of discussions, resulting in many architectural trends aimed at finding a proper architectural solution that ensures human wellbeing as well as the coexistence of all other constituents in the global eco system (31).

- Bioclimatic Architecture.
- Environmental Architecture.
- Energy Conscious Architecture.
- Sustainable Architecture.
- Green Architecture.
- Ecological Architecture.
- Carbon Neutral Architecture.
- Regenerative Architecture.

1.4. Sustainable Architecture Paradigms

A look back over the past one hundred and twenty years demonstrate that the industrialization-related economic and ecological problem had a significant impact on architectural discourse. There have been 5 paradigms with significant influence which have promoted the sustainable architecture and the already built environment since the beginning of the twentieth century.

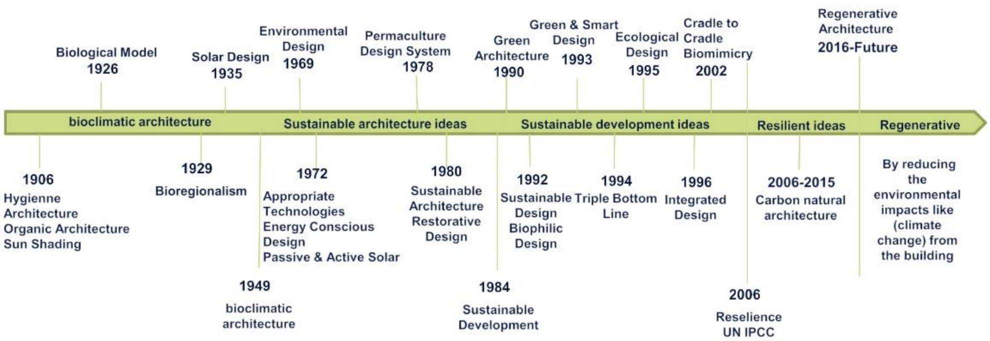

Figure (3): Timeline of contemporary history of sustainable architecture

Source: Djoko Istiadji, A., Hardiman, G., & Satwiko, P. (2018). What is the sustainable method enough for our built environment? *IOP Conference Series: Earth and Environmental Science*, *213*(1). https://doi.org/10.1088/1755-1315/213/1/012016. Designed by the author.

This classification is not rigorous and should not be construed as such; rather, it is a trial of categorization of ideas with the aim of clearer awareness of the progress and connection between the development of the built environment and sustainability (33). Thus, Shady Attia distinguishes seven paradigms for thinking about sustainability.

Table (1): Sustainability Paradigms

Sustainability paradigms influencing architecture in 20th and 21th centurys			
Paradigm	**Period**	**Influencer**	**Paradigm Theme**
Bioclimatic architecture	1908 - 1968	Olgyay, Wright, Neutra	Discovery
Environmental architecture	1969 - 1972	Ian McHarg	Harmony
Energy conscious architecture	1973 - 1983	AIA, Bal comb, ASES, PLEA	Energy efficiency
Sustainable architecture	1984 - 1993	Brundtland, IEA, Feist	Resource efficiency
Green architecture	1993 - 2006	USGBC, Van der Ryn	Neutrality
Ecological architecture	1996 -	Sim Van der Ryn, and Stuart Cowan	Neutrality
Carbon natural architecture	2006 - 2015	UN IPCC, Mazria	Resilience
Regenerative architecture	2016 - Future	Lyle, Braun art, Benyus	Recovery

Source: Shady Attia. (2018). *Shady Attia Regenerative and Positive Impact Architecture Learning from Case Studies*. http://www.springer.com/series/8903.

Bioclimatic Architecture

In 1963 Architect Victor Olgyay (1910 – 1970) defined bioclimatic architecture for the first time in his book "Design with Climate: Bioclimatic Approach to Architectural Regionalism." The main concept of Bioclimatic Architecture is the design of a human-friendly spatial environment while taking climatic conditions, specific site characteristics, and design requirements into consideration.

Because since Industrial Revolution, as well as the principle of function-shape has been marginalized in modern architecture comfort to the usage of technologies that regularly use energy and leave an environmental footprint. (34). from that time, the relation between form and energy was abandoned and an architecture based on technology with high energy consumption was adopted. As a result, there has been a return to environmental values that seek to conserve available resources while also protecting the environment. To use bioclimatic architecture, it is essential to consider the several climatic conditions of the building's site, along with the climate in general, the mesoclimate, and the climate surrounding the building, which is specified by local elements or the microclimate. Include the architectural skin, which necessitates considering the temperature, humidity levels, solar radiation, and albedo, in addition to the wind direction and speed as aspects to take into account when attempting to achieve comfy conditions. Considering the inside factors, it would focus more on thermal comfort and psychological comfort (35). Bioclimatic architectural design is based on passive, vernacular, and smart strategies that can significantly affect the effectiveness of a building with the base of thermal comfort, minimum energy usage, and environmental protection (36).

In architectural design Working on solar radiation control, cooling and heating loads, internal gains management, natural ventilation, and geo-pathology. An ideal building direction that designs the main façade with a south direction and excludes poorly insulated walls and windows on the west side of the residence will reduce energy costs by permitting maximum solar radiation throughout the winter (35).

1.4.1. Environmental Architecture

Environmental architecture is an approach of addressing the surrounding environment in order to design within its constraints. It means to create designs that are in harmony with their surroundings. The first attempt to apply environmental architecture dated back to Ancient Greece's usage of sun heating around 500 B.C, and continued until the Roman era. The discussion of the harm done to nature as a result of progress made in the industrial revolution, late 19th century. As a solution, several architects and researchers, like McHarg (1962), Schumacher (1972), Ron Mace (1972), and others, attempted to design with nature at the interior and urban planning levels to minimize this harmful impact (37).

In 1992 Thomas A. Fisher, proposed the five main principles of an environmentally oriented designs (38):

- **Healthy interior environment:** By using materials and techniques for building that do not emit any toxic gases. In addition, take the necessary measurements to ensure that natural ventilation is used to its maximum potential.
- **Energy efficiency:** By taking all necessary measures and precautions to minimize the amount of energy consumed by the buildings. In addition to the use of advanced technology for HVAC, lighting, heating, and so on, which promotes the energy conservation principle.
- **Ecological building materials:** By utilizing renewable resources. In addition to the use of various environmental materials, which promote the principle of environmental preservation and balance.
- **Building form:** By using of the proper orientation and geometry that could achieve the maximum utilization of building environmental performance. In addition to consider all factors affecting the building design such as site, region, climate...etc. in order to generate a harmony among both the building and the surrounding environment.
- **Good design:** By integrating various design parameters (for example, structure, materials, and atheistic), in order to achieve well-built, convenient, and beautiful living spaces.

1.4.2. Energy Conscious Architecture

Energy Conscious oriented architecture, in its wider definition, is based on achieving an efficient building balance in all aspects related to energy through the Appling of passive solar design techniques, energy saving appliances, and materials, and the usage of renewable energy sources. The first energy crisis, which occurred in the 1970s, coincided with the emergence of the energy conscious architecture movement. Architects and urban planners demonstrated a proclivity for incorporating solar and energy-saving strategies into building design. This movement was based on the use of energy codes and standards developed during this time period to meet the needs of occupants while reducing energy consumption to its bare minimum. The following are the main principles of an Energy Conscious oriented architecture (31):

- **Incorporate solar passive techniques into building design** to reduce loads caused by conventional cooling, heating, ventilation, and lighting systems.
- **Design energy-efficient lighting and HVAC systems** by incorporating energy-saving equipment, control, and operation approaches.
- **Use renewable energy systems**, such as photovoltaic solar or solar water heating technologies, to meet a portion of a building's energy demands while reducing conventional energy consumption.
- **Use efficient materials and construction methods and reduce transportation energy,** by avoiding the usage of higher energy building materials like steel and glass, among others. In addition, to minimize energy consumption, use available construction materials and renewable energy sources.

1.4.3. Sustainable Architecture

Sustainable Architecture brought up many challenges to architecture discourse which resulted from an attempt to include Social and Economic factors side by side to Environmental science facts, responsive techniques, and technologies. These challenges opened the gate to deepen more into sustainability through three main domain (39):

- **Environmental performance of buildings:** The ability to reduce environmental degradation caused by building design, construction, and operation.
- **Socio-economics:** The ability to improve residents' sense of belonging to a specific location in order to make them more loyal to their surroundings and the environment. This is accomplished through the implementation of socioeconomic approaches such as

education, social incentive, economic incentive, and policy formulation.

- **Architectural design:** By allowing residents to have their physical and mental well-being in their built environment in connection with nature.

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) later coined the phrase "Whole Life Sustainability." It broadens the definition of sustainable architecture to include buildings that incorporate local identity into the design process (40). The main fundamentals of sustainability in architecture are:

- **Economy of Resources** (Conservation Principle): It is concerned with reducing usage of nonrenewable natural resources during the construction stages and operation stages of a building. There are three resource-saving strategies: energy, water, and material conservation.
- **"Cradle-to-Grave" Life Cycle Design** (Efficiency Principle): It is concerned with the methodology used to analyses the construction process and its environmental impact.
- **Humane design** (Humanitarian Principle). The most important principle It is concerned with the livability of all global ecosystem constituents. In other words, the interactions between humans and the natural world.

1.4.4. Green Architecture

After the Glass box and the high-rise buildings became the icon of the city, The Green Movement grew as an effective combining of all previous environmentalist movements. Along with many other major challenges such as economic stability, energy depletion, pollution, climate control, and so on. these factors combined to form a grassroots movement in favor of Green Ideology.

Green architecture, *is an approach to building that minimizes harmful effects on human health and the environment.* The "green" architect aims to protect the water, air, and earth by using ecofriendly materials and construction practices (41).

The process of designing a green building begins with a comprehensive knowledge of the site's aesthetics and difficulties. An ecological strategy to design tries to harmonize the proposed mechanisms with the current ecosystem processes of Mother Nature (42). Following are summaries of fundamental principles linked with the 5 fundamental aspects of green sustainable building design: Sustainable Site, Water Management and Quality, Environmental protection, Indoor Air Quality, and Resource Preservation (43):

Water Systems: regarding to Art Ludwig, make an oasis from greywater, just around 6% of the water we consume is drinkable**.** Irrigation and sewage treatment do not require potable water. The Green Building Design program presents rainwater collection systems, grey water infrastructure, as will as living pools (44). the conservation of Water can be achieved During the lifetime of a building by employing systems of dual plumbing that recycle water for toilet flushing and by consuming it for cars washing. Water conserving fixtures, like ultra-lower flush toilets as well as lower flow showerheads, can aid in reducing waste. Bidets reduce the consumption of toilet paper, hence reducing sewage traffic and increasing the potential for on-site water reuse. Point-of-use water heating and treatment improves water as well as energy efficiency while reducing water circulation (45).

Natural Building: At the core of natural buildings is the desire to reduce the environmental effect of building and many other auxiliary technologies without losing comfort and health. For greater sustainability, natural building employs widely existing, renewable, recycled, or reusable materials. The value of using quickly renewable materials is rising. furthermore, the focus is on architectural design employing natural building materials. The building orientation, including the use of regional climate and site characteristics, as well as the design concentrate on natural ventilation minimize operational costs while also having a positive effect on the environment. In today's environmentally conscious building projects, it's popular to integrate renewable energy sources, recycle rainwater, and find other creative ways to treat and reuse wastewater (46).

Passive Solar Design: This kind of design highlights the practice of utilizing the sun's natural heating and cooling rays to regulate indoor temperatures. The building, or a part of it, allows usage of the sun's heat by enabling the material to absorb and radiate it. Passive systems are minimalistic, containing lower moving elements and no mechanical components. They need less maintenance and can lower or eliminate cooling and heating expenses. Solar energy may be utilized to power homes in all climates through including passive solar design elements and lowering carbon emissions (44).

Solar building designed to maintain a comfortable climate in all four seasons while requiring little power. 30 to 40% potential reductions with an extra cost savings 5 to 10% for passive features.

Direction, double-paned windows, thermal energy storage walls, roof paints, ventilation, evaporating, day illumination, building materials, and so on are all important components. Designs are affected by the direction and intensity of the sun and wind, in addition to the surrounding temperature and humidity. Various designs for various climatic regions.

Green Building Materials: it can be chosen based on attributes like recycled and reused material, zero and maybe lower of toxic harmful air emissions, and lower toxicity, quickly and sustainably renewable harvested resources, higher recyclability, durability, and locally manufacture (47).

Living Architecture: As human bodies, the environment capable of metabolizing nutrients and waste. This is the focus of Living Architecture, which incorporates green features into buildings to capture, save, and purify water, clean air, and procedure other nutrients. Additionally, Living Architecture discusses the biophilia, which is the recognized health benefit of interacting with ecosystems in the built environment (48).

Green roofs: perform multiple functions for a building, including consuming rainwater, supplying insulation, generating a natural environment for wildlife, rising benevolence and reducing stress of users in around roof by supplying an aesthetically appealing landscape, and helping to reduce urban average temperatures and heat island impacts mitigation (49).

Green Walls: Planting greenery on the facade of a building, often termed as vertical greenery. in Comparison with green roofs, the green walls can protect increased of exposed hard areas in urban environments where skyscrapers buildings are the dominating architectural style (50).

1.4.5. Ecological Architecture

Sim Van der Ryn and Stuart Cowan defined the Ecological Design as "*any form of design that minimizes environmentally destructive impacts by integrating itself with living processes"* in their book Ecological Design (1996). Ecological design is an integrated ecologically responsible design concept that aids in demonstrating the interconnected relationship between the eco-system and a variety of other fields such as agriculture, engineering, management, urban planning, etc. To express this relationship, the prefix "eco" is used; for example, eco-system, eco-management, etc. (51).

There are five ecological design principles that are based on collaboration between different sectors and disciplines in order to achieve eco-system balance and stability (52):

- **Solutions grow from place:** To design in accordance with detailed understanding of a specific location. To put it differently, the design should identify both local conditions and local human needs.
- **Ecological accounting informs design:** To design in accordance with environmental standards that ensure the stability of the eco-system. This is accomplished by carefully considering all ecological costs/impacts resulting from ecosystem components such as population, resources, and pollution.
- **Design with nature:** To use living systems as a model, metaphor, and unit of measurement for the built environment (Bio-mimicry approach).

- **Everyone is a designer:** To involve different sectors, disciplines, and stakeholders in the design procedure regarding to encourage the underpinning impulse of an open-source movement.
- **Make Nature visible:** Using the biophilia concept developed by Edward Osborne Wilson and Steven Kellert. This is accomplished by integrating the design process with nature in order to be a reflection of it.

1.4.6. Carbon Neutral Architecture

As a result of the recent exponential increase in carbon emissions, also regarding to mitigate climate change, Governments and environmental organizations around the world attempted to limit rather than reduce carbon emissions. This was evident throughout the policies and regulations that were put in place to provide a framework to work within.

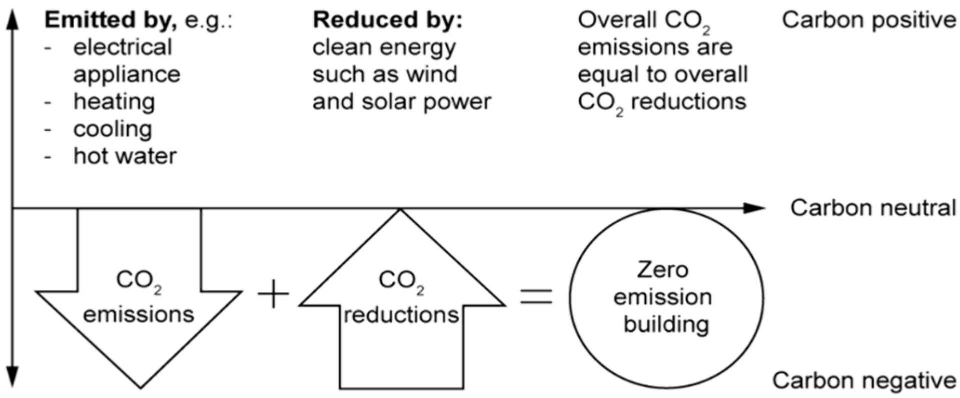

Figure (4): The net carbon footprint

Source: Wang, X., & Ramakrishnan, S. (2021). *Environmental Sustainability in Building Design and Construction*. Springer International Publishing. https://doi.org/10.1007/978-3-030-76231-5.

In a carbon-neutral building, emissions of greenhouse gases are reduced throughout all phases, including manufacture, construction, and use. The emissions that arise are counterbalanced by climate-friendly initiatives, resulting in a **zero**-carbon footprint over time. This can be accomplished, for instance, by installing solar cells on the rooftop or exterior walls to mitigate the building's emissions.

Wood is a carbon storage, there is a correlation between the amount of carbon in wood-based building material and the amount of carbon dioxide absorbed during tree growth. During the lifetime of a building, new forests that capture and absorb carbon dioxide emissions can be grown to replace the wood used in construction.

The Greenest City action plan (GCAP) initiative, based on the work started in 2009 and which would expect to be applied by the year 2020. This action plan consists of ten primary goals which are classified into three main topics: wastes, carbon, and ecosystem. It provides baseline data as well as key strategies for achieving its goals. Having more green buildings that reduce CO_2 emissions is one of the most important key strategies. The ten main goals can be summarized as follow (53):

- Green Ecological Economy.
- Climate Leadership.
- Green buildings.
- Green transportation.
- Zero waste
- Access to nature.
- Lighter footprint.
- Clean water.
- Clean air.
- Local food

1.4.7. Regenerative Architecture

The philosophical and technological foundation for regenerative design originated from the Ecological Sustainability and the contradiction between Technical Architecture and Living System Architecture processes that emerged in the early 20th century (54). However, the term **"Regenerative Development and Design"** first appeared in 1996, by John Tillman Lyle's first exhaustive articulation and handbook *"Regenerative Design for Sustainable Development*". he established the theoretical framework, main principles, and strategies for a regenerative approach that aims to recover environmental damage caused by irresponsible human behavior against their environment (55).

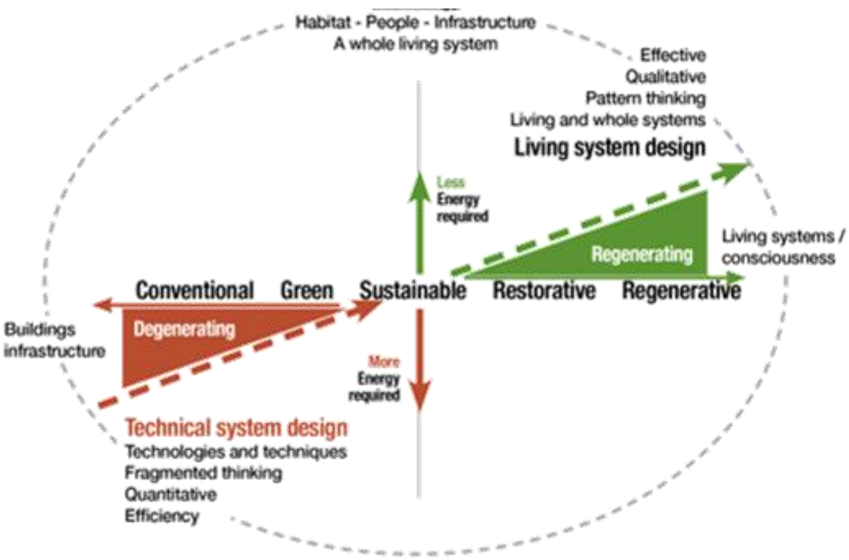

Figure (5): Technical System Design Contrasted to Living System Design

Source: Zingoni De Baro, M. E. (2022). *Cities and Nature Regenerating Cities Reviving Places and Planet*. https://link.springer.com/bookseries/10068.

Regenerative designs aim to promote High-performance buildings that reduce energy consumption and water consumption through the usage of passive and active systems, relying on renewable energy and grey water sources, relying on natural landscapes for storm water management, linking community resources with natural habitats, maintaining productivity while respecting the environment, food, and economy and having a strong sense of place and history.

Regenerative Design principles can be summarized as follow (56):

- **Safe and Healthy Materials:** The safe use of materials, as well as the avoidance of panned and harmful materials, in effort to enhance a positive environmental impact.
- **Material Reuse:** Using used materials to implement life cycle close loop strategies.

- **Renewable Energy and Carbon Management:** Boost the proportion of renewable energy to meet the carbon balance target.
- **Water Stewardship:** To treat water resources as valuable assets by wisely managing these vital resources.
- **Social Fairness:** To ensure that progress toward a sustainable process is made while also providing value to all stakeholders and without harming the environment.

1.5. Climate Change and Greenhouse Gas Emissions (GHG)

It is getting increasingly challenging to ignore climate change's causes and effects around the world. Climate change is primarily taken full responsibility for the reduction in crop production and the aggravation of food insufficiency (57), hence aggravating poverty (58), With increasing disease prevalence (59).

Eventually, Climate change is the greatest barrier to economic progress and growth (60). Agriculture and industrial processes consume the most energy, accounting for 73% of GHGs (61).

In Europe, the building industry and cities are fully responsible for greater than 50% of total GHG emissions. These emissions are primarily attributable to the consumption of heating and cooling (12%) and the manufacturing process of building materials (62). Most of GHG emissions make a progressive deterioration of the GHG effect and an increase in global temperatures (63), with significant implications for urban areas (64). Therefore, climate change is the most important intermediate effect of GHGs (65).

The last six years have been the warmest on record. The hottest years are 2016 and 2020, with temperatures 1.29°C (2.33°F) and 1.27°C (2.29°F) greater than before the industrial era (1850-1900), respectively (223). The temperature rise in Africa has been significantly quicker than the worldwide average (223). According to the Intergovernmental Panel on Climate Change (IPCC), Africa will achieve temperature changes that are 2°C higher than before the industrial level by 2080 (66). Consequently, Africa is estimated to bear the brunt of the effects of climate change.

Carbon dioxide, which is particularly released into atmosphere, is one of the important GHG causing global warming then climate change. CO_2 emissions reached new highs of 36.4 million tons in 2018, accounting for more than 65% GHG emissions(67).

1.5.1. The Linkage Between Climate Change and GHG emission

The level of GHG emissions is influenced by a variety of factors. Globally, Energy production and consumption are responsible for more than 60% of human-caused GHG emissions (68). This includes the use of gasoline for transport, the generation of nonrenewable energy, the production of natural gas and oil, as well as cooling and heating of buildings. As the quantity of GHG in the atmosphere increases, it gets more effective at absorbing infrared radiation and lowering infrared emissions to space, causing the surface and lower atmosphere layers to warm. A rise in GHG concentrations enhances the accumulation of energy in the climate system, causing variations in ocean warming and surface air, variations to the water climate cycles, extraordinary phenomena like: heat waves, heavy precipitation, melting ice, and sea levels rising (69).

This is how meteorological and oceanic data measure the phenomena of global warming, which is often referred to as "Climate Change" to underline that it is not only a concern of rising temperatures but it also changes in other aspects (flow of water, air movement, acidification of the oceans, sea level, extraordinary events).

1.5.2. Climate change and Carbon Emissions: Evidence and Causes

Since prehistory to the late 1700s, humans have existed in an atmosphere containing around 280 parts per million by volume (ppmv) of carbon dioxide. This indicates that one million cubic meters of air has $280m^3$ of CO_2. The use of steam engines after the industrial revolution increased atmospheric CO_2 concentrations, However, the increasing was only around 10 ppm for approximately 100 years following the industrial revolution. From the 1870s through 1970, the atmospheric content of CO_2 rose at an almost consistent pace of 0.28 ppm annually. Industrial development in developed countries continued during this period, which began with the expansion of imperialist and militarization in Asia and Europe, which persisted across 2 world wars and tremendous economic development in developed nations (70).

Since emissions of CO_2 from developed nations were too significant to be handled on the planet and CO_2 concentrated in the atmosphere at an extremely high rate of approximately 1.85 ppm annually, the rate of atmospheric CO_2 concentrations concentration increase has accelerated significantly since 1970 (71). from January 2007 until January 2018 because of the economic development, the annual increase in atmospheric CO_2 concentration is around 2.36 (ppm).

Global carbon emissions will increase to 42.4 metric tons by the end of 2035, representing a 42.7% more over 2007 levels (72). Considering these growing trends, the global community and policymakers have begun to emphasize the importance of reducing carbon emissions in order to face the issues posed by global climate change.

As a result, in December 2015, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement, a new worldwide agreement to address climate change (73). Countries submitted national plans outlining their efforts to handle the challenge of climate change after 2020 as part of the preparation for this agreement. These Intended Nationally Determined Contributions (INDCs) cover a wide range of challenges, including avoiding, adapting to, and dealing with climate change. Nonetheless, minimizing GHG emissions are essential (74).

The Paris Agreement's overarching climate goal is to keep the rise in international average global temperature below 2°C over before industrial levels, and to follow action to reduce temperature rise to 1.5°C above preindustrial levels. Controlling global warming to any levels suggests that the overall quantity of CO_2 that can ever be released into the atmosphere is to finite. Thus, from a geophysical standpoint, global emissions of CO_2 must reach net zero (75).

Figure (6): Sustainable Development Goals (SDGs)

Source: Hák, T., Janoušková, S., & Moldan, B. (2016). Sustainable Development Goals: A need for relevant indicators. *Ecological Indicators*, *60*, 565–573. https://doi.org/10.1016/j.ecolind.2015.08.003.

1.5.3. Carbon Footprint Analysis: Promoting Sustainable Development Agenda

The phrase "Carbon Footprint" is now commonly used in public discussion concerning responsibility and climate change mitigation. The phrase itself is founded on the terminology of Ecological Foot printing (76), carbon footprint is the quantity of GHG emissions connected with human consumption or production that contribute to climate change. As according Haven (2007), the estimation of the carbon footprint of an office chair is a "*life-cycle assessment that took into account materials, manufacture, transport, use, and disposal at every stage of development.*" (77).

In the United Kingdom, Carbon Trust attempted to establish a more widespread knowledge of what a product's carbon footprint is by circulating a proposed methodology for public consultation (78). *"A methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions)".*

"A technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing these to each output product (we [The Carbon Trust] will refer to this as the product's 'carbon footprint')." (78)

It is highlighted that just the inputs, the outputs, and item processes directly related with the product must be incorporated, whereas indirect emissions, like people heading to the factory, should not be taken into account. Lifecycle thinking appears to be one of features of carbon footprint estimations. Carbon Trust and Defra have initiated a uniformity process to create a Publicly Available Specification (PAS) for the LCA methodology used by the Carbon Trust to measure the embodied GHG in products (79).

The Global Footprint Network, an organization that collects annual 'National Footprint Accounts', considers carbon footprint to be a portion of the Ecological Footprint. The term "carbon footprint" is used interchangeably with "fossil fuel footprint" or "demand on CO_2 area" or " CO_2 land". It is defined as *"The demand for biocapacity required to sequester (via photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion"(80).* It includes the biocapacity required to absorb the part of fossil CO_2 that the ocean does not absorb. which is typically that of unharvested forests". But this definition hasn't changed the conventional concept of the carbon footprint as a measuring of CO_2 emission or CO_2 equivalents.

1.5.3.1. Carbon Footprint Definitions

Table (2): Sustainability Paradigms

Source	Definition
BP (2007)	"The carbon footprint is the amount of carbon dioxide emitted due to your daily activities – from washing a load of laundry to driving a carload of kids to school."
British Sky Broadcasting (Sky) (Patel 2006)	The carbon footprint was calculated by "measuring the CO_2 equivalent emissions from its premises, company-owned vehicles, business travel and waste to landfill." (Patel 2006)
Carbon Trust (2007)	"a methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions).

Source	Definition
	"a technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing these to each output product (we [The Carbon Trust] will refer to this as the product's 'carbon footprint')." (CarbonTrust 2007, p.4)
Energetics (2007)	"the full extent of direct and indirect CO_2 emissions caused by your business activities."
ETAP (2007)	"the 'Carbon Footprint' is a measure of the impact human activities have on the environment in terms of the amount of greenhouse gases produced, measured in tonnes of carbon dioxide."
Global Footprint Network (2007)	"The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion." (GFN 2007)
Grub & Ellis (2007)	"A carbon footprint is a measure of the amount of carbon dioxide emitted through the combustion of fossil fuels. In the case of a business organization, it is the amount of CO_2 emitted either directly or indirectly as a result of its everyday operations. It also might reflect the fossil energy represented in a product or commodity reaching market."
Paliamentary Office of Science and Technology (POST 2006)	"A 'carbon footprint' is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product. It is expressed as grams of CO_2 equivalent per kilowatt hour of generation (g CO_2 eq/kWh), which accounts for the different global warming effects of other greenhouse gases."

Source: Pacheco-Torres, R., Roldán, J., Gago, E. J., & Ordóñez, J. (2017). Assessing the relationship between urban planning options and carbon emissions at the use stage of new urbanized areas: A case study in a warm climate location. *Energy and Buildings*, *136*, 73–85. https://doi.org/10.1016/j.enbuild.2016.11.055.

From the available literature and definitions, there is no homogeneity in carbon footprint definitions (81). According to their survey, Wiedmann and Minx (2007) They proposed the definition of 'carbon footprint' as follows: *"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."*(81)

They defined in 2007, carbon footprint It is a calculation of the complete total quantity of CO_2 emissions generated indirectly and directly by an action or more during a product's life cycle.

1.5.3.2. Carbon Footprint by Sector

The building industry is supposed to be one of the primary sources of GHG, where building projects accounting for a significant source emitting

CO_2. Therefore, estimating emissions from construction is essential way to keep emissions at a manageable level. A study by R. Pacheco-Torres measured the construction-related CO_2 emission for a studying case with three floors single-family detached homes. They discovered that foundations and structures account for 39% of the embodied carbon (82). They mentioned that the home's CO_2 emissions were 358.55 kg CO_2 /m^2.

In another study, the effect of CO_2 emissions generated by the energy needed to keep the building at a temperature constant of 19°C in the winter and 25 c in the summer was analyzed. It studied a variety of conditions, Containing of a constant surface area, constant volume, square floor plan, and a variable number of levels. The conclusion was reached that the design stage is the perfect time to implement energy-saving plans (83).

The building industry is a leader in lowering energy consumption with energy-efficient building solutions that effectively lower CO_2 emission. Some countries are enacting new regulations to limit energy use based on building performance. However, the average quantity of energy consumed per capita by buildings in the world has not changed significantly over the last two decades. CO_2 emissions have risen at a rate of about 1% per year since 2010.

In the recent days, Climate change as well as the availability of long-term natural resources became a global concern, Particularly, in cities, where the majority of the global population exists. Cities generate 50% of all global waste, use more than 60% of total natural resources, and generate more than 75% of total GHG emissions. Consequently, the existing paradigm of linear natural capital exploitation is causing a significant environmental footprint, putting a heavy strain on the planet's ecosystems by, among other things like, raising temperatures, increasing the risk of flooding, reducing biodiversity, and increasing pollution rates. This trend was anticipated to last for the coming years, despite the increase of GHGs mitigation and Carbon dioxide (CO_2) reduction activities. In 2020, the Emissions of CO_2 and GHGs decreased by around 6% because of the COVID-19 pandemic (84), this was due to the economic slowdown and travel bans and many other reasons. However, this was only a transitory improvement, as emissions will rise again once the world economy has recovered.

To meet the climate change crisis, countries' attempts to reconstruct their economies after a pandemic must initiate long-term structural adjustments, that modify the path of CO_2 and other GHGs in the atmosphere. These must reshape economies to be more sustainable, healthy, secure, and resilient. Consequently, the current crisis may present a chance for a profound and systemic transformation toward a more sustainable city.

1.5.3.3. Growing material Demand and Green House Gas Emissions

Over the past few decades, since the building industry expanded significantly and is one of the most polluting industries (just behind food production, actually). It generates over 40% of the world's CO_2 (85). With an increased highlight on the emissions from building materials, GHG emissions are typically quantified in kg CO_2 per unit of material used or per m^2 of floor area, regarding to the 100-year Global Warming Potential (GWP100) indicator and data from given manufacturers' Environmental Product Declarations (EPDs) (86). In the recent years, there has been a lot of focus on the importance of using eco-friendly building materials to minimize the building industry's negative effect on the environment. A holistic approach to the choice of sustainable materials should consider the building's life cycle, integrating with the building performance and embodied energy (87). **The extraction of raw materials**, production methods, delivery to the site location, and building procedures **the operational phase**, and **end-of-life recycling** and potential for reuse are all part of a building material's entire life cycle (88). Choosing sustainable building materials is difficult since it necessitates an analysis of the material's embodied impact on the environment throughout its entire life cycle, in addition to its energy performance as part of building operations (89).

CHAPTER 2

GLOBAL NEED FOR LOW CARBON BUILDING INDUSTRY

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2.1. Introduction

In recent years, the issue of climate change has become a pressing concern for the global community. Buildings and cities are major contributors to greenhouse gas emissions, which are responsible for global warming and its associated environmental impacts. Therefore, there is a growing need to reduce the carbon footprint of buildings and cities in order to mitigate the effects of climate change. this chapter provides an introduction to low carbon buildings and cities, and explaining why it is important, highlighting the need to reduce greenhouse gas emissions and tackle climate change.

Then focuses on low carbon materials and their role in reducing the carbon footprint of buildings. by defining the term "low carbon materials" and explaining their importance in reducing the carbon footprint of buildings. also discusses various types of low carbon materials that can be used in building construction, such as recycled materials, natural materials, and low carbon materials.

2.2. Low Carbon Buildings and cities (intro & overview)

Cities generate a great majority between 60 to 80% of world CO_2 emissions. In The Organization for Economic Co-operation and Development (OECD), cities with higher levels of urban growth generate more CO_2 emissions. CO_2 emissions have risen at a rate of about 1% per year since 2010. Moreover, an increase in CO_2 emissions from buildings was achieved by 45% over normal (90). Carbon emissions are expected to raise global temperatures by at least 1.5 ° C or more by 2030–2052(91). As a result, cities all over the world must urgently limit carbon emissions.

In 2015, the Paris Agreement was negotiated, almost all cities have declared low-carbon emission policies. The European Union has set a target of carbon neutrality by 2050 (91). There is a direct relationship between the overall human-caused CO_2 emissions and the amount of warming at the Earth's surface. Furthermore, the moment of a tone of CO_2 emitted has only a minor impact on the quantity of warming it will eventually cause. This tends to mean that CO_2 emissions produced centuries ago contribute further to global warming, and the current rate of warming is measured by the concentrated total of CO_2 emission levels.

Human-caused CO_2 emissions are presently the highest in recorded history. In fact, recent data show that global CO_2 emissions in 2022 were 170 times more than they had been in 1850 (92).

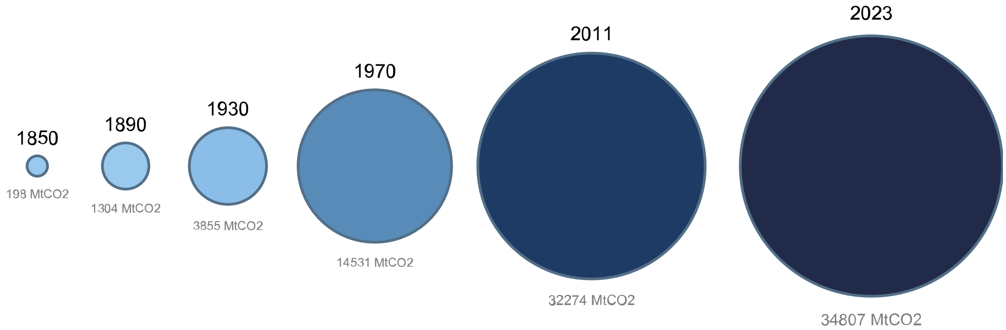

Figure (7): Carbon dioxide emissions caused by human

Source: Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Bakker, D. C. E., Hauck, J., le Quéré, C., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Anthoni, P., Bates, N. R., Becker, M., Bellouin, N., … Zeng, J. (2022). Global Carbon Budget 2021. *Earth System Science Data*, *14*(4), 1917–2005. https://doi.org/10.5194/essd-14-1917-2022.

The concept of the low carbon is derived from national dreams to build low carbon economies and communities that consistently integrate adaptation and mitigation of climate change, allowing response of communities to climate change through efficiently planned and organized buildings. This concept is a common theme in city history, especially in the last few decades (93).

Several works in Europe and America to make cities more ecofriendly and healthier originated from the issues of rapid urbanization. Europe's urban population doubled During the first fifty years of the 19th century, resulting in the progress of slum dwellings, sewage poisoning of urban water supply, and cholera and other disease epidemics. This tends to result in the 1830s Sanitary Reform movement, in which towns were deliberately rebuilt according to sanitary principles to eradicate dirt and disease from quickly expanding and overpopulated cities (94).

In 1850, the UK was the leading CO_2 emitter, with emissions approximately six times higher than the second-highest emitter, the United States (95). France, Germany, and Belgium ranked the top five emitters. In 1898, Ebenezer Howard launched the Garden City movement in the UK In response to filthy and crowded industrialized cities in the late 19th century (96). The core idea was to create a city for healthy lifestyles, with identity communities bordered by greenery of open areas, public parks, and agricultural fields that would assist the city in achieving self-sufficiency. At the same time, the sudden growth in the urban population as a percentage of total population in the US from slightly more than 10% in 1840 to approximately 50% by 1910 caused poverty environmental and social conditions in cities. As a result, the City Beautiful movement introduced a new aesthetic concept to enhance cities by beautification, with a focus on the building projects of parks, and monuments (97).

From 1850 to 1960, global emissions rose steadily due to industrialization and growth of population, especially in the US. This development was only interrupted by historical events including the Great Depression of the 1930s as well as World War II's in 1945. China and Russia's emissions began increasing in the 1950s as their economies grew. Between 1960-2011 While global emissions continued to rise in general, most of industrialized cities established their per capita emissions in the 2nd half of the 20^{th} century. This table highlights some earlier movements that are related to the current concept of carbon conscious cities.

Table (3): Sustainable Movements

year	Movement	Concept	Relevance to carbon conscious
(1840s)	Sanitary reform	Eradication of disease, especially cholera, and removal of filth. Innovations in the removal and disposal of sewage and waste, as well as the delivery of clean water, lead to the development of water and sewage infrastructure.	Physical infrastructure is critical to the operation of a healthy city.
(1898)	Garden City	Recapturing nature in urban planning, which resulted in the New Town movement in the United Kingdom and its colonies, and, as a result, low-density, car-dependent suburbs. New design principles recommend for cities and towns to be surrounded by greenspace, such as gardens, agriculture, and recreation areas. Land uses—commercial, residential, industrial, and so on—are spatially differentiated within the town.	Planning paradigms can significantly change the layout of cities, but they can also have unanticipated consequences.
(1890s)	City Beautiful	City beautification through the building projects of parks, grand boulevards, and monuments, with a focus on street layout and a strong modernist suburban style	Ideas for cities can move around the world and be given different expressions.
(1960s)	Resilience City	the concept of resilience is the ability of a system to absorb external disturbances and reorganize itself on the basis thereof to return to the same function, structure and original identity.	focus on the development of low-carbon infrastructure, energy-efficient systems, and sustainable transportation solutions.
(1990s)	Eco-city	Citizens' and society's well-being can be improved through integrated urban planning and management that takes advantage of the benefits of ecological systems. Designing cities based on ecological principles and keeping them in balance with nature	Fundamentally challenged modernist planning and set out to reshape cities to meet global and local ecological needs such as carbon reduction.

year	Movement	Concept	Relevance to carbon conscious
(1990s)	Sustainable city	Based on ecology, but with a focus on reducing city metabolism, reducing car dependence, and enabling integrated economic and social outcomes	Enabled a framework for reducing energy consumption in order to achieve global and national sustainability goals.
(2000s)	Water sensitive city	Urban water management approach that emphasizes circular design of water systems, such as rainwater harvesting and recycling, green roofs, rain gardens, and bioswales	Water and energy consumption in cities are inextricably linked.
(2000s)	Smart city	A digitally connected city that uses information and communication technologies (e.g., sensors, Internet of Things) to measure, manage, and improve quality of life and urban activity efficiency.	Smart systems make it easier to reduce energy consumption and integrate local solar and wind systems into cities.
(2000s)	Low-carbon city	Separates the urban economy and activities from the use of fossil fuels, focusing on energy efficiency, renewable energy, and green transportation.	Carbon is the main focus that must be addressed
(2000s)	Net-zero carbon city	Goes further than low-carbon city to eliminate all fossil fuels within a larger system boundary and regenerate urban and regional environments with carbon-sequestering landscapes and circular economy approaches.	All of this must be integrated into urban areas.

Source: (Seto, K. C., Churkina, G., Hsu, A., Keller, M., Newman, P. W. G., Qin, B., & Ramaswami, A. (2021). *Annual Review of Environment and Resources From Low-to Net-Zero Carbon Cities: The Next Global Agenda*. https://doi.org/10.1146/annurev-environ-050120.) and edited by the author

As a result, the anthropogenic expansion of GHGs in the atmosphere, such as CO_2, nitrous oxide, and methane, is the main cause of climate change. Rising temperatures, rising seas, Water deficit, desertification, biodiversity loss, and disputes over scarce resources have all posed extraordinary issues and challenges to humanity as a due to climate change (98). Around 70% of international CO_2 emissions are associated with urban zones due to they combine socioeconomic actions that produce emissions relevant to climate change (99), which are projected to rise significantly as estimates show that 68% populated urban areas by 2050 (63).

Since the year 2000, there has been a rapid increase in studies on lowering CO_2 emissions caused by anthropogenic activity, which introduced some definitions in many literatures:

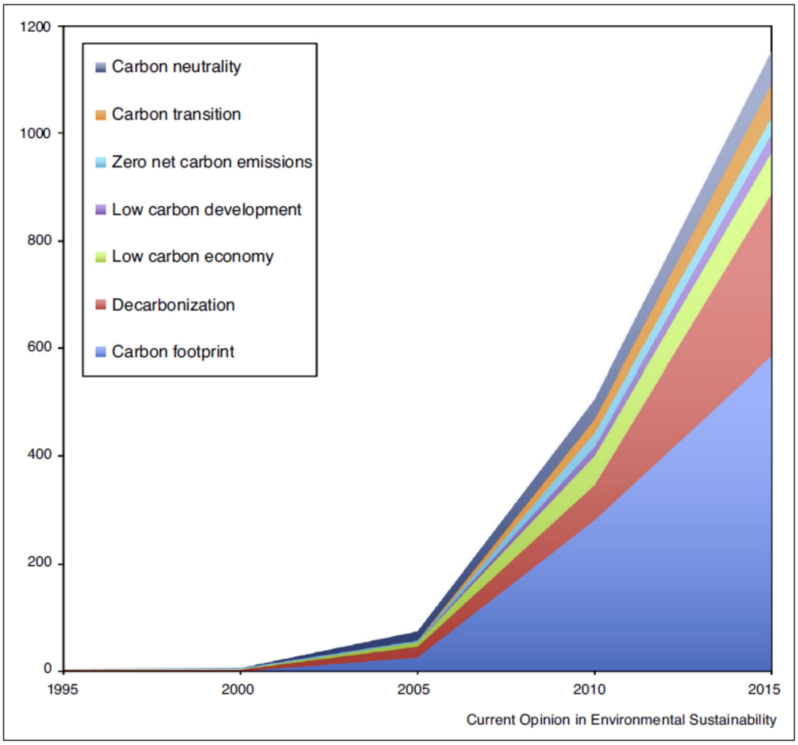

Figure (8): Carbon footprint developments levels in journal publications from 1995-1999 to 2015-2019, by total year.

Source: Hoornweg, D., Freire, M., Lee, M. J., Bhada-Tata, P., & Yuen, B. (2011). *Cities and Climate Change*. The World Bank. https://doi.org/10.1596/978-0-8213-8493-0.

- **The Decarbonization** is the operation whereby the energy production and local economies have been less dependent on CO_2 -emitting fossil fuels (100). **Deep decarbonization** necessitates dramatical reductions in CO_2 emissions and significant reforms in certain economic sectors.
- **The low carbon economy** is the result of a decarbonization operation, and it was officially identified by the UK government in 2003 (101). It originally identified as the best scenario for lowering local CO_2 emissions to a low rate, this definition continues to be used

today. It is rarely mentioned how 'low' emissions must become, then a much more formal definition, an economy which the GHG emissions are "decoupled" from economic expansion, indicates that emissions will drop dramatically to zero.

- **A carbon transition** is a development path that involves shifting from largest to smallest emissions of carbon. It starts with the Carbon Peak that ends by zero carbon emissions. Although it is similar to decarbonization, it integrates the reduction of CO_2 emissions Relying to social evolution which has a more specific conclusion.

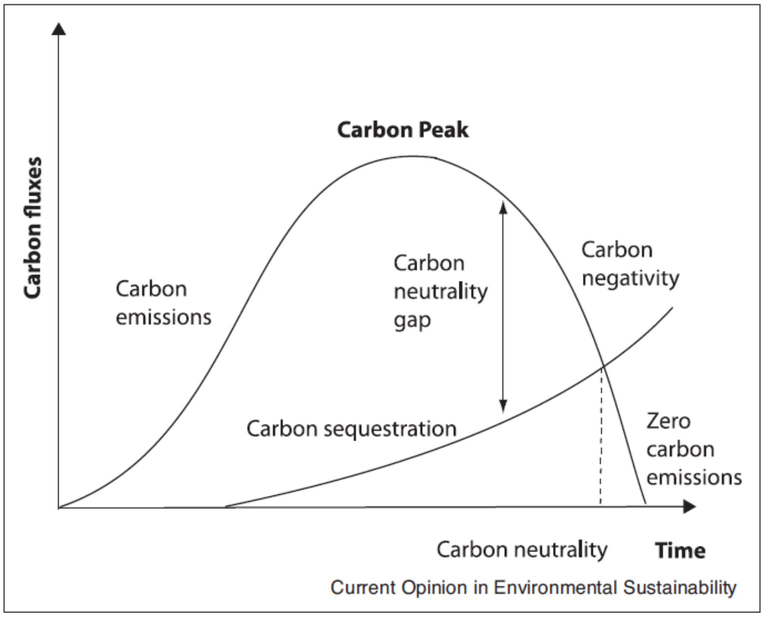

Figure (9): The carbon neutrality resulting from intersection of the carbon transition curve with the carbon sequestration curve. The carbon transition starts with the Carbon Peak and concludes with zero carbon emissions.

Source: Grainger, A., & Smith, G. (2021). The role of low carbon and high carbon materials in carbon neutrality science and carbon economics. *Current Opinion in Environmental Sustainability*, *49*, 164–189. https://doi.org/10.1016/j.cosust.2021.06.006.

In 1997, a general-purpose local carbon transition curve was presented to illustrate how nations adjust to increased CO_2 emissions over time, as their primary energy source is wood and later fossil fuels to starting to fall emissions as they highly depend on renewable sources of energy (102).

- **Low carbon development** is an equal to "development pathway that can accomplish social and economic progress while addressing climate change" It is especially crucial for middle- and low countries, which confront difficulties in lowering CO_2 emissions but might "leapfrog" the vast usage fossil fuels by becoming little dependent on the fuelwood, which still represents for 50% of entire global wood production (103).

  Carbon neutrality When CO_2 emissions enter the atmosphere are counterbalanced by CO_2 captures from the atmosphere, carbon neutrality is achieved. Which is a less specific target than zero carbon emissions, but it is easier to count on a global scale. It integrates environmental (earth's atmosphere) degradation control and terrestrial restoration, similar to the UN SDG of neutral to land degradation. A project reaches carbon neutrality just when its carbon transition curve intersects its carbon sequestration curve, resulting in a zero-carbon neutrality gap between the two curves. Also, greater "negative emissions" result in carbon negativity, that can minimize concentration of CO_2 in atmosphere to the point where the warming impact is no longer a challenge. The carbon neutrality concept is started when humans purchased carbon offsets to balance their emissions (104). It was adopted by communities and organizations before expanding to the national scale.

There are three requirements for reaching carbon neutrality:

1- Reduce CO_2 emissions while manufacturing and using materials and energy sources in order to speed up emission peaking and the carbon transition.

2- Increase CO_2 removals.

3- CO_2 removals is used to offset carbon dioxide emissions.

- **Zero carbon building** employs an adequate amount of renewable energy sources that are carbon-free all year long to power all household energy needs (Lifestyle-appropriate home operations and appliances). Connection to the grid is mainly for the purpose of supplying energy that is in excess of household needs, as well as for emergency supply during periods when local energy grids can be down.

- **Low Carbon Buildings** are buildings that do not consume CO_2 -emitting energy throughout the span of an entire year. These buildings called carbon neutral or carbon positive, as they produce sufficient CO_2 -free energy to power themselves.
- **Carbon footprint** This approach is based on life cycle analysis and relates to the mass of CO_2 or all GHG emitted "directly or indirectly by an action or concentrated over the life phases of a project." Carbon footprint (CF) is calculated differently by ecological footprint index, and it includes CO_2 emissions from all energy sources and many other actions (105).

As a consequence, buildings are at the core of any work to control climate change and achieve SD. This needs extensive changes in building design and operation, land use patterns, production and consumption of energy, transportation systems, and the infrastructure and techniques that support everyday life, such as water and waste (106). building industry considered as world's main contributors to GHG emissions, accounting for an estimated 39% of emissions in 2017(107). The use of operational energy has decreased as building efficiency increases and the use of renewable energy has increased. embodied carbon on which architects have the greatest influence has remained relatively stable.

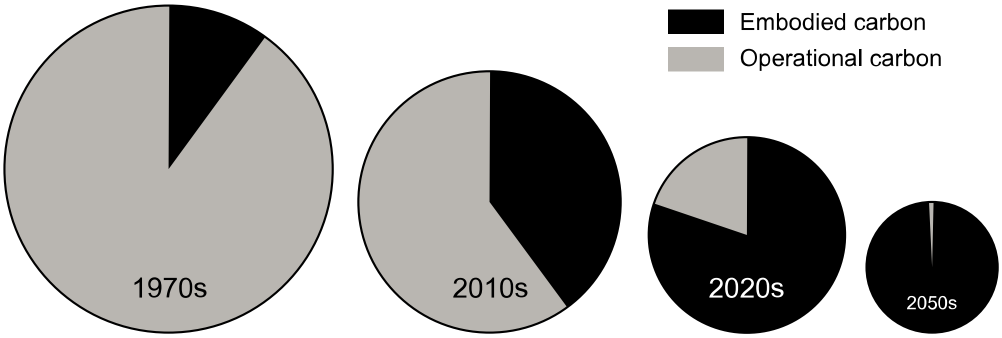

Figure (10): Share of embodied and operational energy in UK buildings, with size of pie representing total energy

Source: Orr, J., Drewniok, M. P., Walker, I., Ibell, T., Copping, A., & Emmitt, S. (2019). Minimising energy in construction: Practitioners' views on material efficiency. *Resources, Conservation and Recycling*, *140*, 125–136. https://doi.org/10.1016/j.resconrec.2018.09.015.

For example, in the UK to achieve its legal obligation to be zero carbon by 2050, it is clear that the carbon emissions from buildings must be minimized. The Royal Institute of British Architects has set embodied carbon minimization goals for the built environment of 50–70% by 2030.

Building Whole life carbon = Operational carbon + Embodied carbon

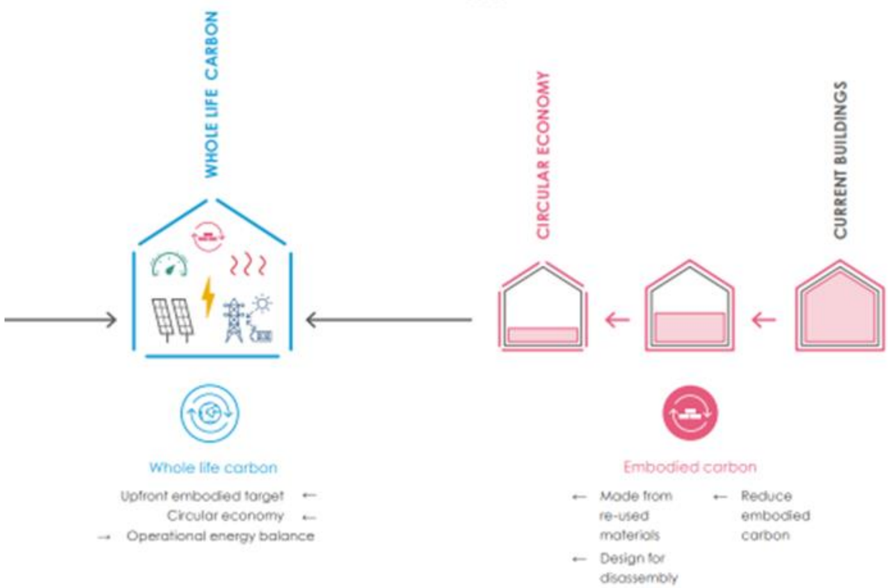

Figure (11): Building whole life carbon

Source: *Sustainability and Net Zero Design Guide-Sustainability Annex*. (2022).

The Life Cycle Analysis of building analyses its environmental effects from its origin in the natural resource assets to its disposal or recycling as waste in the environmental sinks (108).

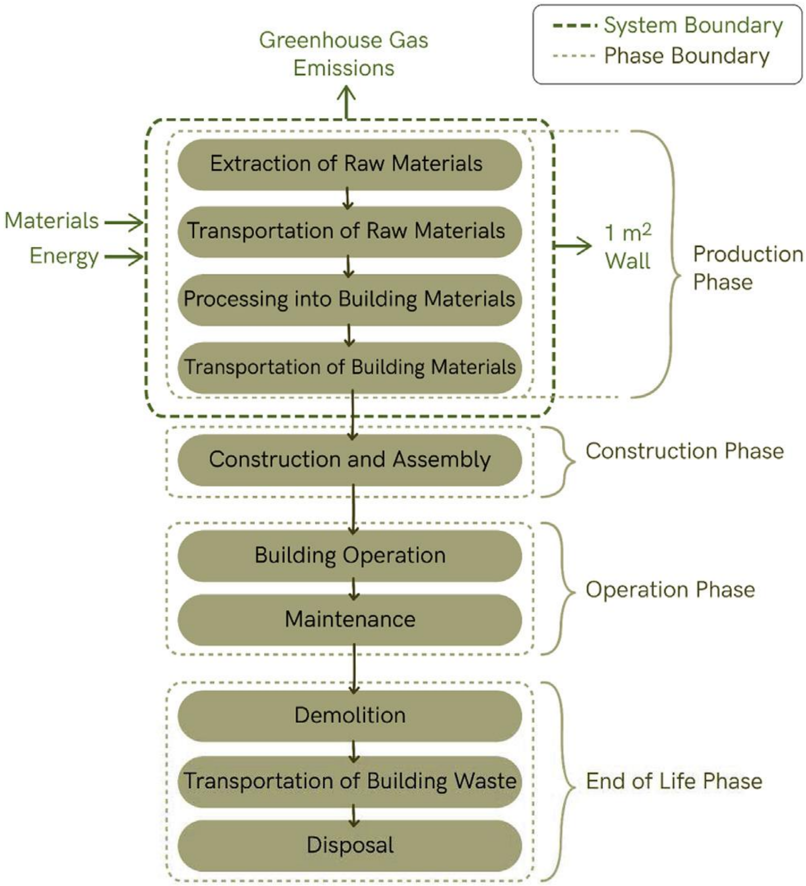

Figure (12): Building life phases

Source: Akadiri, P. O., Chinyio, E. A., & Olomolaiye, P. O. (2012). Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector. *Buildings*, *2*(2), 126–152. https://doi.org/10.3390/buildings2020126.

Materials used in building projects are established through a manufacture process that includes raw natural material extraction, raw material processing, melting, manufacturing to end products, and transportation to sites. Evey step consume energy, which is also reflected in carbon emissions. The entire carbon emissions of all building materials and the construction required to combine them together, are referred to as the building's embodied carbon. Embodied carbon represents for approximately 20% of carbon emissions from the building industry (109).

2.3. Low Carbon Materials for Low Carbon Buildings

A building's lifespan is divided into several phase es, starting by the extraction process of raw materials and ending with the destruction at the end of the building's life. Each one of these phases emits a different amount of carbon into the environment. There are tools available to measure these phases, which include manufacture, construction, usage, and end of life. For the building to be definitely low carbon, all of these phases must be assumed in the overall carbon calculations. These phases are defined by life cycle assessment tools such as Tally (110) as follows:

1- The ‘Production’ phase includes, supplying raw material, manufacturing, and transportation.

2- The ‘Construction’ phase includes transportation and the construction installation process.

3- The ‘Use’ phase like maintenance, repair, replacement, operational energy, and operational water.

4- The ‘End of life’ phase includes demolition, transportation, waste processing, disposal, recovery, reuse, and recycling potential.

From beginning to end, all of these aspects of a building contribute to its carbon footprint. Therefore, to reach a holistic low carbon building, all of these stages and processes must be included in CO_2 emissions from the building. Reducing the carbon footprint of any of these stages may have architectural impacts for the building itself, depending on how and where the materials are harvested, the energy demand and energy source of a building, and whether the materials have the potential to be recycled after demolition. The use stage is usually the most carbon-intensive stage of the life of the building. This is due to the building's use of fossil fuels as an energy source, and it is also the most time-consuming stage of a building's life when considering how many years a building is typically in service. As a result, many current carbon policies only include the use stage and exclude the productions, constructions, and end-of-life phases.

The 2030 Challenge is an example of this it defines carbon neutral as operating without the use of any fossil fuel or greenhouse gas emitting fuel. The graph below (Figure 13) illustrates the 2030 definition of carbon neutral design as provided by the 2030 Challenge. While that is a good goal to achieve, it does not account for all aspects of carbon emissions associated with a building.

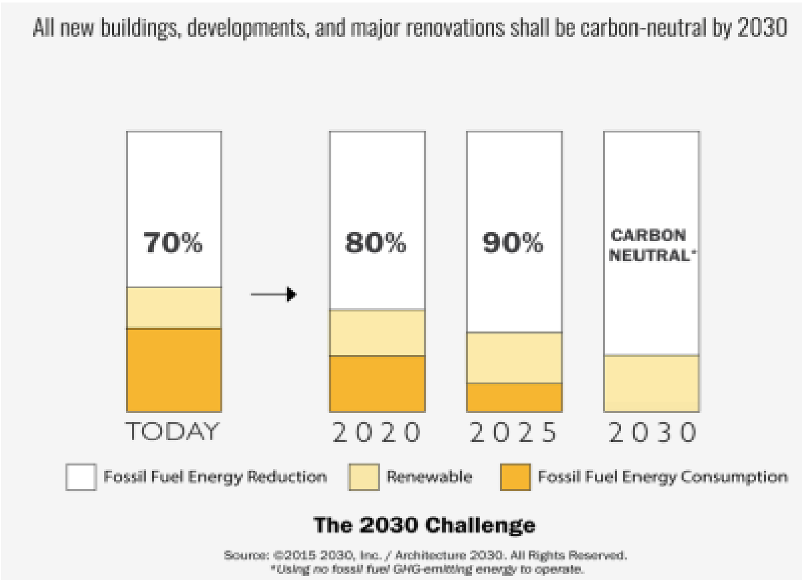

Figure (13): The 2030 challenge

Source: Study of Zero-Carbon architecture for a Business Centre M. ARCH (EXE) (Master of Architecture) (Executive) School of Planning Architecture and Design Excellence (2022).

There are lots of examples of carbon-counting policies that currently just account for the operational phase of a building's life. These include Canada's ZCB (Zero Carbon Building) policy and the United Kingdom's Zero Carbon Hub. The ZCB program is the only one and the first in North America. The quote from the Canada Green Building Council website describes their commitment to carbon efficiency, with the goal of reducing carbon emissions through architecture. This new standard is North America's only one that includes carbon as its primary performance measure. This emphasizes the importance of energy efficiency while also prompting us to consider the types of energy we use and support more renewable energy generation both on and off the building sites." (111).

2.3.1. Low-carbon building materials classifications

It is difficult to find a clear and straightforward classification for low-carbon building materials. However, some initiatives helped to understand and organize these materials, such as: London Energy Transformation Initiative (LETI) which highlights on low-carbon alternatives for two primary categories of project:

- small domestic
- medium/large residential and commercial.

Small domestic: Small-scale project construction is frequently characterized by using of mass concrete footings, brick and block walls, and wood joist floors, with the occasional steel beam or moment frame thrown in for good measure. Figure (14) shows a comparison between these traditional materials with alternatives., with descriptions of each alternative provided in Table (4) and discussed below.

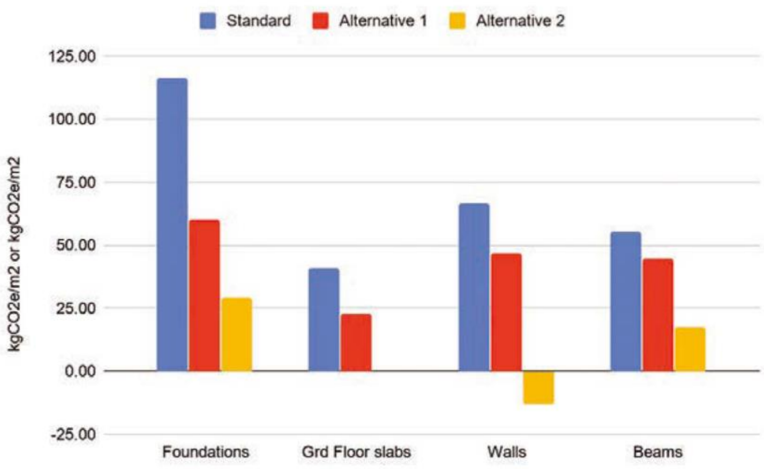

Figure (14): Embodied carbon calculations for options presented in Table (4)

Source: Pan, W., & Teng, Y. (2021). A systematic investigation into the methodological variables of embodied carbon assessment of buildings. *Renewable and Sustainable Energy Reviews, 141*, 110840. https://doi.org/10.1016/j.rser.2021.110840.

Embodied carbon measures are almost totally taken from version 3 of the ICE database, which covers stages A1–A3(112).

Table (4): Embodied carbon for standard construction materials and lower-carbon alternatives (small scale)

	Standard building materials	**Alternative 1**	**Alternative 2**
Foundations	Concrete trench foundations (0.45m wide × 1m deep trench)	Screw piles with concrete ground beams (4m long, 0.3m helix screw piles at 2m centres with 0.3m × 0.3m ground beam)	Stone trench foundations (0.45 m wide × 1m deep rubble trench with 0.2m × 0.45m ground beam)
Ground-floor slabs	Ground-bearing slabs (200mm compacted fill with 150mm concrete)	Suspended timber floor not recycled at end of life (150 × 47mm joists at 400mm centres, sleeper walls ignored for purpose of comparison, 15mm plywood decking and 50mm blinding to underside)	
Walls	Cavity walls (100mm aggregate blocks with standard bricks, rockwool insulation)	Timber frame with standard insulation and timber cladding (145 × 47mm studs at 400mm centres, 15mm OSB each side, 20mm brick slips, rockwool insulation)	Timber frame with IsoHemp blocks and lime render (assumed 300 × 47mm studs at 400mm centres with 300mm IsoHemp blocks) (NB Fig. 2 includes effects of sequestration)
Beams	UC 203 × 203 × 52*	UB 254 × 146 × 37	350mm deep × 230mm wide* glulam beam not recycled at end of life

Source: Pan, W., & Teng, Y. (2021). A systematic investigation into the methodological variables of embodied carbon assessment of buildings. *Renewable and Sustainable Energy Reviews*, *141*, 110840. https://doi.org/10.1016/j.rser.2021.110840.

Medium/large residential and commercial: Issues encountered on larger-scale projects differ from those encountered on smaller-scale projects. One such example is the greater role that lateral stability plays, in addition to other issues including procurement, construction speed, and robustness considerations. While numerous of the choices mentioned in the Small domestic section are applicable on a larger scale, there are many other alternatives solutions that can be considered Table (5). Figure (15) shows a graphical comparison of the embodied carbon of these.

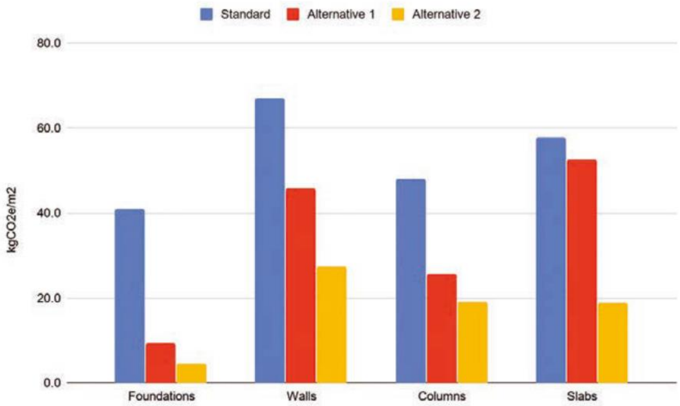

Figure (15): Embodied carbon calculations for options presented in Table (5)

Source: Pan, W., & Teng, Y. (2021). A systematic investigation into the methodological variables of embodied carbon assessment of buildings. *Renewable and Sustainable Energy Reviews*, *141*, 110840. https://doi.org/10.1016/j.rser.2021.110840.

Table (5): Embodied carbon for standard construction materials and lower carbon alternatives (medium scale)

	Standard building materials	Alternative 1	Alternative 2
Foundations	Concrete piles (450mm diameter)	Timber piles not recycled at end of life (250mm square piles, top 2m concrete)	Vibro stone columns (700mm diameter columns)
Columns	Concrete or steel columns (300 mm square, 2% reinforcement or UC 203 × 203 × 46)	Glulam columns not recycled at end of life (350mm square, buckling length 3m)	Limestone columns (275mm square)
walls	Cavity walls (100mm aggregate blocks with standard bricks, 140mm rockwool insulation)	CLT (100mm CLT panel, 140mm rockwool	SIP walls (172mm panels, expanded polystyrene

	Standard building materials	Alternative 1	Alternative 2
		insulation, brick slips)	insulation and brick slips outside)
Floors	Concrete slab (200mm thick slab, 80kg/m3 reinforcement)	CLT (170mm thick CLT panel, 60mm wet screed)	Steel beams with timber joists not recycled at end of life (45 × 240mm LVL joists at 400mm centres spanning to UB 254 × 102 × 28 primaries, 15mm plywood decking)

Source: Pan, W., & Teng, Y. (2021). A systematic investigation into the methodological variables of embodied carbon assessment of buildings. *Renewable and Sustainable Energy Reviews, 141*, 110840. https://doi.org/10.1016/j.rser.2021.110840.

Benchmarking requires the creation of databases in order to truly influence footprint building, and databases have been created all over the world in response to this need. The Inventory of Carbon and Energy (ICE) by the University of Bath, the Construction Carbon Index (CCI) by the University of Singapore, and the U.S. Life Cycle Inventory are three main examples of these databases that aid in the determination of embodied carbon produced over the life cycle process for a specified product (113) It must be mentioned that ICE and CCI were founded before there were no product category regulations, which means that there may be some misunderstanding and irregularity in product comparisons because the assessment boundaries were variable now at moment (113). also, it is worth mentioning that the Carbon Trust in the United Kingdom introduced the world's first carbon label in 2006. While much progress has been made in the field of carbon accounting, there is indeed a long gap in terms of accuracy, interaction comparison, and the use of carbon labels for decision making.

2.3.2. Examples of Low Carbon Building Materials and Technologies

Low carbon building materials can be derived from materials that have low embodied carbon and energy in the manufacturing, assembly, and transportation. these materials are interpreted differently in different contexts due to the broad definition. Metal products, for example, are considered higher embodied carbon materials due to the carbon-intensive extraction and refining processes involved. on the other hand, Recycled products from metal utilized in new buildings, can be called as low carbon.

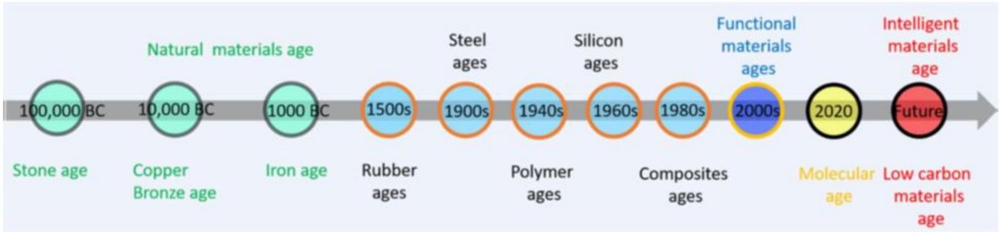

Figure (16): The main materials timeline

Source: Korkmaz, S., Erten, D., Syal, M., & Potbhare, V. (n.d.). *A Review of Green Building Movement Timelines in Developed and Developing Countries to Build an International Adoption Framework*.

These kinds of materials have been the focus of studies and innovation. This has concluded in several innovative buildings materials made from products and recycled materials. Following are many examples of currently developed low carbon materials and products:

1- **Low carbon bricks:** Since 2009, These have been implemented and rolled out for mass manufacturing. The usage of 40% from fly ash helps to minimize the CO_2 emissions from traditional bricks (115).

2- **Green concrete:** Traditional concrete's raw materials can be replaced by industrial leftovers and recyclable materials. for example, Using fly ash and granulated blast furnace slag in place of carbon-intensive Portland cement. Washed copper slag can be utilized in place of aggregate or sand, and recycled granite from a demolished debris can be utilized in place of granite.

3- **Green tiles:** These ceramic materials composed of more than 55% recycled glasses and many minerals. The products convert waste glasses to tiles that can be used for indoor and outdoor tiling and cladding in buildings. The reflective recycled glass components impart an attractive character to the products.

4- **Recycled metals:** Metal product manufacturing is a extremely carbon intensive process. The life cycle effectiveness of metal products, on the other hand, can substantially minimize their consumption of energy for production, such as, by 95% for aluminium, 80% for lead, 75% for zinc, and 70% for copper. This is due to the fact that metals that have been recycled multiple times can still retain their characteristics (116). Other methods of reusing metal without going through the full recycling solution (includes remelting the old metal and remolding them into new one) include reusing current metal structural components, like steel from columns and beams, that still have structural performance. Eventually, metal products unrelated to building projects, such as containers of shipping, can be reused in building projects.

As interest in low carbon building concepts has increased, a lot of organizations have established codes, rating systems and standards, that support government regulators, professional building, and users to confidently embrace green building.

2.4. CO_2 Emissions of Low Carbon Building Materials and Building Life Cycle

Building materials account for 20% from total energy consumption in the building life cycle regarding to Adalbert's survey in Sweden (117). Materials preparation is the 2nd largest source of total life cycle of carbon emissions. This also clearly demonstrates that building materials have high carbon implications, and calculating their carbon emissions is essential. Even so, the building's characteristics are unique, as are the used materials and the construction techniques. To approximate the carbon emissions in the embodied phase of a building, the calculation range and method must be defined. The carbon emission factor technique is used to measure the carbon dioxide emission model in the materialisation phase, due to the theoretical basis of the mass of the inputs and the mass of the output, in accordance with the law of conservation of mass (114). In the embodied phase, the carbon emission factor technique can be used to build the carbon dioxide emission model. The basic formula is as follows:

Carbon emissions = Carbon emission factor x Carbon source consumption

On the opposite, related to the building life cycle the measurement of carbon emissions is extremely complicated. The Life Cycle Assessment (LCA) method is mainly used to measure a product's carbon emissions over its complete lifecycle, including raw materials, manufacturing, usage, and demolition. The building materials have higher carbon emissions, with indirect carbon emissions accounting for more than 92% (114). In 2008 research by Sharrard created a hierarchical LCA model to measure the energy consumption and environmental effect of the building industry in the US. This Input Output Life Cycle Assessment (IO-LCA) measures the environmental impact of the materials, and this analysis method is used to measure the environmental effect of the construction phase (118).

Estimating carbon emission in the embodied phase is a challenging task. Different techniques should be used to measure emissions based on the characteristics of each phase, which is both scientific and practical. However, in order to calculate carbon emissions in this phase, the scope of this phase must First, be defined regarding to the division of the building total life cycle. Second, the carbon emissions are measured separately based on the contents of this phase. The carbon emissions of the building materials are measured by using the **material balance** technique during the material production and transportation phases, and the entire carbon emissions are calculated by calculating the corresponding emission factors and carbon source consumption (114). The direct carbon emissions are lower during the design and preparation stages, but the design strategy and efficiency have a significant effect on the carbon emissions of the building over its complete lifecycle. A low carbon level framework should be developed to significantly minimize the carbon emissions of the building's life cycle through layer efficiency.

2.5. Meeting Global Needs with Low Carbon Materials

Global warming and climate change are caused by the release of GHG. Carbon dioxide (CO_2) accounts for 72% of entire greenhouse gas emissions, followed by methane (18%) then nitrous oxide (9%). therefore, the CO_2 emissions are the primary cause of climate change challenge. CO_2 emissions have increased dramatically over the last 50 years and will continue to increase at a rate of nearly 3% each year. The concept of low carbon emission green building is proposed on the assumption that everyone on the planet is taking action to deal with climate change.

The building industry is the biggest consumer of materials and energy globally(119). As a consequence, buildings are accountable for 19% of the total of GHG emissions (120). CO_2 concentration in the air was 270 parts per million at the starting of the industrial revolution. this is concentration, which had already reached 377 parts per million, is extraordinary not just in the last 740 thousand years, but possibly even in the last 55 million years (121).

There are 2 major causes of climate change: a natural causes caused by changes in the sun's orbit and the parameters of Earth's orbit, and human-caused causes, the biggest significant of which is extreme greenhouse gas emissions from human activities (122). According to recent research, buildings provide the significant abatement opportunities for minimizing GHG emissions in the short term.

Policymakers have responded by enacting regulations that require developments in building material and performance, as the European Union's (EU) Energy efficiency of Buildings Directive. These rules have clearly highlighted the operational GHG emissions related to energy use in actions like heating spaces, cooling, and lighting. but even so. These rules drivers, have not accomplished to the embodied carbon related to the initial production of buildings. The United Nations Framework Convention on Climate Change (UNFCCC) stakeholders have decided to agree to "stabilise GHG concentrations in the atmospheric air at a level which would help avoiding harmful anthropogenic impacts on the climate system" (123).

Mitigation of climate change refers to reducing the amount of future climate change (124). The IPPCC defines the mitigation as actions that reduce GHG emissions or increase the amount of carbon sinks that remove GHGs from the air (125). The challenges affiliated with global warming and climate change push us toward more sustainable architectural concepts like low carbon green buildings. These challenges affect not only our environment, but also our social and economic lives. Therefore, global actions to reduce these emissions are necessary, especially in the building sector, where opportunities abound.

CHAPTER 3

LOW CARBON MATERIALS STRATEGIES AND GREEN BUILDINGS INDUSTRY

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3.1. Introduction

The use of low carbon building materials strategies in the green building industry is becoming increasingly important due to the urgent need to reduce carbon emissions and mitigate the effects of climate change. The construction sector is responsible for a significant portion of global greenhouse gas emissions, primarily through the use of energy-intensive materials such as concrete and steel.

To address this issue, the green building industry has developed various strategies to reduce the carbon footprint of buildings. One such strategy is the use of low carbon building materials, which include materials that are produced using less energy, have a lower embodied carbon, or are made from renewable resources. these materials not only have a lower carbon footprint but can also provide additional benefits such as improved insulation and reduced energy consumption.

Overall, the use of low carbon building materials and strategies in the green building industry is a critical component of efforts to address climate change and reduce carbon emissions. While there are challenges to be overcome, the growing support for sustainable construction practices and the increasing availability of green materials suggest a bright future for the industry.

3.2. Green Buildings Industry and carbon emissions

Green building is the procedure of improving the building operation to reduce harmful effects on the environment and the occupants. This does not stop when the construction is completed, but also Proper architecture and implementation can help a building identify as green while it is in use and even after it is demolished (126).

The procedure of building projects from a simple family home to the largest structure megaproject can have a variety of environmental impacts, including:

1- Direct destruction of natural ecosystem as a result of logging, mining, and many strategies of extracting natural raw materials

2- Building material production methods involve waste, water, and air pollution, as well as substantial energy consumption, with various estimates from 5% - 8% of worldwide CO_2 emissions attributable to cement manufacturing only.

3- Runoff and erosion from sites of constructions that can harm surrounding plant life and waterways

4- Air pollution is caused by utilization of robust equipment powered by engines that produce emissions such as diesel or gasoline.

5- CO_2 emissions are high When materials and machinery are transferred across great distances.

6- Spills and many incidents that cause environmental pollution, air, or water with such toxic chemicals

These challenges have the potential to endanger the end result of every component of the supply chain. According to this paper (127) The hundreds of environmentally friendly building methods can be divided into some major categories like:

1- **Energy efficiency:** Buildings made with green and environmentally friendly techniques require less power to build and operate. Layout changes, insulation layers, land placement, and alignment, and even exterior material colour can all enhance energy efficiency.

2- **Waste reduction:** With better managing, building the new structures can produce almost no waste at all.

3- **Low-impact building materials:** On the site reducing waste instructions combined with the usage of building materials that generate fewer wastes during production dramatically minimizes the environmental effect of building projects. Many of these materials are common (like dimensional timber for framing) made to narrower specifications.

4- **Indoor air quality:** Smart choice of materials will not only minimize waste and enhance project profit margins, but will also provide other benefits. Indoor finishing materials that emit few to no volatile organic compounds (VOCs) create more healthy environments for their occupants.

5- **Site impact:** It is possible to optimize structure orientation on the site to take benefit of sun light and passive cooling and heating and hence reducing energy consumption. Proper raw land placement and preparation also decreases the possibility of erosion, water destruction to the structure's foundation, and other issues. Careful positioning that preserves existing current trees not only benefits the local environment, but it can also keep the building temperature cooler due to the shading.

6- **Water use:** green building techniques can help to minimize waste of water and control surplus water outside building. Buildings consume 14% of all consumed drinkable water worldwide, but a few changes can make a significant shifting in conserving potable water for uses besides flushing and washing.

Embodied carbon is caused by carbon released into the atmosphere as a result of human activity from non - renewable energy sources and other natural resources. Embodied carbon is analysed on a life cycle core, considering emissions that occur at all phases along the supply chain. In descending order of impact, the following are the primary sources of carbon emissions:

- Incineration of fossil fuels (like: coal, gas) in the materials productions, and extraction emissions for any of those fuels.

- Fossil fuels used to generate electric power or other forms of energy needed for the materials productions, and the total life cycle extraction emissions from those fuels
- CO_2 emissions from the chemical reactions in the production of cement, iron, and aluminium, for example
- CO_2 emissions from the combustion of fossil fuels in transportation as well as site equipment, and the total life cycle extraction emissions for those fuels
- CO_2 emissions produced during the ending life handling of materials, such as the combustion of plastic products or the transformation of wood to methane at landfills
- CO_2 emissions from forestry degradation and soil carbon release
- CO_2 emissions caused by refrigerant leaks
- Embodied carbon reduction measures have an impact on the previous stated procedures, either directly and indirectly, in order to reduce emissions in the building industry. such as, prohibiting the disposal of woods and many biogenic materials in landfills would minimise the emissions of CO_2 from organic matter decomposition, in addition alternative procedures techniques used had lower carbon effects.

3.3. Strategies for Using Low Carbon Materials in Building Industry

The Intergovernmental Panel on Climate Change has defined buildings as the sector with the highest opportunity for carbon reductions, due in part to the substantial economic benefits that result from improved building performance (125). A quarter of the building’s climate challenge is attributed to the manufacturing of building materials and building works, which cause for 10% of international energy-related GHG emissions (128). Along with the rise emissions that arise from the manufacturing process and the widely consuming of these materials, the manufacturing of steel and cement accounts for the majority of these emissions. Also, Aluminum, glass, and insulation materials all emit significant amounts of carbon (129).

CO_2 emission still is a blind spot in building emission reduction strategies. So, it is a must reconsider how to build our buildings in order to reduce CO_2 emissions. Strategies vary from building less with better designs that endure longer, use little material, or low carbon materials. To minimize the need for new materials, circular concepts in constructions transform buildings to banks of valuable materials which can be reusing by the "urban mining."

For building materials, a double strategy is needed, There isn’t another way to reduce CO_2 emissions of the greatest commonly used of building materials like: reinforced concrete and many others traditional building materials such as plastic, aluminium, and glass. while trying to increase bio-based materials' market share

Figure (17): Approaches to addressing embodied carbon in building materials that are both upstream and downstream. PEEB graph

Source: *Embodied Carbon-A Hidden Heavyweight for The Climate*. (2021).

So, striving for the circularity in the production and use of building materials, both traditional and alternative, is a must.

Figure (18): The Urban Mining and Recycling (UMAR) Experimental Unit is built mainly by materials which is recyclable, reusable, and compostable. (Architects: Werner Sobek, Dirk E. Hebel & Felix Heisel, Photo: Zooey Braun)

Source: (https://www.linear.eu/en/blog/urban-mining-cities-as-raw-material-mine/, 2022)

Adapting building materials and designs to the regional climate is essential. In hot climates, thermally dense building materials are required, like mud, natural stone, and bricks. In humid subtropical regions, materials with poor thermal resistance and natural ventilation, like wood, bamboo, and lightweight facades, are preferred (130).

Figure (19): Building materials must be designated to suit the regional climate. (Architects: T3 Architects, Photo: ALISA Production)

Source: (https://www.archdaily.com/954693/hippofarm-bioclimatic-dormitories-t3-architects/5ff853f963c017436800024e-hippofarm-bioclimatic-dormitories-t3-architects-photo, 2023)

In order to reduce carbon emissions the Programme For Energy Efficiency In Buildings (PEEB) introduced this Building Materials Checklist (131)

- A life cycle analysis depend on regional data will be used to lead design decisions.
- Selecting Building materials that are suitable to the local climate.
- Low-carbon materials are replaced over CO_2 -intensive materials such as aluminium and steel.
- Using minimum processed materials that require fewer resources for manufacture and are simple to recover and reusing
- Materials that are resistant and require less replacement or maintenance
- Reusing materials rather than manufacturing new materials ("urban mining").
- Local value chains can greatly reduce transportation emissions while also strengthening the local economy.

With estimated population growth and economic development in the next decades, the Reference Technology Scenario (RTS) predicts that global need for steel will rise by roughly 30%, cement by 10%, and aluminium by approximately 75% through 2060, compared to 2017 levels(132). The predicted future changes vary from the observed changes over the last two decades, which has seen massive multiplies in cement and steel demand, owing primarily to population fast growth. Materials demand and manufacturing must be managed in order to minimize the consequences on natural resources, climate, air, and water.

Therefore, the base of the UN SDGs, Goal 12 guarantee sustainable consuming and production trends (United Nations General Assembly, 2015) is reducing the impact of materials. The goal involves a target (target 12.2) to reach sustainable natural resource efficient and management resource use by

2030. This is described regarding material impact (the quantity of main raw materials required to meet a country's needs) and local material utilization (the quantity of natural resources used in economic procedures). Moreover, the goal is to significantly minimize waste production through recycling, reduction, and reuse (target 12.5).

Then, The Clean Technology Scenario (CTS) assumes significant minimization in industrial CO_2 emissions, with emissions falling by approximately 45% by 2060 from 2017 levels, compared with a raising of approximately 15% by 2060 in the RTS. The CTS now recognizes from RTS reducing material demand via material efficiency techniques. So, if material demand changes constantly keep to rise in parallel with population and gross domestic product (GDP) growth, as estimated by the RTS, an even significantly larger emissions reductions per unit of material generated will be required.

For example, cement the CTS assumes a 30% minimization in emission levels by 2060 compared to 2017(132). If the demand of cement remains at RTS levels, emissions density would have to be minimized by roughly 40% to achieve the same CTS emissions minimization. This would be a significant economic and technical difficulty. Considering the sluggish achievements in the innovation, demonstration, and implementation of innovative manufacturing processes that provide a substantial minimization in their CO_2 footprint. While reducing the amount of materials required via the implementation of material efficiency techniques would not minimise the need for hard works to minimize CO_2 emissions of material manufacturing, it would engage to the entire CO_2 emissions minimization goal, resulting in more moderate necessities to minimize emissions per unit generated.

As previously stated cement manufacturing procedure is one of the most building ways that contributes the most to GHG emissions (The cement industry accounts for nearly 8% of world GHG emissions.) Emissions are caused mainly by the process of extraction (approximately 60%) of raw natural materials (which emits GHGs: CO_2, NO_2, NOx, and SO_2) and the need to keep furnace temperatures high (40%) (133),(62). It is projected that the manufacturing of one tonne of cement emits an average of 0.7-0.99 tonne of CO_2 /t, depending on a variety of variables such as the percentage of clinker used (134).

Also, as another example, bricks necessitate a high-energy process that includes several production phases varying from evaporation (20-150°C), dehydration (150-650°C), vitrification (900-1316°C), and cooling (1300-20°C). This process requires a significant amount of energy and results in GHG emissions of approximately 0.15 tonne of CO_2 /t.

But Cement is linked to more than 50% of another materials used in the building industry today (62). even bricks, which have been used as a main building material throughout history. Bricks were utilized in Roman era, across the Middle Ages, into the Renaissance, and for the build of typical nineteenth-century towns, and for modern cities, in which approximately 1500 billion bricks are manufactured annually (135).

Lastly, from many previous literatures some specific techniques for producing low-carbon building materials can be implemented, such as: Low Carbon Emission Approaches were proposed and organised into 8 main strategies, which are referred to as LEAs. that enable for reduction of GHG emissions during the lifecycle of a building material.

- **LEA 1 - Use of alternative materials** (136): This approach tends to replace by linked materials with low GHG emissions for use in the production of building materials such as: cement and concrete.
- **LEA 2 - Use of reusable materials - recycling – waste** (137),(138): This approach applies the principles of the Circular Economy and is focused on using recycled materials from demolition of buildings (construction and demolition waste - CDW) and solid or urban waste.
- **LEA 3 - Use of natural materials** (139): This approach targets to create new building materials from natural raw materials like wood, soil, clay, and hemp.

- **LEA 4 - Use of local materials** (140): This approach focuses on using of local materials (as well as CDW), which reduces the distance from raw materials to the production site.
- **LEA 5 - Innovation of the production process** (141,): This approach is required for the Application of new innovations that can reduce GHG emissions, such as Carbon Capture and Storage technology (CCS) and Carbon capture and utilization (CCU).
- **LEA 6 - Use of renewable energy sources** (137): This approach is focused on the Application of a renewable energy sources system.
- **LEA 7 - Increase in performance** (142): This approach focuses on improving material performance while minimizing the amount of raw natural materials needed to reach the same level of efficiency.
- **LEA 8 - Correct applications** (143): This approach seeks to improve the best building material applications within phase of construction in hopes of avoiding waste materials and poor application efficiency.

3.3.1. Constraints and Opportunities

Constraints: While using alternative materials risk of the performance (144) degradation risk of using too much catalysts, because the manufacturing of all components still involves huge CO_2 emissions (145) the lack of many alternative materials (146) the production sector's lack of knowledge (147) and the differences in aesthetic appearance (146).

While using recycled and waste materials. The literature review also highlighted some constraints, like the marginally higher cost for equal design strength (148), the failure of workability (148), the raising cement amount into reused base concrete compared to the identical mechanical properties of base natural concrete (138), a limited expertise in the manufacturing sector, and also the differing aesthetic appearance.

Some limitations in the use of natural raw and local materials because of need for compensation for low efficiency by expanding the thickness of building materials and components (149) and a scarcity of skilled workers. On the other hand, related to improvement of the production procedures the main constraint is the high costs of introducing advance technology such as CCS and CCU (150).

Using green energy and renewable energy sources have high costs for implementing renewable energy sources and lower levels of green energy generated in the local grid.

Opportunities: to reduce GHG emissions many studies have investigated the possibilities of finding supplemental materials for the manufacturing of cement conglomerates or other solutions for reducing clinker GHG emissions (151). Not even just cement, This strategy has also been used effectively with many materials, including asphalt roads (152) and bricks (141). Some examples of chances: Coal fly ash is a byproduct due to the burning of pulverised coal in thermoelectric plants (145),(153), Granulated slag is a byproduct of the cast iron manufacturing process, in which huge quantities of liquid slag are created, similar to Portland cement (153), Silica fume is a side item of the electric furnace manufacturing industry of metallic silicon and iron-silicon alloys, ash from rice husk (153), bioethanol (154) and waste of red clay bricks (155).

Recycled materials, such as demolition materials (CDW) these materials can be utilized as a resource to create 2nd raw materials. Applying CDW in the manufacturing process reduces emissions, energy consumption, CO_2 emissions, potential for global warming and landfill space. Besides that, using CDW lowers costs by mitigating the impact of disposal (138), (148). According to Rosado et al., CDW could minimize GHG emissions when used recycled materials from manufacturing location nearby to the construction site (156).

By using of waste materials like fly ash as well as furnace slag, when mixed with other tactics, can minimize CO_2 emissions by up to 32% and energy consumption by up to 80% in the manufacturing procedures (157). Bricks could also be done by combining solid waste (158) or by reusing urban waste, thus also reducing Carbon footprint (141).

Several benefits of using natural materials include the limited amount of processing and inexpensive materials, the product's health, local accessibility (149), the possibilities to activating regional inventive chains that able of reclaiming elements of the building traditions, as well as the possibility of several natural raw materials to take a larger amount of carbon during the entire life cycle than that emitted during the product's manufacturing (159).

The innovation of CCS and CCU systems, carbonate looping technology, enriched oxygen and oxy-fuel innovations, bio-technological carbon capture, and post-combustion carbon capture by using capturing techniques all are examples of new technologies being used to reduce CO_2 and GHS emissions (150). Furthermore, the usage of calcium-silicate-hydrate-based process steps in manufacturing of bricks, geopolymer-based procedures, and many innovation strategies, as well as the usage of the natural brewer's yeast blended with hydrogen peroxide to generate a new Autoclaved Aerated Concrete (141).

Using tyres, not recycled papers and plastics as an alternative fuel in cement manufacturing (160), Besides that, GHG emission reductions from other product life cycle stages could be reached utilizing electrified vehicles for as long as the power is generated by using renewable sources such as sun, wind, and water (161). electrified vehicles could be used to minimize emissions during the manufacturing, transportation, and applying stages.

Lastly, several studies show that improving the implementation of materials and technological devices can help reduce material waste and CO_2 emissions. Improved The prefabrication and assembly in advance of technological aspects are procedures (162,), also using technologies and softwares like the Building Information Model (BIM) and Augmented Reality (AR) within the installation phase are examples of innovative strategies (163).

3.3.2. Regulations and policies

In the building industry, embodied carbon is calculated in accordance with European Standards (EN 15804 and 15978), and International Standard (ISO 21930). These standards are reciprocally convenient, and the ISO standard was founded on the EN standards. Architectures usually use life-cycle assessment (LCA) software to measure embodied carbon emissions (in contrast to software for LCA professionals), which ensures compliance with the needed criteria while trying to hide some of the fundamental complexities.

Biogenic carbon emissions from sustainably managed forestry combustion of biogenic materials like woods are usually estimated as zero emissions. The basic assumption is that a sustainably managed forest can recover a comparable emission of CO_2 in future growth. This is consistent with industry standard and the EN 15804/ISO 21930 standards. Biogenic carbon storage in building materials is typically calculated separately from emissions, as are the latest EN 15804/ISO 21930 standards. In this direction, they are offered to the government making stakeholders as additional information. It is up to the users to make use of this extra info.

The main performance data for the building embodied carbon reduction policies and regulations are represented in the table below:

Table (6): The building embodied carbon reduction policies and regulations

Policy Code	Policy name	Carbon Impact	Cost Efficiency	Impleme-ntability	Enforc-eability	Sum of Scores	Examples Provided
R1	Life-cycle carbon limits for new Buildings	5/5	3/5	3/5	3/5	14	Vincent, Douro-Dummer, London
R2	Low carbon cement and concrete Policy	5/5	3/5	2/5	3/5	13	Singapore, Masdar City, Portland, Dubai
R3	Material-efficient structural design Requirement	4/5	5/5	3/5	3/5	15	Singapore, San Francisco, Los Angeles, Seattle
R4	Density bonus for carbon efficiency	3/5	5/5	4/5	4/5	16	Seattle, Washington, other US cities, Singapore
R5	Zero carbon construction sites	2/5	2/5	4/5	4/5	12	Trondheim, Oslo, Malmö, Göteborg, Stockholm

Policy Code	Policy name	Carbon Impact	Cost Efficiency	Impleme-ntability	Enforc-eability	Sum of Scores	Examples Provided
R6	Construction materials efficiency Declaration	1/5	4/5	4/5	4/5	13	
R7	Expedited permitting for low carbon Projects	1/5	3/5	4/5	5/5	13	San Diego, Seattle
R8	Prohibiting extremely high emitting Materials	1/5	3/5	3/5	2/5	9	North Bend, Washington, Tuttle
R9	Life-cycle carbon calculation and Reporting	1/5	3/5	4/5	4/5	12	London

Source: Kumari, L. M. T., Kulatunga, U., Madusanka, N., & Jayasena, N. (2020). *Embodied Carbon Reduction Strategies for Buildings* (pp. 295–308). https://doi.org/10.1007/978-981-13-9749-3_28.

3.3.2.1. Embodied Carbon Reduction Measure Categories

Regardless of the function and type of building, the proportional amount of CO_2 emissions as well as operating carbon to the entire carbon life cycle of a material may vary greatly. and also factors such as location, climatic condition, type of fuel used, building orientation, and building massing. from this aspect, the percentage of carbon emissions from traditional building life cycle carbon has been estimated to differ from low as 20% or less for traditional office or residential buildings to high as 80% or a higher for lower energy buildings such as laundries (164). The increased percentage impact of CO_2 emissions to life cycle carbon as a result of the reduction share of operating carbon has founded in a major transition in the area of attention toward investigating approaches for minimizing the embodied carbon of building materials. These strategies include using low carbon materials, the reusing materials, recycling, and minimization of materials, the choosing of a structurally optimum solution and structural analysis, as well as the enhancement of building operations.

The approximated achievable reduction in a building's CO_2 emissions added to the approximated operating carbon to measure the building's life cycle carbon. The approximated life cycle carbon minimizations then can be used as the primary method for selecting the optimal approach or optimal combination of relevant approaches by taking into account the impacts of an embodied carbon minimizations approaches on the building's other significant economic, environmental, and social impacts. The life cycle assessment (LCA) method was widely used to approximate the CO_2 emissions of various building materials and products, and the carbon emissions rates of various machinery and equipment and operations engaged in the building's construction and operation.

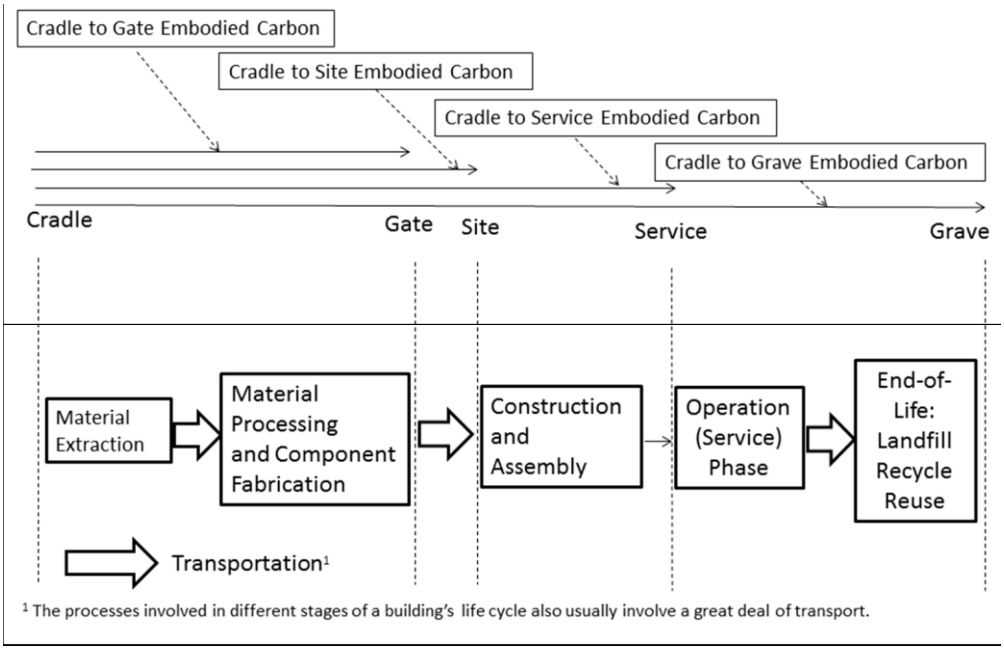

Figure (20): Different phases of a standard building's life cycle.

Source: Akbarnezhad, A., & Xiao, J. (2017). Estimation and Minimization of Embodied Carbon of Buildings: A Review. *Buildings*, *7*(4), 5. https://doi.org/10.3390/buildings7010005.

3.3.2.1.1. Cradle to Gate Embodied Carbon of Materials

Theoretically, the cradle-to-gate embedded CO_2 of materials be responsible for three categories of CO_2 emission:

1- CO_2 emissions from production and processing of materials

2- Emissions caused by carbon combination release in raw materials

3- Emissions caused by a decrease in the CO_2 emissions quality of the machinery utilized to procedure materials, for example The progressive depletion of carbon from equipment production

Previous studies have invested a great deal of effort to inquiry the cradle to gate embodied carbon of the building materials and improve CO_2 emissions innovations used in measuring the CO_2 impact of buildings. for example, Research by Hammond and Jones as part of the University of Bath's Carbon Vision Buildings Program, England, resulted in the creation of an exhaustive inventory of the CO_2 emissions of building materials, that's since been used many studies (165). However, it should be mentioned that the manufacturing processes applied can have a massive effect on the carbon emissions of materials. The manufacturing process used to produce a specific material, on the other hand, can differ significantly from a producer to another, based on the used technology and the characteristics of the natural raw material sources accessible to the producer. Besides that, transport factors can vary significantly from one producer to another based on location of his sites, material mining, suppliers, and facility layout, resulting in significantly variable CO_2 emissions from transit for various manufacturers. After measuring the cradle to gate embodied carbon emission factor for building material using LCA or finding a reliable local estimations f_j^{c-s}. The entire cradle to gate embodied carbon of a building can be calculated by multiplying the amount of every material employed in a building by its equivalent cradle-to-gate CO_2 emissions factor and adding all the total calculated results. Conversely, the cradle to gate embodied carbon factor f_j^{c-g} can then be utilized to measure the cradle to site embodied carbon factor f_j^{c-s}, in which after that can be used to calculate the entire cradle to site embodied carbon of the building.

3.3.2.1.2. Cradle to Site Embodied Carbon-Impact of Transportation

The cradle to site embodied carbon can be calculated by incorporating material transportation CO_2 emissions to the cradle to gate embodied CO_2 calculated though the manufacturing process analysis. Construction usually necessitates extensive transportation, such as:

- Materials and equipments transportation from the vendor's location to the construction site
- materials transportation, equipments, and workers among construction site facilities
- Project staff transportation to and from the construction site

Regarding to the United States Environmental Protection Agency, the building sector accounts for 6% of overall Lightweight truck use and 17% of total medium & heavyweight truck use, accounting for 28% of total transportation related emissions in the US. The Motor Vehicle Emission Simulator (MOVES) and Emission Factor (EMFAC) models are widely used to determine the emissions of carbon involved with those on construction vehicles.

3.3.2.1.3. Cradle to Service Embodied Carbon—Impact of Construction Operations

The huge growth in analyzing the environmental effects of various construction cases has resulted in a number of studies focused on developing methodologies for measuring energy consumption and CO_2 emissions during the construction process. Cole measured the energy and GHG emissions compared to other alternative steel, wood, and structural concrete systems (166).

Guggemos and Horvath also created a Construction Environmental Decision-Support Tool (CEDST) to measure the environmental effects of commercial building construction (167). CEDST uses a detailed technical graph to measure the consumption of energy and CO_2 emissions from the construction phase with regards to the building materials, transitory materials, and machinery chosen by the designer and builder. Guggemos and Horvath illustrated through a case study that a planned choice, like the use of a mixer truck of concrete with a 335 hp engine rather than a 565 hp engine, can result in a 12% reduction in project energy consumption. the need for real site info, like the quantity of fuel, energy, water, and different materials utilized by various contractors, is a constraint for these techniques, making them impossible of estimating CO_2 emissions before the action is completed. To solve this challenge, Hong et al. developed a model that uses available data on the sort as well as the energy efficiency of equipments, the quantity of materials utilized, and the criteria of the construction project and site to measure the consumption of energy and CO_2 emissions from the construction process (168).

In order to mitigate the CO_2 emissions of construction equipment, Ahn and Lee developed the approach of Operating Equipment Efficiency (OEE) as the ratio of useful operating time to entire operating time (169). They evaluated by this concept the swap between the OEE of the equipment and the generated CO_2 emissions of the earthmoving activities. The findings revealed that management planning choices like fleet size affect not just cost and schedule of a project, but also its environmental impact.

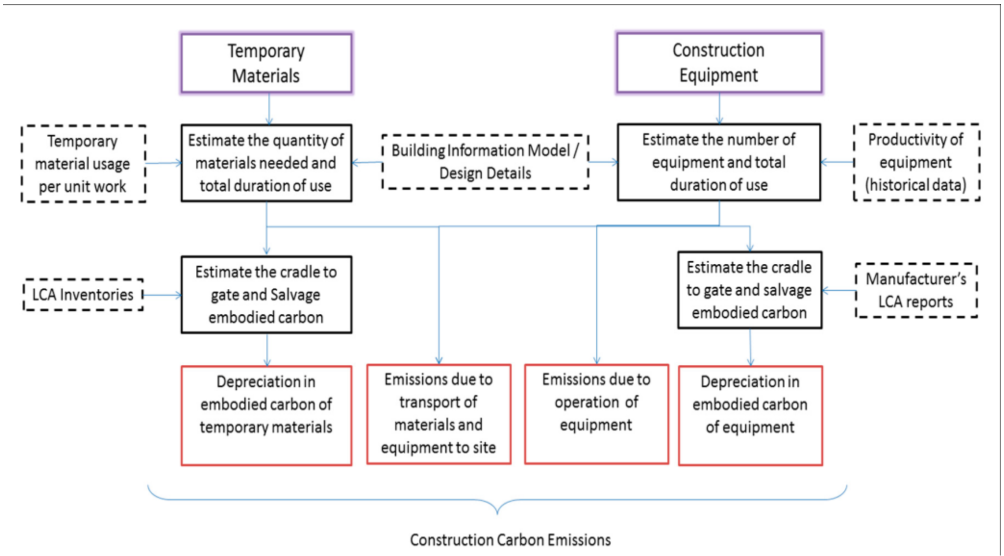

Figure (21): A framework for estimating carbon emissions during the construction phase

Source: Akbarnezhad, A., & Xiao, J. (2017). Estimation and Minimization of Embodied Carbon of Buildings: A Review. *Buildings*, *7*(4), 5. https://doi.org/10.3390/buildings7010005.

A research by Akbarnezhad, Ali and Xiao, Jianzhuang proposed that a systematic approach to estimating carbon emissions during the construction process must take into account two important emission sources:

1- Indirect emissions as the embodied carbon quantity of temporary materials and equipment depreciates

2- Direct emissions from construction equipment operation

And they also introduced A framework for estimating entire construction carbon emissions by taking into account the two important sources of emissions mentioned above (170).

3.3.2.1.4. Cradle to Grave Embodied Carbon

Assuming the embodied carbon from cradle to grave necessitates estimating the carbon emissions caused during the end-of-life (EOL) phase of a life cycle of the building. The greatest popular approaches for handling with a building that has reached ending of its life are landfilling and demolition, reusing, and recycling. The selection of end-of-life strategy can have a great effect on the building's end-of-life CO_2 emissions and many other environmental effects (171). The ideal EOL approach for a building is determined by a number of variables, such as the materials employed, the initial design of the building elements, the existence of necessary local technology solutions for recycling and reuse, the existence of a local market for these procedures' products, and the existence of suitable landfills for debris disposal.

Vitale *et al.* presented a comprehensive LCA to evaluate the environmental effects of a number of residential buildings in southern Italy during building’s end-of-life phase. In this analysis, a comprehensive modeling of energy and material consumption, as well as emissions from various both inside and outside site elements conducted in popular EOL approaches, was carried out built on a comprehensive quantitative measurement of mass and flow of energy across all of the connected systems (171).

Akbarnezhad *et al.*, proposed a simpler approach for quantifying CO_2 emission of reusing and landfilling end-of-life techniques and applied it on a concrete building (170). The proposed approach for quantifying the CO_2 emissions of the recycling technique entails:

1- Quantifying the overall quantity of recyclable materials existence applying quantity take off tools such as BIM

2- Identify possible recycling process by taking into account existing local recycling technologies

3- Recognising the specific recycling operations that are involved in each recycling process

4- Trying to identify the factors of CO_2 emission for every operation applying methodologies comparable to those previously mentioned for estimating construction emissions and measuring the CO_2 emissions caused in every operation by taking into account. The amount of materials that must be procedure

5- Trying to calculate the equivalent CO_2 emissions value of the end recycled product, that are then compared to the entire emissions of the recycling procedure to assess the recycling strategy's CO_2 emissions implications

It was stated that adopting the proposed approach to quantify the CO_2 emission of various recycling methods can be utilised as an optimization tool to identify the ideal recycling method for a specific project (170). Once especially in comparison to landfilling and recycling, the reusing approach can result in significant minimizing in the CO_2 emissions of the building by conserving the embodied CO_2 invested in component manufacturing as well as material processing for their finalist version. In light of this, Akbarnezhad et al. proposed a method for calculating the CO_2 emissions of reusable materials, designed for disassembly (DfD) structural components. Furthermore, the reusing strategy may necessitate component storage and also increased transit of materials and components between facilities, which must be taken into account when assuming CO_2 emissions. End-of-life emissions assumed by using approaches proposed in the previous studies will then be added to the measured cradle to service embodied CO_2 to measure the building's cradle to grave embodied carbon.

3.4. Frameworks for apply using low carbon materials

The United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Paris agreement of 2015, with 189 countries as signatories, were the two primary impetuses for the innovation of a future of low carbon and related low carbon economic expansion. Nations are encouraged to create policies that would stabilize the atmospheric accumulation of carbon dioxide and GHGs, while also nullifying the harmful impacts of climate change. Despite having various responsibilities for reducing emissions, developing cities are obligated to prevent harmful anthropogenic activities that tamper with the global climate. Although, anthropogenic changes in the structure of the atmosphere of the earth have been the main reason of negative climate change. The largest challenge starts from rising levels of CO_2 (and also N_2O) emitted by fossil fuel combustion and engineering materials, which will remain in the atmosphere for the foreseeable future. Even though biotic activities contribute to GHG emissions, human activity via combustion of fuels and materials is the largest contributor of CO_2 and NO_2 emissions (Fig. 22).

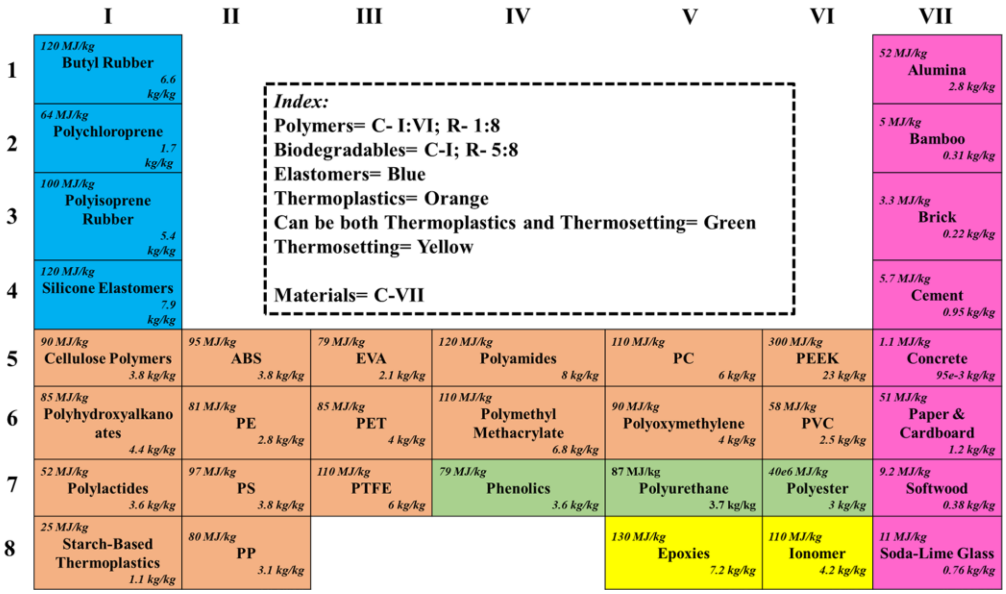

Figure (22): A periodic table of several basic materials, along with their embodied emersions (top left) and global warming potentials (bottom right)

Source: Das, O., Restás, Á., Shanmugam, V., Sas, G., Försth, M., Xu, Q., Jiang, L., Hedenqvist, M. S., & Ramakrishna, S. (2021). Demystifying Low-Carbon Materials. *Materials Circular Economy*, *3*(1), 26. https://doi.org/10.1007/s42824-021-00044-0

As a consequence, Carbon emission and climate change are being caused both indirectly and directly.

The innovation of a low carbon industry can help to slow the rate of increase in GHG emissions. As an example, research and development (R&D) programmes are prioritised as a means to decarbonize products and procedures in order to develop a low carbon industry (172). Worldwide, there is a critical necessity for large-scale research and development (R&D) on low carbon materials. Nonetheless, most governments continue not to prioritise the using of low carbon materials and related technologies, causing an integration barrier in policies of environmental (172). This issue is exacerbated by a lack of understanding about the multifaceted aspects of low-carbon materials, as well as insufficient definitions that fail to describe the holistic nature of these materials. Nowadays, the approach of low carbon materials is greatly limited to the constructions and building materials industries. Even so, the evolution of this approach must also make sure that these performance characteristics of the materials are improved or at the very least retained.

Therefore, some innovations started to appear like One Click LCA lists low carbon building materials as

1- Natural raw products such as those with lower energy production procedures.

2- Recycled material.

3- Materials that can be reused (173).

The amount of operation carbon in a material is also significant in determining whether it is low of carbon. Because just a few elements from the periodic table are used in building materials, so the definition of low carbon materials is limited. Besides that, the building industry has a limited knowledge of the real nature of low carbon materials.

The Fishbone Diagram below shows the various strategies for developing low-carbon materials. It is a framework that may be used to improve a low material (174). This framework suggests Several approaches for developing low carbon materials/products like:

1- Creating materials at the atomic or molecular scales to allow for better circularity.

2- Material processing technologies that are efficient.

3- Purchasing locally sourced, renewable materials.

4- Using recyclable materials to improve circularity and sustainability.

5- Material/product design for long life span and without producing wastes.

6- Ensure that the functional characteristics are preserved.

7- Improved energy efficiency.

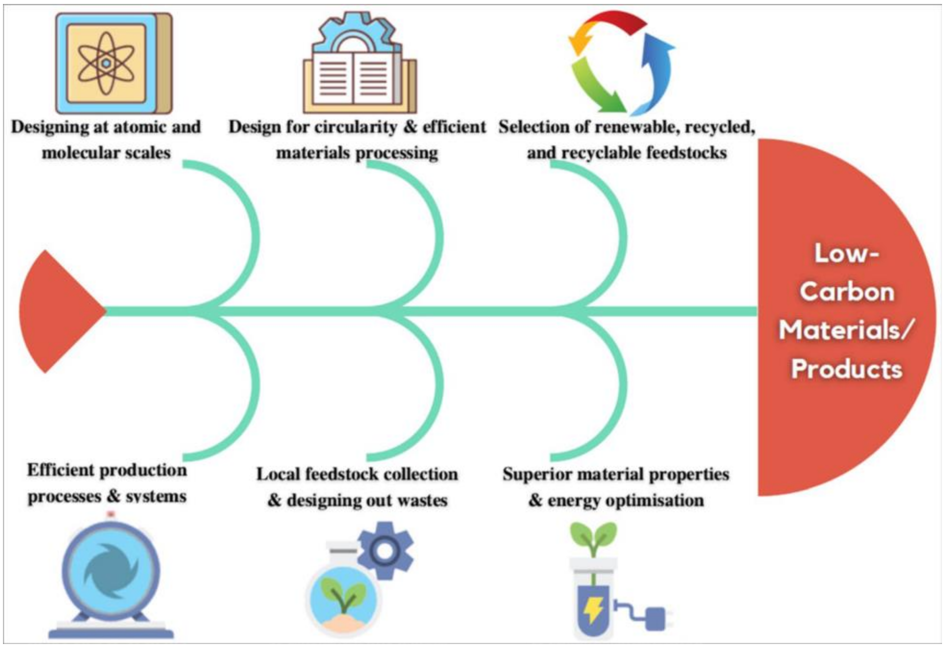

Figure (23): Fishbone Diagram (23) a framework that can be used to develop a low carbon material

Source: Das, O., Restás, Á., Shanmugam, V., Sas, G., Försth, M., Xu, Q., Jiang, L., Hedenqvist, M. S., & Ramakrishna, S. (2021). Demystifying Low-Carbon Materials. *Materials Circular Economy*, *3*(1), 26. https://doi.org/10.1007/s42824-021-00044-0

In 2019, a framework for emissions of carbon analysis based on (BIM) and (LCA), comprised of 4 steps(175):

1- Identifying the limit of emissions of carbon in a project lifecycle

2- Creating a database of carbon emission coefficients for buildings in China by using software like: Revit, GTJ2018, and Green Building Studio for inventory analysis

3- Estimating carbon emissions at every phase of the life cycle

4- Clarifying the carbon emission calculation results.

The framework was developed using a research case of a hospital in China, which has a hot summer and a cold winter.

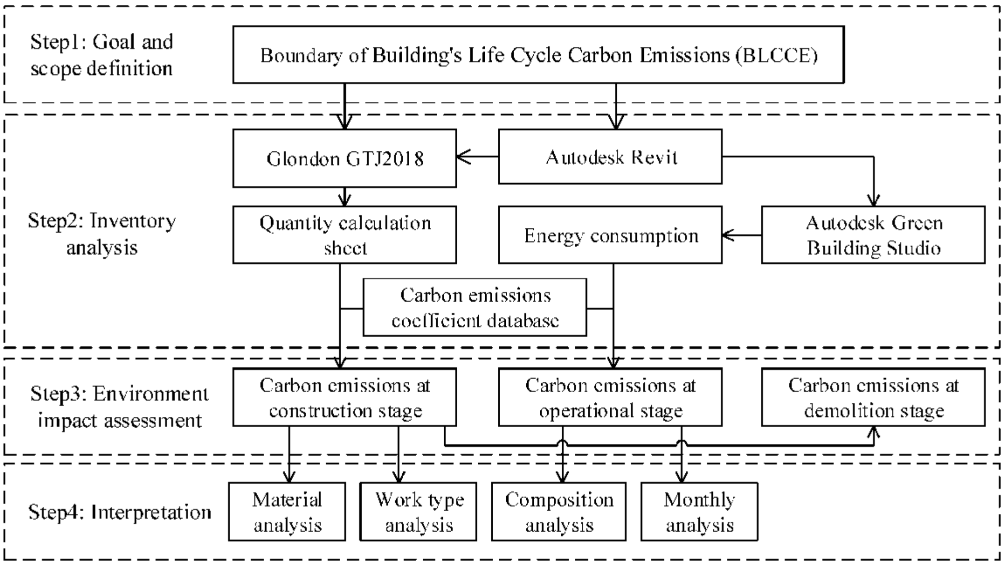

Figure (24): BIM–LCA based methodology framework for analyzing Building's Life Cycle Carbon Emissions (BLCCE).

Source: Lu, K., Jiang, X., Tam, V. W. Y., Li, M., Wang, H., Xia, B., & Chen, Q. (2019). Development of a Carbon Emissions Analysis Framework Using Building Information Modeling and Life Cycle Assessment for the Construction of Hospital Projects. *Sustainability, 11*(22), 6274. https://doi.org/10.3390/su11226274.

The analysis shows that Approximately 49.64% of all carbon emissions result from reinforced concrete engineering during the construction phase, while HVAC contributes the most (approximately 53.63%) during the operational phase. This analysis serves as an effective reference for comparable buildings in similar areas, as well as supplemental guidance for future carbon emission reductions (175).

In August 2020, to achieve the vision by 2050, (CO_2 emissions in New Zealand associated with building products and materials are significantly lower than they are today) a framework proposes that (176):

1- Initially, buildings' whole-of-life embodied carbon (in kg CO_2 -e/m- of building) will be needed to be reported as part of the process for obtaining a building permit.

2- As a consequence, Buildings will also be required to achieve a mandated cap on their whole-life embodied carbon to gain a building permit.

3- The cap will be enforced gradually over time in accordance with a clear schedule in order to achieve the increasing emissions reductions needed by the National Emissions Reduction Strategy.

4- The cap levels will be established in accordance with best practises and in collaboration with the Sector to achieve that they are ambitious but achievable, and will be evaluated at each level.

5- Data on the embodied CO_2 from buildings accumulated during the reporting stages is saved in an archive and released publicly in the interests of transparent and open information sharing for the benefit of the Sector's collective knowledge.

6- Public organisations with property portfolios present a chance for the government to lead the way in establishing the techniques and processes required to make the necessary significant modifications, one step closer to private sector buildings.

7- Government initiatives with public sector clients and Building Consent Authorities will show how total embodied CO_2 for a building can be measured, reported, managed, and reduced.

Step 1	Step 2	Step 3	Step 4	Step 5
New public sector buildings to report Whole Life Embodied Carbon.	All new buildings to report Whole Life Embodied Carbon.	All new buildings to meet Whole Life Embodied Carbon initial caps.	All new buildings to meet Whole Life Embodied Carbon intermediate caps.	All new buildings to meet Whole Life Embodied Carbon caps that achieve net zero emissions for New Zealand.
New public sector buildings to report Whole Life Embodied Carbon.	New public sector buildings to meet Whole Life embodied carbon initial caps.	New public sector buildings to meet Whole Life embodied carbon intermediate caps.		

Scope of the whole-of-life embodied carbon framework increases over time

Figure (25): The proposed stages for how this will occur are shown below. The time frame of these changes will be determined in consultation with the sector

Source: Chandrakumar, C., McLaren, S. J., Dowdell, D., & Jaques, R. (2020). A science-based approach to setting climate targets for buildings: The case of a New Zealand detached house. *Building and Environment*, *169*, 106560. https://doi.org/10.1016/j.buildenv.2019.106560.

The framework proposes two categories of buildings:

- Small buildings with fewer than three storeys and less than 300m^2 gross external floor area.
- Large buildings with more than three storeys or a gross external floor area of 300m^2.

Small buildings will be able to use a simplified measuring tool that will use some standard material amounts and embodied carbon info as needed. It will minimize the time and effort needed for reporting for these buildings, which are probably to be of standard buildings and also where owners are less probably to have access to the resources or expertise required for full calculations.

For huge buildings the design team is probably to have extra resources in this area, they will be necessary to utilise the project specific information instead of default information. They can use more advanced tools and analysis to identify opportunities to minimize embodied CO_2, even engaging Life Cycle Analysis practitioners to conduct detailed assessments of buildings. The reporting of embodied CO_2 data will be consistent across all buildings, increasing the Sector's collective knowledge of how to achieve reductions(176)

3.5. Case example of low carbon buildings:

3.5.1. Casa Tecla, Italy

Casa Tecla, situated in Italy, stands as an innovative exemplar of sustainable architecture, seamlessly blending ancient building methodologies with cutting-edge technology. The construction of this prototype house involves the 3D printing of raw local clay in an intricate layering process, totaling 350 layers. This unique fusion not only showcases the aesthetic potential of 3D printing but also addresses critical environmental concerns. A key attribute of the clay used in Casa Tecla is its natural thermal insulation properties, enhancing the building's energy efficiency. The significance of this project lies not only in its architectural ingenuity but in its dedication to environmental responsibility. The choice of raw local clay aligns with a broader sustainability goal, as it can be recycled continuously, mitigating its impact on carbon emissions and, consequently, global warming. This endeavor is particularly noteworthy in the context of providing low-cost emergency housing for climate refugees, exemplifying how innovative architecture can contribute to both social and environmental well-being (225)

Figure (26): Embodied Carbon emissions (A1-A3) kgCO2e/m2: 0

Source: Tecla, (2021), Available online at: https://www.3dwasp.com/casa-stampatain-3d-tecla/, (Accessed on 26 December 2021).

3.5.2. Sara Kulturhus Center, Sweden

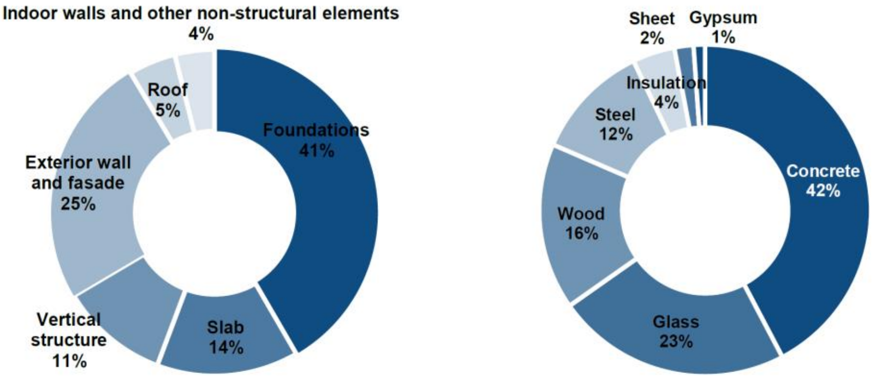

Figure (27): Embodied Carbon emissions (A1-A3) kgCO2e/m2:128

Source: Celine Kozak, & Marwa Dabaieh. (2023). *Sustainability Of Multi-Story Wood Buildings: Can the Swedish forestry keep up with the demand?*

Sara Kulturhus Center, situated in Skellefteå, Sweden, and masterfully designed by White Arkitekter, emerges as a beacon of sustainability in the realm of architectural innovation. As the second tallest wooden tower globally, this cultural center not only showcases the aesthetic possibilities of timber construction but also serves as a key player in the reduction of carbon emissions. The complex operates on a carbon-negative model, representing a groundbreaking approach to sustainable building practices. The heating system relies on a geothermal pump, harnessing the Earth's natural energy to maintain a comfortable environment within the structure. Additionally, the center is powered by an extensive array of 1,200 square meters of solar panels, a testament to its commitment to harnessing renewable energy sources. The incorporation of supplementary renewable energy from the grid further solidifies Sara Kulturhus's dedication to minimizing its carbon footprint. In an era where climate concerns are paramount, this cultural center stands as a symbol of how architectural endeavors can actively contribute to the global effort to reduce carbon emissions, providing a sustainable blueprint for future developments worldwide (226).

3.5.3. The Arc, Indonesia

The Arc, a remarkable architectural feat located in Indonesia, specifically at the Bali Green School, stands as a testament to innovative design and sustainable construction. Crafted from bamboo, this structure showcases a unique blend of functionality and environmental consciousness. The 14-meter-high arches, formed by bending bamboo, create a mesmerizing double-curved roof for the Bali Green School gymnasium. The design not only achieves a striking visual aesthetic but also emphasizes the utilization of minimal materials to yield maximum spatial efficiency.

One of the key features of The Arc is its thoughtful consideration of the local climate. Situated in the tropical environment of Bali, the architects prioritized natural ventilation to enhance the building's sustainability. Openings strategically placed at the apex of the canopy facilitate the escape of warm air, promoting effective temperature regulation. Additionally, vents around the base of the structure further enhance the natural airflow, eliminating the need for conventional air conditioning systems. This eco-friendly approach not only aligns with the principles of environmental stewardship but also contributes to a harmonious coexistence with the natural surroundings of the island. The Arc at the Bali Green School stands as a shining example of how architectural ingenuity can be harnessed to create structures that are both aesthetically pleasing and environmentally responsible (227).

Figure (28): Embodied Carbon emissions (A1-A3) kgCO2e/m2: 0

Source: Noer Agustin, S., & Ketut Acwin Dwijendra, N. (n.d.). *Selvia Noer Agustin, Ngakan Ketut Acwin Dwijendra Sustainable Development Strategy in the Bali Green School Area Sustainable Development Strategy in the Bali Green School Area*. https://doi.org/10.32832/astonjadro.v12i2.

3.5.4. Glyndebourne Croquet Pavilion, England

The Glyndebourne Croquet Pavilion, nestled in the scenic landscape of England, stands as a beacon of sustainability and circular economic principles. This unique garden pavilion, designed for the Glyndebourne opera house, showcases a commitment to minimizing its carbon footprint through innovative and environmentally conscious practices. Employing a reversible design, the pavilion can be dismantled, and its components reused, emphasizing a dedication to sustainability that goes beyond the typical lifespan of a building.

Intriguingly, the pavilion's structure is fashioned from diseased ash trees, providing a second life to these reclaimed materials. The interior of the pavilion boasts a distinctive cladding composed of discarded champagne corks collected from the site, bound together by mycelium—a natural, fungus-based adhesive. This not only repurposes local waste but also introduces an element of organic ingenuity into the pavilion's design.

The exterior of the Glyndebourne Croquet Pavilion is equally compelling, featuring tiles crafted from oyster and lobster shell waste. This ingenious use of seafood byproducts not only lends a unique aesthetic to the structure but also underscores the architect's commitment to utilizing local waste streams in a sustainable manner. In essence, the Glyndebourne Croquet Pavilion serves as a model for future architectural endeavors, showcasing how thoughtful design, circular economy principles, and a dedication to local materials can harmoniously coalesce to create structures that are both environmentally responsible and aesthetically captivating (228).

Figure (29): Glyndebourne Croquet Pavilion, England

Source: (https://www.dezeen.com/2021/03/30/glyndebourne-croquet-pavilion-opera-house-bakerbrown - studio/, 2023)

CHAPTER 4

LOW CARBON BUILDING INDUSTRY IN EGYPT

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4.1. Sustainable Development and Egypt's Vision 2030

Egypt is located in northern African desert zone, with a "hot-arid" climate. The climatic conditions of this kind of region have determined the incorporation of certain passive climate control strategies, summer temperatures vary from 80°F (27°C) to 90°F (32°C), with values of temperatures reaching 109°F (43°C) over the Red Sea coast. With a steady wind, winter temperatures vary from 55°F (13°C) to 70°F (21°C). Egypt is the 38th largest country in the world, covering 1,001,450 square km (386,660 square miles) (177).

Before 1952, agriculture accounted for a huge part of Egypt's economy. In the 1960s, this suddenly turned into an ambitious industrial planned programme. Most reforming proposals were proceeding as proposed until the 1967 war, also known as the second Arab-Israeli war, then Egypt lost a very important piece of its land (Sinai) and the entire country's economy was diverted to military reform efforts to reclaim the occupied land. The investing strategy was reoriented in the 1980s, but mostly of the reformation initiative was wasted until the renowned revolution in 2011 (178).

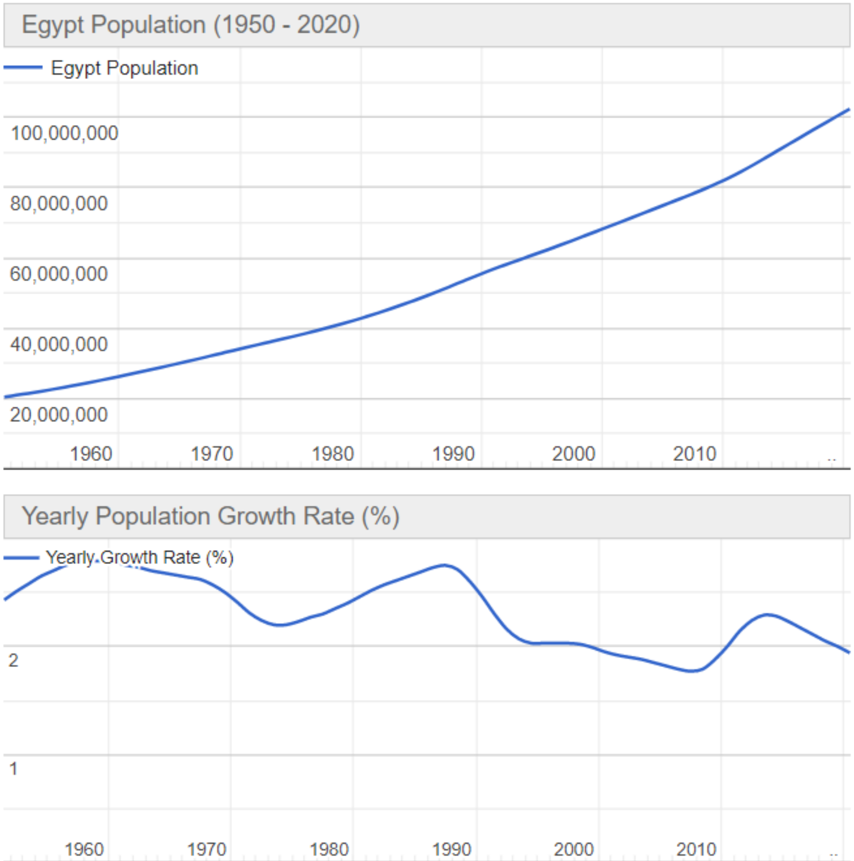

Figure (30): Population of Egypt and Annual Population Growth Rate

Source: (https://www.worldometers.info/world-population/egypt-population/, 2023)

Egypt's total population was expected to overstep 106 million in 2022, with a yearly population growth rate of 1.8%, increasing from 121.8 million to 151 million in 2050, and in 2100 expected to reach 200 million (180). Over the next few decades, Egypt's demographic pyramid will rise throughout all age groups (135). However, the rise is more significant among younger age groups than among those in their old age (181), Consequently, policy should be targeted towards at building new cities to meet the future demand for new housing units.

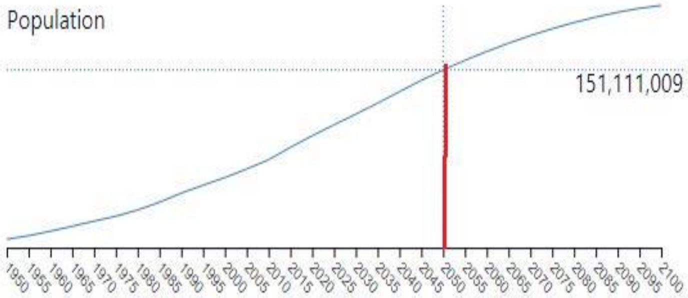

Figure (31): Graph of Egypt's Population (1950-2100)

Source: Kajaste, R., & Hurme, M. (2016). Cement industry greenhouse gas emissions – management options and abatement cost. *Journal of Cleaner Production*, *112*, 4041–4052. https://doi.org/10.1016/j.jclepro.2015.07.055.

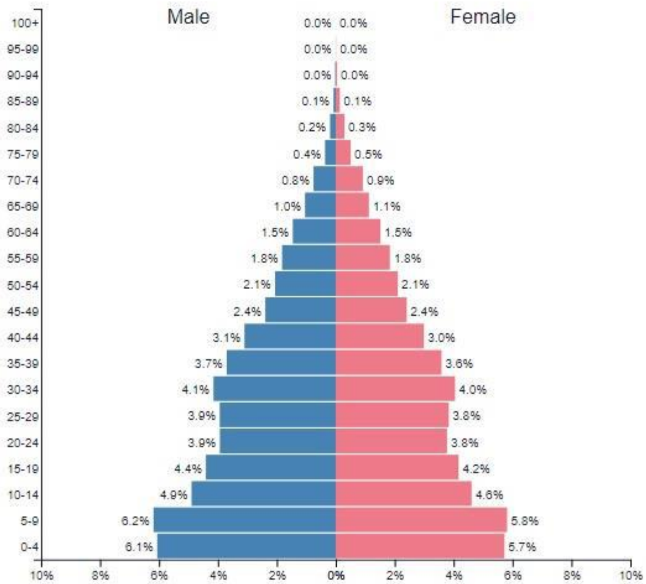

Figure (32): Egypt's Population Pyramid

Source: Kajaste, R., & Hurme, M. (2016). Cement industry greenhouse gas emissions – management options and abatement cost. *Journal of Cleaner Production*, *112*, 4041–4052. https://doi.org/10.1016/j.jclepro.2015.07.055.

Egypt's government has spent the last three decades revising building codes in an effort to improve energy efficiency in the industry and decrease GHG emissions. Most of the new codes for buildings have been imported from other pioneering nations in the industry (177). This initiative was motivated by the understanding that population growth will eventually place tremendous demands on all facets of the Egyptian government, Consequently, these demands could severely limit Egypt's economic growth in the future (182). suggestions for performance improvement in this region have been made, but there has been a lack of interest and manpower. While a lot of people are debating this quandary, others are looking for alternative scenarios to resolve the same problems and raise awareness of sustainability (182).

Several studies on green architecture concepts in Egypt have discovered a gap between theoretical principles and concept implementation. Regardless, the traditional design method in Egyptian culture is related to green architecture (183). Environmental review on Egyptian buildings conducted by researchers shows the implementation of many sustainable and environment concepts, such as the using the passive concept in conserving energy consumption in buildings, with regard to orientation in design to minimize the sun-exposed area, whilst also minimizing the area by the windows, as well as finishing with lighter colors on exterior surfaces of building facades.

Some Egyptian researchers describe sustainable building as making use of exclusively locally sourced materials (such as mud brick) and traditional shapes (such domes and vaults) to create low-cost buildings. in 2004 survey study conducted in Egypt focused on Egyptian culture in order to understand the green concept (184). This survey focused non-professionals from a wide range of Egypt's most significant regions, representing all Egyptian zones. According to the survey, 60% of city dwellers choose walking as a form of transportation, and 71% are homeowners, The most prevalent building material combination was concrete with red brick (67%), followed by mud brick walls with a hardwood ceiling (13.5%). The most used type of brick is fired clay brick (41%), followed by red brick from "Tafla" (Tafla is a type of clay that, once dried, becomes extremely durable) 52% prioritized to use of artificial cooling and heating techniques (air conditions, fans, and electric heater). Light colors with large wall sections, small-depth windows, shutters, and high-tech heating insulation were common passive design principles used in buildings.

Double walls and hollow block walls were uncommon methods used in some designs (183).

The Green Architecture concept is currently being implemented in Egypt, following the establishment of the Supreme Council for Green Building in 2009, which reports to the Ministry of Housing and one of the most essential tasks is to map state of sustainable building and governing codes in Egypt that are appropriate for the regional requirements and conditions. To achieve this, The Council will collaborate with international organizations and authorities in accordance with the climate conditions of Egypt (185) and (182).

Regardless of the reality, the majority of architects recognize the significance role of climatic considerations in building designs and most of Egyptian architects have engaged in a huge number of academic studies on the green architecture. Besides the large numbers of climate professionals advising on design projects. Many studies have found that building design with respect for climatic conditions and environmental parameters is largely ignored by the majority of the architects and designers. Engineering and building methods in Egypt depend on unsustainable practices that affect the environment negatively in many different aspects (186). In this regard, The EGBC was officially established in January 2009. It was a vital step in enhancing green building and adopting the Green Building concepts into Egyptian building regulations.

One of the goals of establishing this council is to concentrate on new building techniques, The EGBC may utilize its professional authority to raise the awareness between architects, designers, engineers, contractors, and building’s owners on the positive effects of sustainable development to the individual, the community, and the country.

Then after that, The EGBC gave its approval to the creation of an Egyptian green and sustainable rating system named the Green Pyramid Rating System (GPRS) To play its role immediately to evaluate the green building performance. After the GPRS, which was finished in January 2009, the Council approved the establishment of a rating system framework, and a National Committee was constituted (182). Realizing the region's specific environmental, economic, and social issues, the rating system will assist in identifying what form the "Egyptian Green Building" should be. To achieve this target, the rating system will enhance Egypt's strategy by incorporating best practices and strategies successfully implemented via the US, South America, Europe, the Middle East, and Asia.

The levels of the Green Pyramid System (GPRS) are:

1- Certified

2- Silver Pyramid

3- Gold Pyramid

4- Green Pyramid

5- The highest level of certification in most other international systems is labeled platinum, but the highest rate in (GPRS) is labeled green (184).

Figure (33): The Green Pyramid System

Source: Elfiky, U. (2011). Towards a green building law in Egypt: Opportunities and challenges. Energy Procedia, 6, 277–283. https://doi.org/10.1016/j.egypro.2011.05.031.

Inspired by Egypt's ancient civilization, and integrating the present into the future, Egypt has adopted a strategy for achieving SD which is described by high ambition, serious commitment, and dynamic innovative thinking. Egypt Vision 2030's Sustainable Development Strategy (SDS) represents a significant progress in the direction of inclusionary development. Consequently, creating a road to development via economic and social justice and rebuilding Egypt's regional leadership role. The SDS reflects a guideline for maximizing competence in order to achieve the dreams and goals of Egyptians for a decent and fair living (187).

In addition, it represents the spirit of the new constitution, establishing prosperity and welfare as the core economic objectives that must be achieved via sustainable development and equitable, geographical, and sectoral expansion. As a result, the SDS was created using a holistic approach. to strategic planning in which varied civil society representatives, local and international development partners, and governmental organizations collaborated to establish comprehensive goals for all pillars and sectors of the country (187).

Around the previous thirteen years, Egypt has faced the challenges provided by the 2008 worldwide financial and economic crisis, the political and social unrest that began across 2010 in Middle East and North Africa, and two major nationwide uprisings in 2011 and 2014. Egypt overcame these obstacles by adapting and setting the stage for future development. By having vision, having strong political leadership, having active public support, and working together internationally and regionally.

Prior to the SDGs' launch in September 2015, The Egyptian Constitution, which was produced and ratified in January 2014, includes a commitment to sustainable development (188). This modified Egyptian Constitution, which was approved by a national referendum, aligns strongly with philosophy, concepts, and aims of SD and the global agenda for 2030. It takes into account the three SD dimensions as well as several of the 17 SDGs, which are referenced throughout its articles as aims, uniting all sectors and government levels and asking all decision makers are necessitated to take part in state-led development phase that aims to accomplish them. This new constitution is a vast advance over the last one since it guarantees residents' access to better healthcare, education, and other basic human needs. It includes articles on improving governance, equality, and social justice.

The launching of the Egypt’s Strategy was the beginning of its execution, to move forward towards implementation phase. The government's plan for the period 2016-2018 reflected this strategy. Furthermore, the government has established the SD strategy for the financial year 2016/2017, which serves as the imolementation plan for the initial implementation of SDS Agenda. In

April 2016, the strategy was introduced and approved by the parliament with an overall the majority, and also the yearly plan was accepted in June 2016.

4.2. Triggers for Sustainability and S.D. Goals

In 2015, in Paris Egypt headed the continent of Africa in climate change discussions at Conference of Parties COP21 and established two major African initiatives, the African Renewable Energy Initiative and the African Adaptation Initiative, through the President El Sisi in his capacity as coordinator of the Committee of Heads of States for Climate Change (CAHOSCC). Egypt recently chaired Africa's 10th Committee on SD to integrate Agenda 2063 and SDG implementations. In April 2016, Egypt organized the 6th special conference of the African Ministerial on Environment as part of Egypt's leadership of the African Ministerial Conference on Environment (2015-2017), where African Ministers adopted the decision (DSS 1/SS6) on Implementation of the 2030 Agenda for SD, the SDGs, and the African Union's Agenda 2063.

Also, Towards the achievement of the United Nations Sustainable Development Goals (UNSDG) (63) The current Egyptian administration's strategy is to take advantage of Egypt's large market. The goal is to make Egypt a reliable A rival that attracts investments from around the world. This can only be accomplished by building massive infrastructure projects, implementing An open market policies and country’s currency deregulation (devaluation), and easing regulations and barriers for foreign investors.

Considering that the majority of Egypt's population lives in only 7% of the country's total land area (1.01 million Km^2). Currently, housing capacity is not sufficient to meet future demand, and given that the expansion rate is expected to remain constant, therefore, the Egyptian administration acted quickly to expand urban areas. Housing and the building of new cities far away from overcrowded old cities prioritized in Egypt's investment plans. As a result, today is the day to build more megaprojects that will enhance the country's infrastructure and help it achieve its ambitious future goals, while also supporting a stable investment environment in Egypt (189). these developments must integrate with the sustainable concept, Sustainable architecture should be regarded as a process and a vehicle for achieving sustainable development. These megaprojects account for a significant portion of GHG emissions, which include carbon dioxide (via building materials) and implicitly (via energy usage), which are the driving forces of pollution and cause the global warming effect on the atmosphere (climate change) (190).

Egypt, with its deserts and delta, limited rainfall, these major growth visions, hot summers, huge cities, long coastline, and only major river, Egypt is very susceptible to climate change. Climate change greatly increases water availability uncertainty, so Egypt must be ready for this new reality, and it must begin preparing now.

4.3. Climate change and Carbon Emissions: evidence and causes on the National Scale

Egypt's climate is semi-arid, with warm, dry summers, mild winters, and very little rain. The country has windy areas, particularly along the Red Sea and Mediterranean coasts. Daily temperatures vary according to season and are affected by the dominant winds. Temperatures in coastal area vary from normal winter lows of 14°C (November to April) to normal summer highs of 30°C (May to October). Temperatures in the inner desert areas vary significantly, especially in the summer, varying between 7°C at night and 43°C during the day. Desert temperatures don't change too much in winter, and can reach 0°C at night but as high as 18°C in the daytime. Egypt has (khamsin), a hot storms, which blow dust and sand spreading across Africa's northern coast. These khamsin storms often occur from March to May and can rise temperatures by 20°C in just 2 hours and last for many days.

Climate change is a real fact in Egypt. Temperatures in Egypt rose 0.34°C per decade between 1961 and 2000, according to the UNDP (191). Climate change poses numerous threats to the country like: exacerbated water scarcity issues, reductions in energy generation from clean hydropower, and decreasing agricultural output as yields fall as well as cultivated land decreases, as parts of the Nile delta that threatened by inundation due to rising sea level. in addition, Labor productivity may also suffer as a result of heat stress and poor air quality.

Egypt's per individual environmental impact is steadily increasing. The increase in GHG emissions has resulted in the formation of black clouds. According to the World Bank, Egypt's carbon dioxide emissions increased to 2.5 metric tons per individual in 2016 from 0.5 metric tons per individual in the 1960s (192). Furthermore, Egypt's CO_2 emissions increased from 225 million ($MTCO_2$ e), a standard metric used to measure CO_2 emissions, in 2005 to 275 $MTCO_2$ e in 2010, and are expected to exceed 550 $MTCO_2$ e by 2030. There are five major emitters (190): Energy production, cement manufacturing, buildings, motor vehicles, and agriculture.

Cement contributed approximately twenty-four $MTCO_2$ e in 2005, with a projected rise to seventy-one $MTCO_2$ e by 2030. As a result, it is the most significant source of carbon pollution. The cement industry's capacity is expected to decrease by 14%. While cement will continue to be one of the top CO_2 pollution sources, accounting for nearly 40% of industrial pollution, so it is necessary to put increased focus on cement production (190).

Buildings contributed approximately 62 $MTCO_2$ e in 2005 and are assumed to contribute roughly 165 $MTCO_2$ e by 2030, owing primarily to increased energy use in residential or mixed-use buildings. In the building industry, the average capacity for reduction is about 24 percent. The majority of building pollution is caused by electricity usage and materials production (Indirect emissions, which account for 65 percent of all emissions). The building industry is responsible for nearly two-thirds of all pollution (190).

Because the building industry is the largest of all industries and has a significant impact on climate change (193). According to this stud, freshwater use in buildings accounts for 17%, recovered wood accounts for 25%, as well as material and energy use, accounts for 40% (193). As a result of the evidence presented in this section, there is an urgent need to incorporate sustainable building strategies and programs into the Egyptian economy.

4.4. Low Carbon Building Industry in Egypt

Egypt is a one-of-a-kind country because of its architectural heritage. The Ancient Egyptian adobe vaulted structures, for example, were typically built alongside temples; and those are the adobe vaulted storage rooms. The adobe vault represents one of the longest-lasting architectural forms created in ancient Egypt, dating from the First Dynasty to the Coptic era. The Ancient Egyptians created these vaults after learning how to build with mudbrick. In the Delta, mud bricks made from Nile sedimentation mud were commonly used, while in desert agglomerations, mud bricks made from desert clay were the mainstream. The architects of Ancient Egypt used adobe vaults both above and underground (in homes and magazines) (in tombs). Egypt's oldest known adobe vault was discovered in the tomb 3500's secondary graves (Qa'a) in the 1st Dynasty necropolis of Saqqara (194). More well-known examples have been discovered in tombs at Beit Khalaf (tombs K1 and K2), Raqqah (tomb R1) (195), and Saqqara (196).

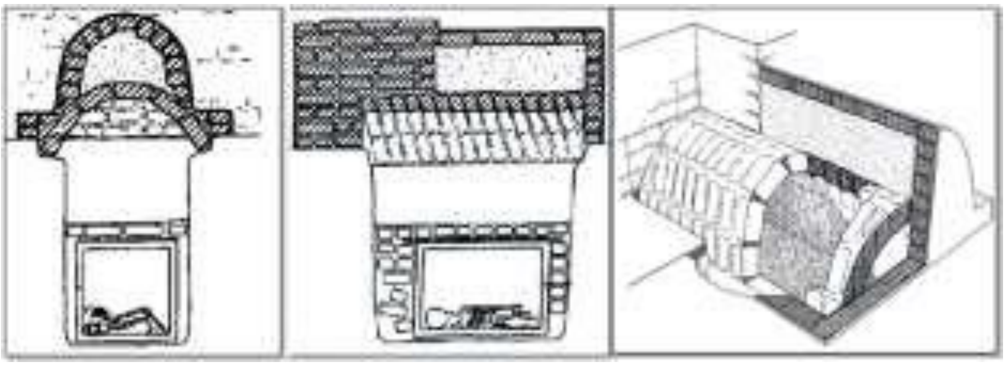

Figure (34): The oldest known Egyptian vaults were discovered in tomb Qa'a at Saqqara, and are made of one course of adobe masonry.

Source: El-Derby, A. A. O. D., & Elyamani, A. (2016). The adobe barrel vaulted structures in ancient Egypt: A study of two case studies for conservation purposes. *Mediterranean Archaeology and Archaeometry*, *16*(1), 295–314. https://doi.org/10.5281/zenodo.46361.

Besides that, there are numerous examples in Old Kingdom funerary architecture where adobe vaults and arches were prominent, and where thick adobe vaults and arches were utilized either above or below ground in large Mastabas in Saqqara, Dendera, and Dara (196) , (198). Many separate adobe vaults were utilized to cover burial chambers in many cemeteries in the Middle

Kingdom, and some other examples of these burial vaults were constructed of burnt brick (198). Brick vaults were only used in a few domestic buildings (199).

Funerary adobe vaulting was still used in the 2nd intermediate period and preceding the New Kingdom, as evidenced by the vaulted roof of Mastaba the causeway Fara'un's (200) and the vaulted chapel at Mazghuna's south pyramid (201).

Throughout the New Kingdom, ancient Egyptian architects tended to favor rock-cut tombs, and continued to use Vaults of brick in funerary architecture, especially in Deir El-Medina and Dira Abu ‘Naga, as well as governmental buildings and palaces.

Brick vaults were popularly used for all purposes from the Late New Kingdom period onwards (198), where they appeared used widely in the late period domestic architecture, and more widely during the Ptolemaic and Coptic periods, such as those houses at Karanis, Dime, Mediante Habu, and Edfu (198).

Ancient Egyptian architecture was mostly made of stone and mud brick. bricks from mud were utilized from the beginning to build homes, palaces, farm buildings, magazines, workshops, castles, and enclosure walls, in addition to temples as well as tombs; the stone was the primary building material among the most significant temples and tombs dating back to the Old Kingdom. Near the end of the Early Dynastic Period, the initial unfired mud bricks appeared and immediately supplanted wattle and daub. it had been the most popular building technique, but it was only used to build temporary structures in later periods.

Later, once the technique of the burning bricks to improve their specifications was developed, a large quantity of clay brick factories were built on the Nile banks in Delta cities, using Nile valley raw material (mud).

Figure (35): The Pharaonic brick industry.

Source: Abdelmegeed, M. (2020). Modified Mud Bricks for Strengthening Historic Earthen Structures: Towards Sustainable and Green Restoration. *Shedet*, *7*(7), 263–276. https://doi.org/10.21608/shedet.2021.29729.1001.

Beginning with the 18th Dynasty, the sandstone replaced limestone as the primary building material in the Theban region and other southern sites. Numerous different stones used for the casing, door frames, and architraves included basalt, granite, travertine, quartzite, and porphyry (203). blocks from stone were delivered to the construction site by boat, then by specially constructed roads and ramps (204).

Wood was used in pharaonic architecture as well, but on a small scale. Timbers were used to construct flat roofs and were put at regular intervals into the massive mud brick walls (198). beams from wood are utilized in the stone buildings to support lower and keep stone blocks in place, as well as to support damaged buildings (204). Wood was also utilized to construct scaffolding, but it was primarily used in the final stages of construction to enhance and decorate the walls, However, it is possible that it was not widely used due to Egypt's lack of timber.

Timber was considered a vital part of architectural buildings at the beginning of Islamic architecture, when wood trade and import became successful in Egypt, particularly for construction works such as ceilings, stairs, domes, columns, built-in cupboards, etc.

In the 1980s, it became illegal to use mud from agriculturally fertile land. This was regarding to the fast depletion of productive land following the construction of a high dam in the 1960s, which stopped the accumulation of river sediments that supplied agricultural lands during the annual flood season. Most clay brick factories were relocated to the edges of cities, and their raw -

materials source was changed to desert clay produced from government-owned quarries.

Currently, there are approximately 3000 clay brick factories in various cities throughout Egypt (205).

Employing approximately 320 thousand direct employees and approximately 2 million indirect laborers. Clay brick manufacturing takes place in around Cairo and some delta cities.

4.4.1. Current Industry Status and Emission Performance

The Egyptian building industry mainly depends on skeleton construction: a reinforced concrete frame provides stability and carrying capacity to the building, before being filled with simple mortar and bricks. Even if an abundance of examples from history demonstrates the durability of bearing walls, this methodology has become the dominant for building construction with several floors or more.

Skeleton construction is definitely adaptable and allows for simple upward extensions. However, small buildings with only one or two floors are increasingly being built in this extremely energy-intensive manner. this type of building emits 438 tons of CO_2 on average. 92% are generated by reinforced concrete (a steel-based construction element) in structural slabs, beams, and foundations, with concrete accounting for 73% and bricks accounting for 8%. changing the construction of smaller buildings to the technique of bearing walls can significantly reduce emissions per building to 183 tons of CO_2. This technique uses masoned walls that support slabs for the ceiling. Saving expensive steel lowering cost of construction. The thick brick walls strengthen the building's exterior, thereby minimizing the amount of energy needed for the cooling and air conditioning systems, thereby reducing carbon emissions.

Several efforts have recently been made around the world to introduce environmental sustainability building materials as a countermeasure to the massive industrialization innovation, the use of natural resources, and increasing carbon emissions (206). However, this has only a limited influence on the majority of Egypt's building industry. Furthermore, because the majority of the population lacks access to information, technology, or technical advice, they are in need of affordably priced good quality housing. A green or sustainable low-carbon material can be a totally new movement, a modification to an existing material's manufacturing process, or a new building technique.

Table (7): Existing Innovations in The Field Of Sustainable Building Materials In Egypt

Building element	Material	Co2 emissions-kgco2	Application	Aspects of sustainability	Obstacles / constraints
Bearing Walls	Natural Stone	0.079 Kgco2e/kg	Common in low-rise buildings such as hotels and remote residences.	Reduce energy consumption by removing unnecessary Reinforced Concrete.	Structural calculations and safety factors, as well as the difficulty in obtaining a licence
	Rammed Earth	48 Kgco2e/m^3	Just few experiments on an individual scale.	Produced on-site with minimal energy that used local soil	Laborious, lack of knowledge, and lack of access to tools
	compressed earth block (CEB)	2.46 Kgco2e/m^2	Just few experiments on an individual scale.	Can just be produced on-site using local materials	Access to tools is difficult, lack of quality control , and knowledge
	Adobe bricks	1.76 Kgco2e/kg	A traditional building material that has been resurrected in some ecolodges and private residences.	On-site production of a local, natural building material	Huge wall thickness, social acceptance, maintenance , and durability
	Cast Earth	-	is a natural material that is composed of cast earth and calcined gypsum.	Construction process optimization (elimination of ramming and excessive form-work in	Still in the experimental stage

Building element	Material	Co2 emissions-kgco2	Application	Aspects of sustainability	Obstacles / constraints
				Renewable Energy)	
	Earth bags	-	Experimented by The Housing and Building Research Center (HBRC) and The Egyptian Earth Construction Association (EECA)	Using locally produced soil which reduces costs.	Still in the experimental stage
	Straw Bale	-	Also experimented by HBRC	A recycled material	in the experimental stage
Ceiling	Domes and vaults: CEB/ Clay bricks/ Adobe	0.24 Kgco2e/kg	Traditional building techniques are being revived in some hotels, private villas, and remote rest houses.	Local traditional skills are more economical, as well as concrete and steel consumption is reduced.	Requires skilled masons, who are becoming increasingly scarce as the tradition fades.
	Flat vaults: Clay bricks and RC beams	0.107 Kgco2e/kg	Experimented in the Aga Khan housing rehabilitation project in Darb El-Ahmar	Minimize concrete and steel consumption, employs more people	Not widely used because beams must be prefabricated.
	Palm reeds (roof panels)	-	Experimented in few projects (ex. A rangers residence in Wadi Al Gemal)	Material that is environmentally friendly and made locally	Used as non structural elements
	Palm reeds (space trusses)	-	In the laboratory experimentation phase	Material that is environmentally friendly and made locally	Starting to move from the laboratory to

Building element	Material	Co2 emissions-kgco2	Application	Aspects of sustainability	Obstacles / constraints
					the production
	Palm reeds (rebars)	-	In the laboratory experimentation phase	Steel replacement inside concrete beams	Under experimentation
	Tree free wood from cotton stalk	-	Experimented by The Egyptian-German Private Sector Development Programme (PSDP) and GIZ organization	Made from recycled materials	Starting to move from the laboratory to the production
Plaster & paint	Lime plastering and lime wash	0.78 Kgco2e/kg	Traditional technique, experimented in the Aga Khan housing rehabilitation project in Darb El-Ahmar	Lime is more environmentally sustainable than cement, has greater workability, and is more cheaper.	To achieve a good quality requires knowledge and training.
	Lime mixture	0.13 Kgco2e/kg	Produced by a private company (Hamco)	A ready-made lime, cement, and sand mixture	Marketing
	Clay	0.24 Kgco2e/kg	Traditional technique that has been revived in some projects	Natural building material	Knowledge, maintenance, social acceptance

Source: Ouf, M. Y., Mahdy, M. M., Ibrahim, S., & ashry, N. (2019). Towards a Sustainable Touristic Buildings in Egypt Using Innovative Wall Materials. *IOP Conference Series: Earth and Environmental Science*, *397*(1), 012024. https://doi.org/10.1088/1755-1315/397/1/012024.

Sustainable and natural building materials are primarily enhanced in the materialization phase in different building typologies, such as hotels, office buildings, residential buildings…etc. In Egypt, the Ministry of the Environment supervise the implementation process and following up on the environmental measures. This is because of presence of a market segment for those kinds of typologies, as well as clients' desire to build environmentally sustainable buildings. Employing sustainable materials in environmental and tourist facilities is thought to be an ideal method to enhance the material and demonstrate its qualities and capabilities. However, the concern of integrating natural sustainable building materials with luxurious and expensive projects would multiply the cost of this type of building project rather than enhancing it as an appropriate building material. figures (32), (33), (34) represent some Examples of sustainable and green building materials in Egypt.

Figure (36): The visiting facilities in the Wadi AL-Hitan protectorate located in Fayoum are built from adobe bricks with load-bearing walls, vaults, and domes produced from locally desert clay. Eco-Architecture is the project's designer.

Source: (https://www.realfayoum.com/wadi-el-hitan/, 2023)

Figure (37): Visitors Center in Marsa Alam's Wadi Al-Gemal protectorate, built with local stone bearing walls and corrugated sheet roofs. Project architects: EECA

Source: (https://www.madaarch.com/c_wg.html, 2023)

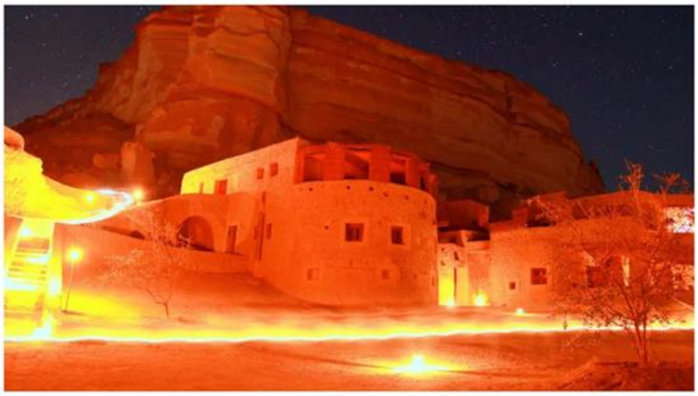

Figure (38): The Adrere Amellal eco-lodge in Siwa Oasis was built using traditional Siwan building techniques and materials. Project architects: EQI

Source: (https://www.ahotellife.com/hotels/adrere-amellal-eco-lodge/, 2023)

4.4.2. Regulations and polices

In order to spread sustainable and low-carbon architecture in Egypt, current legislations and codes must be reshaped. This begins with a review of current local building laws, policies, and rules. Several sections of the Unified Building Law (UBL) No.119, issued in 2008, and its executive annex, issued by Ministerial Decree No. 144, were published in 2009, demonstrate a disregard for important sustainable concepts specially the building materials (207).

These kinds of concepts have been taken into account in the GPRS public review edition published in April 2011 by the Egyptian Green Building Council (EGBC) which was established in the same year as UBL - and the Housing and Building Research Centre (HBRC), but there was no definite time schedule for releasing the final rating system or a timeframe for implementing it. This disunity in building legislation policies ends up making determining the best strategy for spreading sustainable architecture in Egypt difficult. A holistic approach for the greening building codes in Egypt is presented through discussion and criticism on chosen articles from the UBL, a review of the GPRS and its enforcement opportunities, as well as analyses of selected portions of the International Green Construction Code (IGCC) and also the

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard for the Design of high-performing Green Buildings.

In regards to building materials, The IGCC public version 2.0 challenges thirty-seven specific scopes of sustainability and the green environment through its twelve chapters and four appendices, and it includes building materials conservation criteria (208). (Material Resource Conservation and Efficiency) is a specific section that covers resource efficiency, material conservation, and environmental considerations in the following points (209):

1- As a minimum, 55% of any project's net building material usage must be reclaimed, recyclable, or recycled.

2- Waste management and building materials should be planned and implemented in order to reuse and recycle building materials and waste.

3- Fluorescent lamps have a maximum mercury content of 5-8 milligrammes.

In accordance with this section, the building documents must include a building service life plan (BSLP) that specifies the design service life of the building for at least 60 years (210).

Later, ASHRAE published ANSI/ ASHARE/ USGBC/ IES standard 189.1, which is a collaboration between the USGBC and the Illuminating Engineering Society of North America (IES) (211). Furthermore, unlike the old standard 90, Standard 189.1 is concerned not only with energy efficiency of buildings but also with additional requirements such as building materials and resource conservation, as well as building carbon footprint.

The ASHRAE standard regulations that covers the building materials issues named by (Reduction of Materials Environmental Impact) (210):

1- For new buildings, the maximum waste materials is 6000 kg per 1000 sq.m. of all mass in floor area.

2- For every residential building, an area that is created to support the entire building and operate as a repository for discarded materials should be provided.

3- Minimum 50% of nonhazardous demolition and construction waste should be reused or reclaimed rather than disposed of in landfills.

4- Minimum 15% of the building materials used on site must be extracted, recovered, or producted within an 800km radius of the project site.

These standard regulations are complementary to the IGCC regulations; adding both regulations to the unified building law legislations will undoubtedly add an environmental dense to the articles within the law, making it even comparable with other codes from numerous countries like the UK, the US, and Germany, which have made sustainable design mandatory in the building process.

It can be resulted that the Unified Building Law No.119, were not drafted with green and sustainable approaches in mind, and that the GPRS was not created to be compatible with the UBL or its executive appendix. However, it is clear that integration chances exist. The analysis of chosen IGCC regulations, as well as its conformity option, the ASHRAE Standard for the Design of High Performance Green Buildings, reveals the possibility of integrating some of them into the Unified Building Law in Egypt (210).

4.4.3. Strategies and Technologies for Using Low Carbon Materials

1- Improving the use of engineered materials with high durability and strength while using the minimum quantity of material and benefiting from dependable engineering principles like: Structural components (steel/concrete, other...), insulated concrete blocks, trusses, Composite materials with insulating structural panels, and shallow, frost resistant foundations.

2- Implement a construction waste reduction strategy to determine ways to minimize the used materials and the quantity of waste generated.

3- The building industry should adopt a "waste equals food" approach in which at least 75% of all trash is detached out for recycling and then utilized feedstock for a new product instead of being landfilled.

4- Apply for a strong construction waste recycling program, with distinct, Dumpsters neatly labelled for each recyclable material.

5- Train and monitor all crews and subcontractors on the strategies.

6- Determine how to incorporate highly recycled content materials into various parts of the building's elements and finishing.

7- Taking into account all recycled materials, including mixed concrete composed of fly ash, recycled concrete aggregate, slag, floor, or structural steel, carpet padding, and ceiling tiles, carpeting, sheathing, and gypsum wallboard all with recycled content.

8- Investigate the utilization of bio-based structural insulated panels and bio-based finishes and materials, like different kinds of agriboard (insulating sheets manufactured from waste of agricultural and byproducts such as wheat, straw, and barley).

9- Use wood products and lumber products from certified and well-managed forests in which forests are controlled and wood is sourced by using sustainable techniques.

10- Evaluate all systems and products that will be recycled and reused when they reaching their final lifespan.

11- focusing on systems and products that facilitate simple, low-energy detachment and reusing with limited pollution from external debris.

12- Consider the role of transportation in the embodied CO_2 of the building material.

13- Whenever possible, select and utilize local harvested, extracted, and materials which manufactured to promote the local economy while also lowering transportation, energy consumption, and carbon emissions.

4.4.4. Examples of Low Carbon Materials in Egypt

As mentioned in chapter two, Material preparation is the 2nd most significant source of total carbon emissions. This also clearly demonstrates that building materials have significant carbon implications, and calculating their carbon emissions is essential. Concrete, bricks, and steel, as well as emissions generated by mixed with many materials. For every material, manufacturing and transportations emissions must be considered and assuming low-carbon techniques and tried to compare to the material's baseline emissions. The table below represents all material emissions of carbon dioxide from middle income buildings in Egypt over the last 19 years (since 2003), as well as potential savings.

Table (8): Construction Phase carbon Emissions and Savings in Middle-Income Buildings in Egypt during the Past 19 Years

	concrete					**Steel**		**Bricks**		
	Conventional	**Using Type, A**		**Using Type F**						
	Mixed on-site	**Mixed on-site**	**Ready-mix**	**Mixed on-site**	**Ready-mix**	**BF-BOF**	**EAF**	**Clay**	**Concrete**	**Fly Ash**
Emissions in all Buildings (t)	**1,456,592**	**1,390,446**	**1,185,165**	**1,319,300**	**1,097,614**	**88,788**	**80,783**	**755,756**	**469,877**	**206,869**
		66,146	**271,427**	**137,292**	**358,977**	**8,005**			**285,879**	**548,887**
Savings (t)										
		5%	**19%**	**9%**	**25%**	**9%**			**38%**	**73%**

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

4.4.4.1. Alternative materials:

1- Concrete

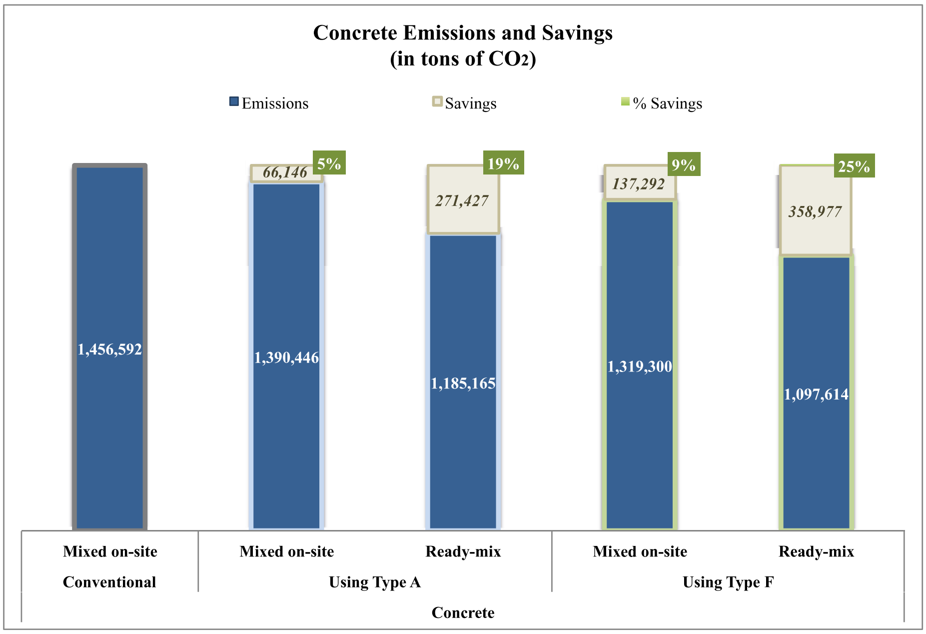

Figure (39): Concrete Emissions and Savings in Egyptian Buildings

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

Table (9): Sustainable Concrete Emissions (Type F – ready-mixed)

Sustainable Concrete (Strength: 25 MPa)									
Additions to the Concrete Mix Adm. Type F	Qty 4		Unit L		Concrete Type				Ready-mix
Concrete Components Qty/m3 (kg)		Vol/R.Bldg (m3)	Roundtrip Distance (km)	Truck Loads	Carbon Emissions/R.Bldg: Transportation Transportation Total in each Production (kg) On-Site (kg) Ready-Mix (kg) Component (kg)				Carbon Emissions in all Residential Bldgs (t)
1. Cement	300			2	55,500			56,023	
2. Water	120			0	0			523	
		185	50				523		1,097,614
3. Fine Aggregates	780			9	0			523	
4.Coarse Aggregates	1410			15	0			523	

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

Concrete configuration assuming ready-mixed concrete and using type F admixture. It results in an additional 16% reduction in CO_2 emissions due to transportation savings (a 25% minimization compared to the base standard case) (212).

2- Steel

The following table shows steel emissions from the two most popular manufacturing routes in middle income buildings over the last 19 years (212). Figure (40) shows these emissions and the possible savings via a low-carbon, sustainable production route had been taken. Due to its lower power consumption, The EAF route should save 9%, or almost 8,000 tons of CO_2 emissions ($KtCO_2$), which is similar to preventing the annual carbon emissions from the power using of 662 houses. Compared to production emissions, transportation emissions are insignificant, accounting in less than 1% of entire steel emissions.

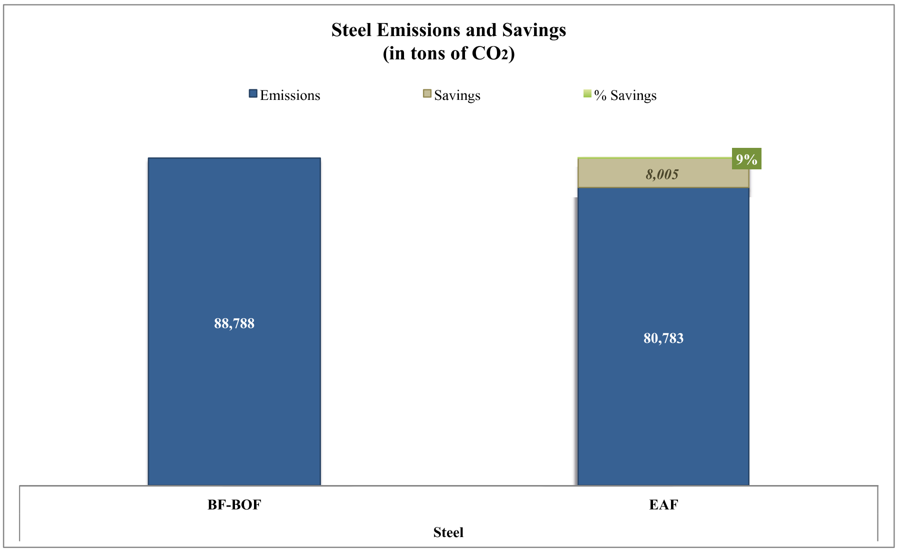

Figure (40): Carbon Emissions from Steel and Building Savings Steel Savings (t) 8,005%

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

Table (10): Steel Emissions in Egyptian Buildings

Steel								
Type of Construction	Production Route	Energy/t (kwh)	Wt. of Steel/R.Bldg (t)	Roundtrip Distance (km)	Truck Loads	Carbon Emissions/R.Bldg		Carbon Emissions in all Residential Bldgs (t)
						Production (t)	Transportation (t)	
Conventional	Basic Oxygen Furnace (BOF)	440				4.62		88,788
			15	50	1		0.039	
Sustainable	Electric Arc Furnace (EAF)	400				4.20		80,783

Steel Savings (t) 8,005 9%

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

The conclusions emphasize the significance of engineering value and sustainable designs in reducing the quantity steel utilised in any structure while maintaining structural safety (212).

3- Bricks

The emissions of three various types of bricks were calculated: clay, concrete, and fly ash. The clay bricks was designated as a traditional type; however, Concrete as well as fly ash bricks were acknowledged as sustainable, low-carbon alternative materials

Table (11): Brick Emissions (Clay vs. Concrete Bricks)

Bricks								
Type of Construction	Type of Bricks	Emissions/ Brick (kg)	No. of Bricks/R.Bldg	Roundtrip Distance (km)	Truck Loads	Carbon Emissions/R.Bldg		Carbon Emissions in all Residential Bldgs (t)
						Production (t)	Transportation (t)	
Conventional	Clay	0.59				35		755,756
			60,000	50	11		4.25	
Sustainable	Concrete	0.34				20		469,877

Brick Savings (t) 285,879 38%

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

Table (12): Brick Emissions (Clay vs. Fly Ash Bricks)

Bricks								
Type of Construction	Type of Bricks	Emissions/ Brick (kg)	No. of Bricks/R.Bldg	Roundtrip Distance (km)	Truck Loads	Carbon Emissions/R.Bldg Production (t)	Carbon Emissions/R.Bldg Transportation (t)	Carbon Emissions in all Residential Bldgs (t)
Conventional	Clay	0.59				35		755,756
			60,000	50	11		4.25	
Sustainable	Fly Ash	0.11				7		206,869

Brick Savings (t) 548,888 73%

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

The tables above show the reductions in carbon emissions that can be reachable by shifting from traditional clay bricks to concrete or fly ash bricks, respectively. Figure (41) illustrates these emissions reduction.

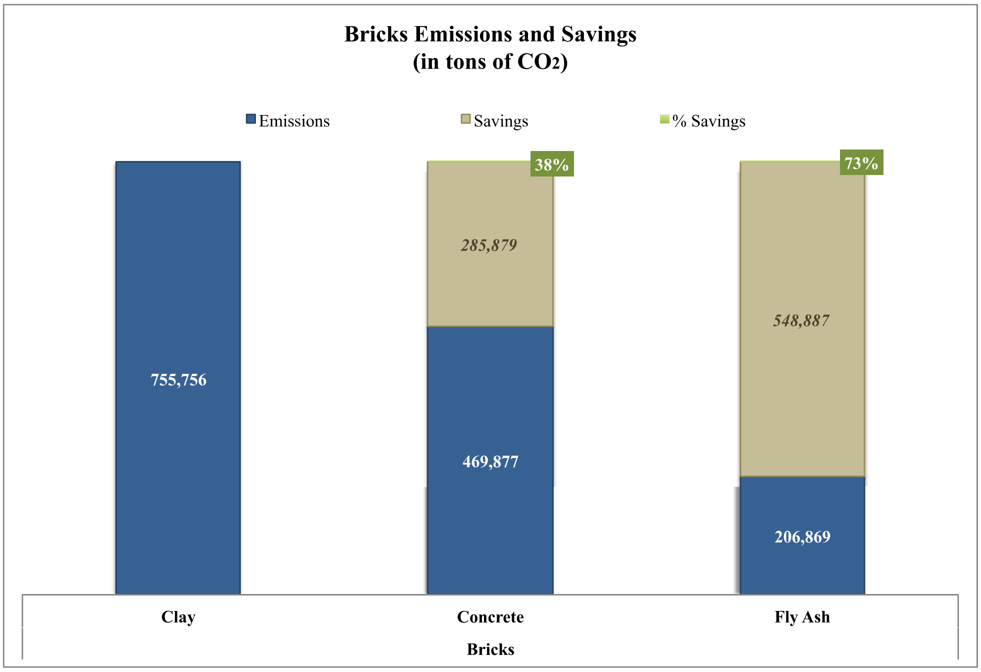

Figure (41): Bricks carbon emissions and savings

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

In comparison to traditional clay brick, concrete bricks save 38% (roughly 286 $KtCO_2$, which is similar to annually reducing CO_2 emissions from the use of power of 23,673 homes). The equivalent savings from using fly ash bricks are 73% (roughly 550 $KtCO_2$, which is similar to reducing the CO_2 emissions from 45,525 homes' energy usage every year). These savings result from the substitution of a chemical procedure in the concrete or fly ash bricks substitutes for the energy-intensive fire process necessary for traditional clay bricks. Also, fly ash bricks result in significantly minimizations than concrete bricks since They are devoid of cement. Changing types of brick has no effect on reductions of transportation emissions, which are the same for all 3 brick types and are approximated to be 5 tons of CO_2 per building.

As a consequence, fly ash bricks should be used as an alternative solution to traditional clay bricks in the Egyptian building industry. However, this may be achieved by providing incentives and tax benefits to productive manufacturers. Alternative bricks, such as earth compressed bricks and blended bricks including 10-20% cement dust, can be considered in Egypt, where the using of fly ash bricks is unusual.

Table (13): Carbon Savings for Various Building Material Combinations

Base Case	**Sustainable Case 1**	**Sustainable Case 2**
Traditional Concrete BF-BOF Steel Production Clay Bricks	Concrete - Type F (ready mix) EAF Steel Production Fly Ash Bricks	Concrete - Type A (ready-mix EAF Steel Production Fly Ash Bricks
No Reductions	30% ~ 916 $KtCO_2$	27% ~ 829 $KtCO_2$
Sustainable Case 3	Sustainable Case 4	Sustainable Case 5
Concrete - Type F (mixed on-site) EAF Steel Production Fly Ash Bricks	Concrete - Type F (ready-mix) EAF Steel Production Concrete Bricks	Concrete - Type A (mixed on-site) EAF Steel Production Fly Ash Bricks
23% ~ 695 $KtCO_2$	21% ~ 653 $KtCO_2$	20% ~ 624 $KtCO_2$
Sustainable Case 6	Sustainable Case 7	Sustainable Case 8
Concrete - Type A (mixed on-site EAF Steel Production Concrete Bricks	Concrete - Type F (mixed on-site) EAF Steel Production Concrete Bricks	Concrete - Type A (mixed on-site EAF Steel Production Concrete Bricks
18% ~ 566 $KtCO_2$	14% ~ 432 $KtCO_2$	12% ~ 360 $KtCO_2$

Source: Saada, J. M. (2015). *A model for the assessment and analysis of the carbon footprint A model for the assessment and analysis of the carbon footprint of residential buildings in Egypt of residential buildings in Egypt*. https://fount.aucegypt.edu/etds.

4.4.4.2. Use of reusable materials - recycling – waste

1- Rice - Straw Brick:

Rice straw residuals in Egypt amount to approximately 3.5 million tons annually. It affects environmental damage and health issues when burned. A lot of Egyptian researches have been conducted to Analyze its potential use as a sustainable, low-carbon material in the brick industry. It can be reused by combining it with cement to create new mixture straw cement blocks that are reasonably priced, recyclable, and provide high thermal insulation (213).

2- Compressed Earth Blocks (CEB):

They are created by compressing the earth inside a mold with a device. According to the Egyptian Earth Construction Association, CEB is a suitable alternative material for construction of walls in Egypt (213).

Figure (42): CEB Blocks are manufactured at the headquarters of the Housing and Building Research Center.

Source: *BFEMU-Volume 43-Issue 2- Page 12-21*. (n.d.).

3- HBRC New Bricks

The Egyptian Housing and Building National Research Center (HBRC) has developed new bricks made from agricultural and industrial waste. Converting solid waste into building material was an innovative idea, given that Each year, Egypt produces 75 million tons of solid trash. These bricks are manufactured from a variety of waste materials (213).

(a) (b)

Figure (43): HBRC New Bricks (a) recycled clay brick (b) Cement dust brick

Source: *BFEMU-Volume 43-Issue 2- Page 12-21*. (n.d.).

4- Innovida Wall Panels

These dense wall panels are composed of 2 sheets of (Glass fibre composite encasing a polyurethane core). Its thermal characteristics can be adapted to every site's climate by utilizing various types of fiberglass fabric. Many countries, including Turkey, Egypt, Oman, and the United Arab Emirates, have begun to use this technique (213).

5- Aerocon Panels

Aerocon panels are composed of two fiber-reinforced cement layers and a lightweight base of Portland cement and binders. this panel is low-carbon and sustainable due to the usage of fly ash and its replacement of wood-based products (213).

6- Insulation Material

A large amount of agricultural wastes may be utilized to generate environmentally friendly thermal insulation materials (Bagasse, Rice hulls, and Coconut coir). In addition to low heat conductivity, low CO_2 emission, and sustainable materials, rice hull insulation panels have reduced moisture levels and greater fire resistance. A rating system is created to identify eco-sustainable thermal insulating materials. To help and guide the architect in selecting the most suitable ecological Insulation Material, every material has a target based on the summation of the following indicators (insulation value, toxicity, waste disposal, diffusivity, cost, and fire resistance) (213).

(a) (b)

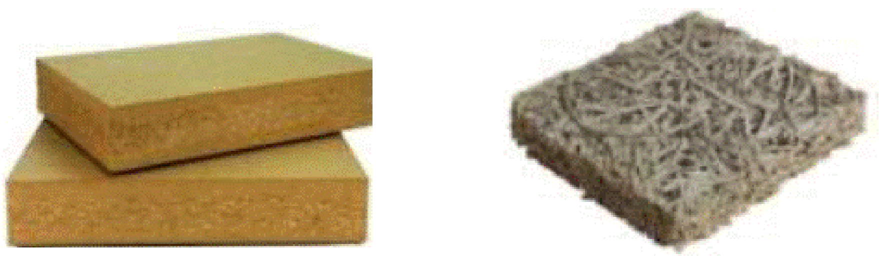

Figure (44): Sustainable insulation material (a) Straw board (b) wood wool board

Source: *BFEMU-Volume 43-Issue 2- Page 12-21*. (n.d.).

4.4.4.3. Use of natural material

Natural materials have lower carbon emissions and toxicity than man-made materials (214).

- **Unfired clay bricks:** the usage of unfired clay bricks in masonry construction has the potential to resolve numerous environmental issues, such as carbon dioxide emissions. It may be an essential innovation for the future of the building industry in Egypt, particularly in regions with a good supply of clays from deserts as source materials (215). In ancient times, unfired clay soil was a popular building material in rural regions. These materials came in a variety of forms, including sunbaked bricks, mortars, and plasters. Besides that, the clay material's ability to be easily recycled by pulverising and soaking without interfering with environment has enhanced the adaptability of this material as a sustainable low-carbon material (216).

- **Rammed earth:** Rammed earth emissions have three times lower than the embodied emissions of using traditional techniques like fired bricks (217). Rammed earth also enhances thermal characteristics and minimize energy consumption for heating and cooling (218), which is insignificant in comparison to traditional methods that use concrete and fired brick.
- **Natural stone:** the carbon emissions from natural stones are very low for example sandstone and granite 64kg of CO_2 equivalent (CO2e) per ton of sandstone and 93kg per ton for granite.
- **Bamboo floor:** Bamboo used in both interior and exterior design. It is a low-carbon and robust building material (213).
- **Linoleum:** It is a renewable, natural, long-lasting, durable, low maintenance product that produces energy at the conclusion of its life span (213).

Figure (45): Linoleum.

Source: *BFEMU-Volume 43-Issue 2- Page 12-21*. (n.d.).

4.4.4.4. Use of local materials

Using locally manufactured building materials reduces transportation distances, significantly minimizing air pollution caused by vehicles. Local materials are frequently more adapted to climate conditions. It may not always be available to use local materials; however, if imported materials are required, they should be used carefully and in very little quantities (214).

4.4.5. Examples of low carbon buildings in Egypt

4.4.5.1. The visiting facilities in the Wadi AL-Hitan protectorate

Figure (46): The visiting facilities in the Wadi AL-Hitan protectorate located in Fayoum are built from adobe bricks with load-bearing walls, vaults, and domes produced from locally desert clay. Eco-Architecture is the project's designer.

Source: (https://www.realfayoum.com/wadi-el-hitan/, 2023)

The Wadi Al-Hitan protectorate in Fayoum unfolds a unique blend of architectural ingenuity and sustainable practices in its visitor facilities. Constructed from locally sourced adobe bricks, the structures boast load-bearing walls, vaults, and domes, all expertly fashioned from the rich desert clay indigenous to the area. This choice of building material not only pays homage to traditional construction methods but also seamlessly integrates the facilities with the natural surroundings. Embracing the ethos of eco-conscious design, the visitor center at Wadi Al-Hitan relies significantly on a solar energy system, harnessing the power of the desert sun to meet its energy needs. This forward-thinking approach not only aligns with contemporary environmental values but also ensures a minimal impact on the delicate ecosystem of the protectorate. The Wadi Al-Hitan visitor facilities stand as a testament to the thoughtful intersection of heritage preservation, sustainable architecture, and responsible energy consumption in the heart of the Fayoum region (229).

4.4.5.2. Visitors Center in Marsa Alam's Wadi Al-Gemal protectorate

Figure (47): Visitors Center in Marsa Alam's Wadi Al-Gemal protectorate, built with local stone bearing walls and corrugated sheet roofs. Project architects: EECA

Source: (https://www.madaarch.com/c_wg.html, 2023)

Nestled within the captivating landscape of Marsa Alam's Wadi Al-Gemal protectorate, the Visitors Center stands as a harmonious union of modern functionality and respect for the local environment. Crafted from locally sourced stone, the center's load-bearing walls not only pay homage to the region's natural aesthetics but also ensure a seamless integration with the surrounding desert terrain. The choice of local stone reflects a commitment to sustainability and a desire to minimize the ecological footprint of the construction. Topping the structures are corrugated sheet roofs, a pragmatic design choice that not only protects against the elements but also contributes to the visual appeal of the center. This combination of traditional building materials and contemporary design principles creates an inviting and environmentally conscious space that resonates with the essence of Wadi Al-Gemal. The Visitors Center serves as a gateway to the protectorate, inviting guests to immerse themselves in the natural beauty of the area while showcasing a thoughtful blend of architectural innovation and respect for the unique local ecosystem (229).

4.4.5.3. The Adrere Amellal eco-lodge in Siwa

The Adrere Amellal eco-lodge in Siwa Oasis stands as a testament to sustainable and harmonious architecture. Imbued with the essence of Siwan heritage, the lodge was meticulously crafted using traditional building techniques and locally sourced materials. The walls, constructed with Kershef, a unique blend of sun-dried salt rock and clay, not only showcase the ingenuity of Siwan craftsmanship but also contribute to the lodge's eco-friendly footprint. The ceilings, composed of sturdy palm beams, add an authentic touch to the structure. Doors, windows, and fixtures, skillfully fashioned from olive wood derived from annual tree trimmings, further emphasize the lodge's commitment to environmental responsibility. As day transitions into night, the ambiance is illuminated solely by the warm glow of oil lamps and candles, echoing a profound connection to nature and a dedication to minimizing the ecological impact. The Adrere Amellal eco-lodge is a true marvel that seamlessly blends tradition, sustainability, and the serene beauty of Siwa Oasis (230).

Figure (48): The Adrere Amellal eco-lodge in Siwa Oasis was built using traditional Siwan building techniques and materials. Project architects: EQI

Source: (https://www.ahotellife.com/hotels/adrere-amellal-eco-lodge/, 2023)

CHAPTER 5

A FRAMEWORK FOR INTEGRATING LOW CARBON MATERIALS IN THE EGYPTIAN BUILDING INDUSTRY

CHAPTER 5

A FRAMEWORK FOR INTEGRATING LOW CARBON MATERIALS IN THE EGYPTIAN BUILDING INDUSTRY

Since the starting of the industrial revolution (1750), carbon dioxide (CO_2) emissions caused by anthropogenic have contributed to climate change, causing increasing in global temperatures(219). Anthropogenic activities have already altered the chemical structure of the atmosphere by raising the concentrations of greenhouse gases (GHG), mainly carbon dioxide(220) Various studies indicate that future climate change could have a significant impact on Africa. The Intergovernmental Panel on Climate Change (IPCC) released a broad evaluation of changes estimated in Africa by 2100 for all climate scenarios, with the primary point being that the whole African continent is very highly probable to warm during this century (221). As a result, every government around the world has been looking for new responses to climate change, and they have been studying the opportunities and possibilities for buildings to be converted to low or zero carbon in order to stop future emissions associated with building sectors. A life cycle analysis for carbon emissions produced from a building life cycle must be performed in order to quantify the building's carbon debt(222). As previously stated, the life cycle must be categorised into phases in order to simplify material flow calculation processes within a building's life cycle, building life cycle division has been identified as a critical step in previous studies. in this framework we focus on the materialization in the construction phase.

5.1. Designing A Carbon Emission Measurement System (Tool) For Egyptian Building Materials

Building materials CO_2 emissions ($BMCO_2$) source data were downloaded from the Inventory of Carbon and Energy (ICE) from the University of Bath at the UK. The ICE database limits its scope to cradle to gate, but a thorough evaluation of carbon emissions would consider whole-life implications, including operations and end-of-life considerations, cradle to grave. This Inventory includes a description of approximately 1800 records of embodied carbon and energy for 34 different classes of building materials. the framework consists of three steps:

5.1.1. The main goal

Of this framework is to consider how the building industry could meet the low carbon agenda. This framework is intended for a broad range of construction professionals, including designers, building owners, architects, engineers, end users, as well as manufacturers of building materials and products.

5.1.2. The analysis,

At this step, we must collect data on carbon emission coefficients (including transportation, materials, and equipment consumption) during the construction phase. A quantity calculation sheet is achieved, By importing Autodesk Revit to https://dashboard.bmco2.org/. Autodesk Revit, the most popular used BIM modelling tool in the field of AEC (architecture, engineering, and construction).

5.1.3. The Environment Impact

calculated in this step to produce more straightforward and persuasive findings. The carbon dioxide equivalent (CO_2 -eq) is frequently used as a unit of measurement for carbon emissions. At the construction phase, carbon emissions are composed of a sub-item project and a measurement project (see Equation (1)).

$$C_{con} = \sum C_{sp} + \sum C_{mp} \qquad \text{Eq. (1)}$$

The sub-item or measure project's carbon emissions equal the quota's carbon emissions coefficient multiplied its quantity (see Equation (2)).

$$C_{sp,mp} = \sum CC_q \times Q_q \qquad \text{Eq. (2)}$$

The final result generates conclusions, focus on environmental issues, clarifies the analysis results, suggest replacement of building materials and makes recommendations.

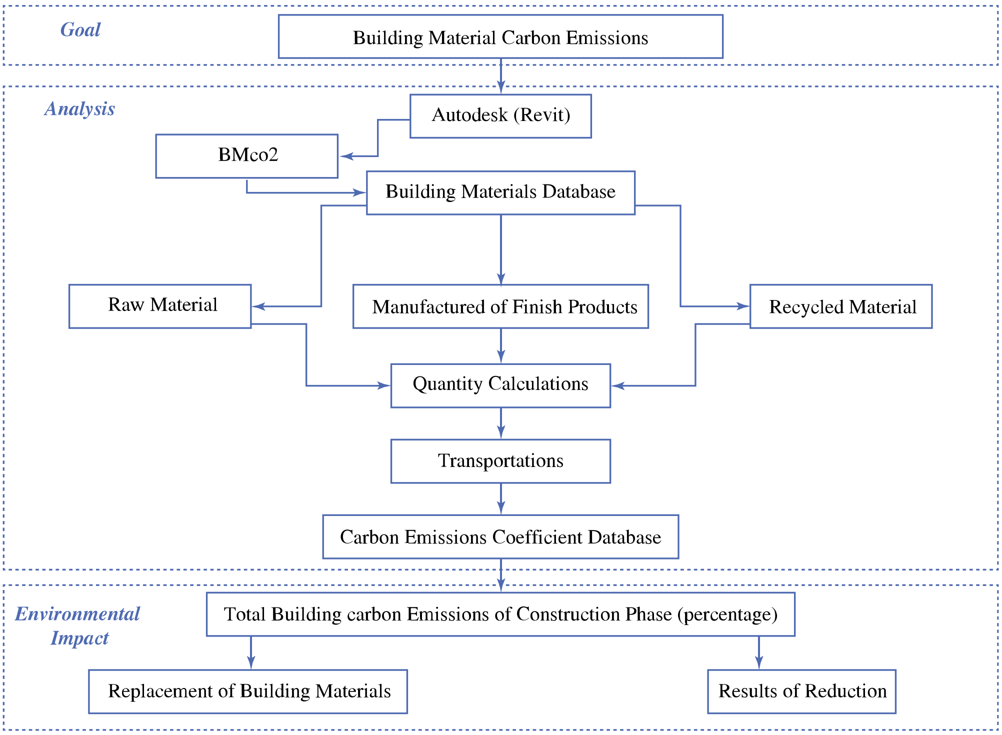

Figure (49): Building materials CO_2 emissions ($BMCO_2$) Framework

Source: Created by the author.

Figure (50): Building materials CO_2 emissions ($BMCO_2$) Framework

Source: Created by the author.

5.2. Applied Study

An Eco Hostel building project will locate in madina al selmaneya, ezbet al safi road, Giza. the total gross floor area will be 100m^2 by using local, sustainable and low carbon building materials. The project will be built by using the Eco Beams techniques, which will be used to frame the house. the building unit consists of two bedrooms, two bathrooms, kitchen, recreation area and a terrace on the upstairs and area for gardening in the backyard. This building technique is strong, secure, easily accessible, easily transferrable, and the material is available on-site for maintenance throughout the building's lifetime.

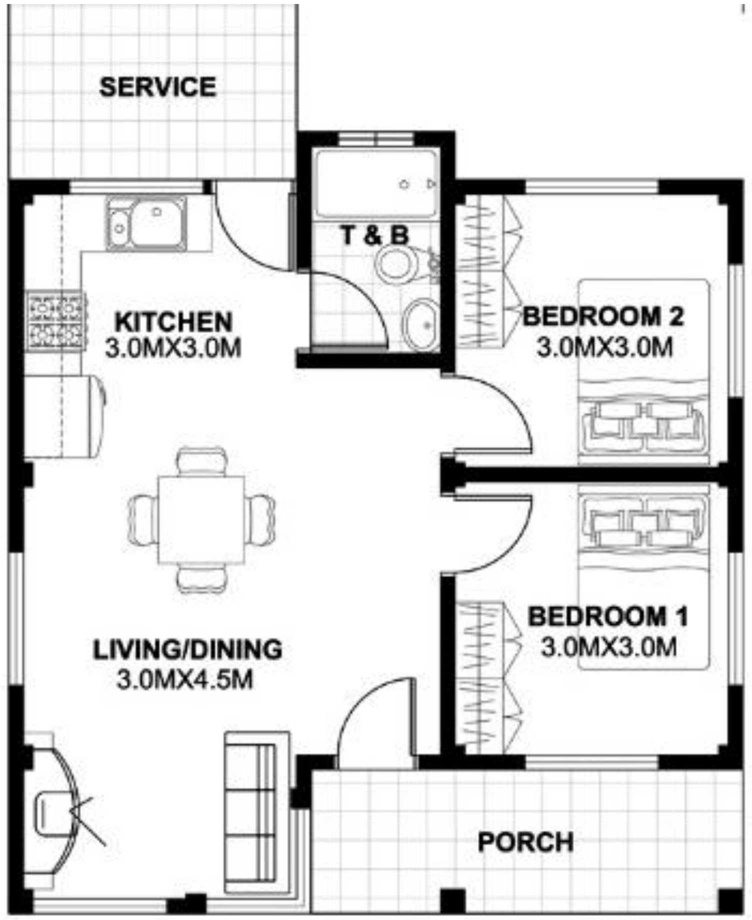

Figure (51): Hostel building project

Source: Created by the author.

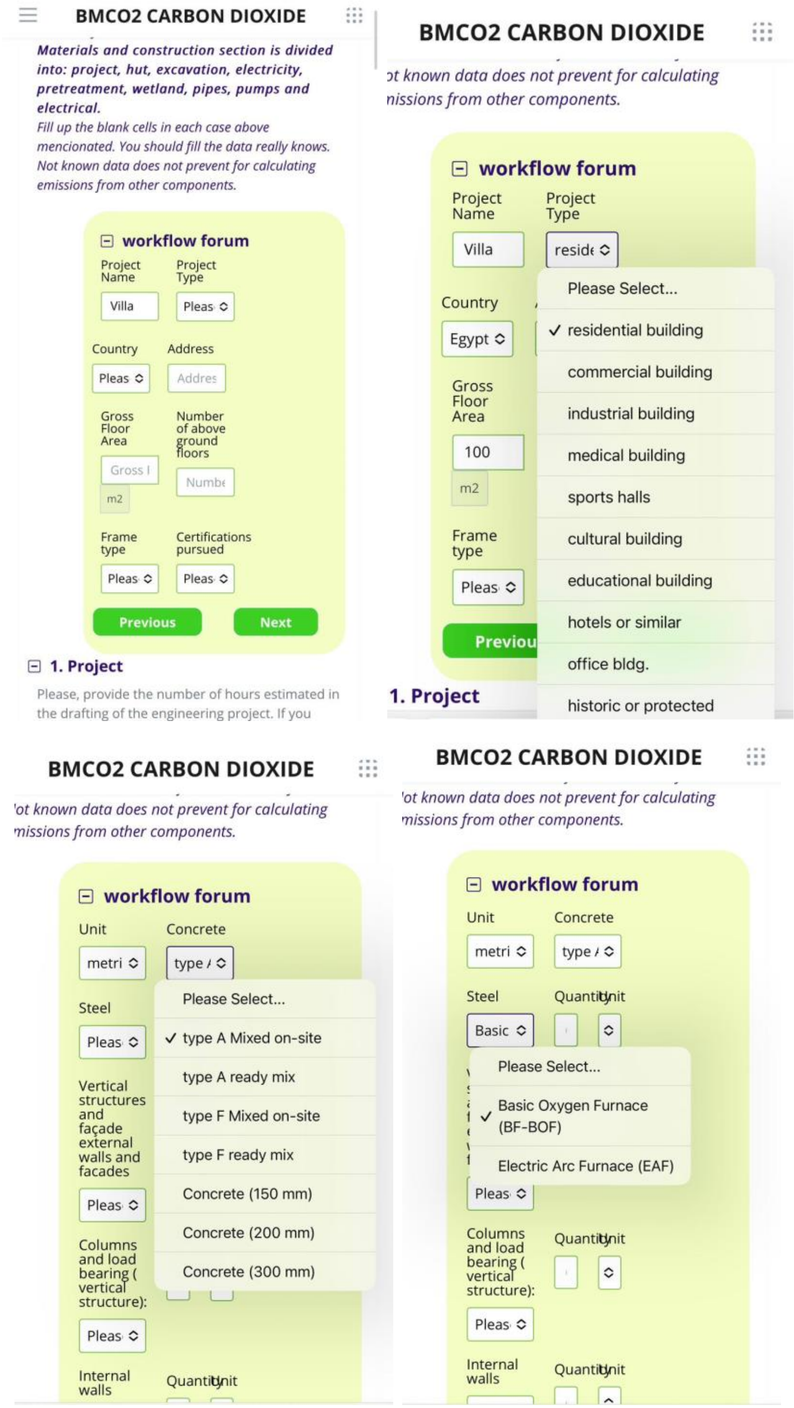

Figure (52): Screenshot for adding building material to the tab of (Bmco2) software

<u>Source</u>: Created by the author.

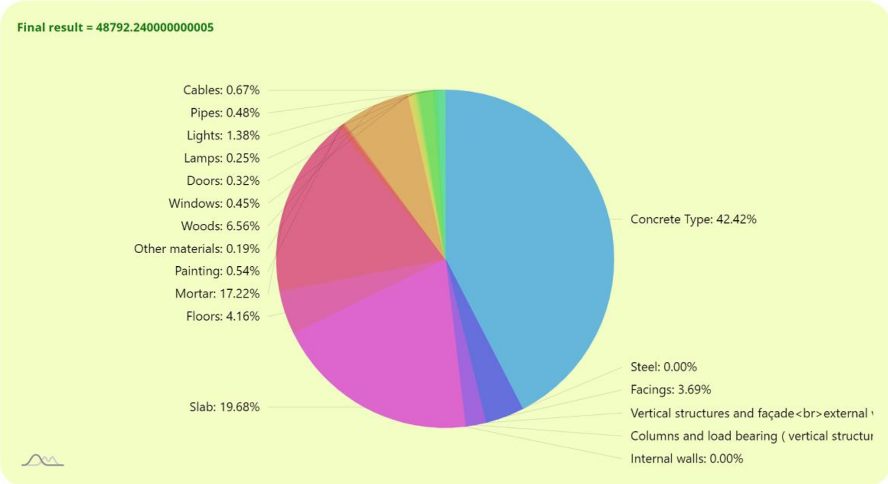

Figure (53): Screenshot from (Bmco2) software for results of calculating emissions from used building materials

Source: Created by the author.

The above figure represents the building materials of the selected project site (Giza) which indicate that the total CO_2 emissions generated is 48792 kgCO_2e.

The Simulation findings suggests some replacement of building materials and makes recommendations for example showed that for every 1000 fired bricks produced, the calculated embodied carbon 5502 kg CO_2e for raw material extraction, processing, manufacturing and delivery of material to the building site. In comparison, for sun-dried bricks, only 0.24 kgCO_2e are emitted. Therefore, if sun-dried bricks are used instead of fired bricks, a reduction in CO_2 emissions up to 5907 kg CO_2e for every 1000 bricks used.

The table below represents a comparative between CO_2 emissions from some traditional building materials and alternative low carbon building materials:

Table (14): CO_2 emissions from some traditional building materials and alternative low carbon building materials

	Traditional building material emissions	Alternative low carbon building material emissions
Concrete Type	Cement, sand, pebbles, broken stone or granite chippings (reinforced).	Slag
	22500 $kgCO_2e$	14400 $kgCO_2e$
steel	Basic Oxygen Furnace (BF-BOF)	Electric Arc Furnace (EAF)
	8028 $kgCO_2e$	2267 $kgCO_2e$
facings	Cement plastering	Plastic paint
	1800 $kgCO_2e$	10.80 $kgCO_2e$
external walls and facades:	red brick (9 cm thickness)	Adobe, sun-dried clay brick for 1000 bricks
	17.7 $kgCO_2e$	7.20 $kgCO_2e$
columns and load bearing	Reinforced steel	Concrete
	1351 $kgCO_2e$	963 $kgCO_2e$
floors	Concrete	Ceramic hollow brick
	5060 $kgCO_2e$	2300 $kgCO_2e$
mortar	Cement and sand	Cement, lime and sand
	12600 $kgCO_2e$	11400 $kgCO_2e$
paintings	Acrylic paint	Plastic paint
	72.8 $kgCO_2e$	59 $kgCO_2e$

Source: Created by the author.

In conclusion, as per the comparative analysis of CO_2 emissions associated with traditional building materials and alternative low-carbon building materials, within the framework of Low Carbon Building Material (BMCO2), accentuates the pivotal role of the design phase in achieving significant emissions reduction. This underscores a proactive approach where sustainable choices made during the initial planning and design stages yield more substantial benefits compared to retrofitting or modifications post-construction. By prioritizing low-carbon alternatives, implementing efficient designs, and considering the entire life cycle of materials, designers can substantially mitigate the carbon footprint of a building. This reinforces the notion that environmental sustainability is best achieved through foresighted decision-making and strategic planning at the onset of a project. As well as the integration of using low-carbon building materials stands as a proactive measure to contribute towards a more sustainable and climate-conscious building industry.

5.3. Frame work Limitation:

While the BMco2 framework has proven to be versatile and effective in assessing and mitigating carbon footprints in various contexts, its application in residential buildings has demonstrated a notable lack of significant limitations. The framework excels in providing a structured and comprehensive approach to understanding and reducing carbon emissions in residential settings. Its adaptability to diverse housing types, energy systems, and consumption patterns has contributed to its success in promoting sustainability at the individual and community levels.

However, it's important to acknowledge that the BMco2 framework, like any tool, may encounter challenges in specific building types beyond residential structures. For instance, in large-scale industrial complexes or specialized facilities, the framework might face limitations in accounting for intricate production processes, unique emissions sources, or industry-specific energy requirements. The complexity of certain industrial systems may pose challenges in accurately capturing and analyzing the carbon footprint within the BMco2 framework.

Moreover, buildings with highly specialized functions, such as research laboratories or data centers, may present limitations due to their distinct energy-intensive operations and intricate technological infrastructures. The framework's generalization may not fully capture the intricacies of these specialized facilities, potentially limiting its precision in guiding carbon reduction strategies in such contexts. As the BMco2 framework continues to evolve, addressing these specific limitations in diverse building types will be essential to ensure its continued effectiveness across a broad spectrum of applications.

5.4. Challenges

Regarding to several socioeconomic changes within the Egyptian community, the use of some low carbon building materials like: conventional structure using mud bricks is no longer accepted by the populace and is being replaced by industrialised building materials. numerous attempts have been made in contemporary times to revive the old mud brick construction, but none have been successful in achieving the goal of utilizing local Egyptian building materials to provide inexpensive homes for the people. Listed below some challenges associated with the usage of low carbon materials in Egypt:

1- Some low-carbon materials are associated with poverty and impairment, while reinforced concrete and burned bricks are connected with modernisation and luxury.

2- Most people consider their home as a lifetime investment and are unwilling to take risks with its construction, making it difficult to get acceptability for a new building material.

3- Open seminars and public events can also serve to promote the material's usage, Without a public-perceivable model, however, the outcome will be useless.

4- The technologies of using low carbon building materials are new in the Egyptian culture, and There is a shortage of information and informational resources on these techniques.

5- there is a shortage of education and trainings for low carbon building techniques, whether to architects, engineers, students, and workers.

6- the building sector is quite conservative, although not always simple to integrate new concepts into well-established surroundings, therefore, to reach the audience for these materials, it could be necessary to engage in advertising strategies.

7- For years, the government has set a wrong example by constructing all of its new government buildings, public buildings, schools, and social housing in both villages and cities with reinforced concrete, regardless of where or in what climatic zones, and even in the oasis of the desert, which has its own unique architectural identity.

8- Local regulations must be modified to be more flexible of alternative materials and building techniques.

9- There are presently no codes or specifications in Egypt that recognise low-carbon materials as allowable building materials.

10- There is no Egyptian local carbon emissions database for building materials.

CHAPTER 6

CONCLUSION

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A straightforward and practical way to minimize the carbon footprint of building, is responsible materials management during the construction phase. the majority of Egyptian buildings are constructed with single-layer brick walls in reinforced skeleton frames (see Figure 46), which is not only inefficient in terms of both thermal performance and energy efficiency but also generates a large quantity of CO_2 emissions that contribute to climate change.

Figure (54): El Gouna single-family home under construction.

Source: Captured by Christoph Banhardt.

Low carbon building materials still face significant challenges in Egypt's construction market. This trend stems from the general belief that traditional materials are more flexible, quicker and more reliable. In addition, the traditional approach is more financially beneficial for the building industry in general which means that the national construction sector has an immediate interest in endorsing it. In conclusion, highlighting the advantages of low-carbon building materials is becoming significantly important to overcome current concerns and promote an ecologically responsible building practise that minimises CO_2 emissions and costs.

Low carbon materials, such as the usage of local building materials, can significantly contribute to resolving Egypt's lack of affordable and suitable housing. The government should approve the shift and begin using local building materials as low carbon materials to build its public buildings and infrastructure. It is suggested to support start-ups manufacturing of building materials by empowering local contractors and implementing supportive regulations and rules.

6.1. Recommendations for Enhancing the Competitiveness of Low Carbon Building Materials in Egypt

1- Improving the social understanding of low carbon building materials via demonstration buildings

2- Supporting cooperative and self-help initiatives

3- Providing education and training by universities and vocational training organizations

4- Documentation and creation of a local carbon emissions database for building materials

5- Establishing a role model as an example through a national housing initiative

6- Providing owner and contractor incentives to employ the material

7- Improving land division and building height planning policies and regulations

8- Developing codes and specifications for low carbon building industry

9- Support small and medium sized manufacturers by empowering local contractors and enterprising individuals

10- Developing a hub-institute responsible for the integration and coordination of all entities

6.2. Recommendations for Future Research and Lessons to Learn

Additional study is required on Local low-carbon building materials and their availability in Egypt. also introducing local carbon emissions database for building materials to help measure carbon emissions from all Egyptian building materials.

Also required study on the social acceptability of the material in order to examine people's opinions and attitudes regarding the redevelopment of low-carbon materials as a contemporary building material employing alternative strategies.

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ARABIC SUMMARY

الملخص

في العديد من البلدان حول العالم، تخضع مواد البناء منخفضة الكربون لدراسات متعددة في السنوات الأخيرة. أما البلدان المتقدمة فقد تم بذل جهد كبير لتشجيع الحد من انبعاثات ثاني أكسيد الكربون من المباني من أجل تقليل غازات الاحتباس الحراري. ومع ذلك في الشرق الأوسط وخاصة في مصر تم إيلاء اهتمام أقل لهذه القضية الهامة. بما أن البيئة المبنية مسؤولة عن حوالي ٥٠٪ من غازات الاحتباس الحراري مما يجعلها أكبر مصدر للانبعاثات ومع ازدياد نمو تشييد المباني. لذلك، وجد أن الحفاظ على مسار نمو منخفض الكربون يجعل بلدنا أكثر كفاءة وصالحة للعيش والاستدامة في نهاية المطاف. وعليه، فإن الهدف الأساسي لهذا البحث هو دراسة ممارسة استخدام المواد منخفضة الكربون في صناعة البناء المصرية لسد الفجوة بين الممارسة الحالية محليًا ودوليًا. لمعرفة كيفية تحسين فرص استخدام هذه المواد في صناعة البناء المصرية، وبالتالي الحفاظ على مسار نمو منخفض الكربون. علاوة على ذلك، ستوفر الدراسة إطارًا لدمج المواد منخفضة الكربون أثناء مرحلة التجسيد، بناءً على فاتورة كميات المباني ونموذج قياس انبعاثات الكربون كمنصة لتقييم انبعاثات الكربون أثناء مرحلتي التجسيد والتشغيل للمبني لاحقًا، يمكن لهذا النظام الأساسي إبلاغ المستخدمين بتأثير تطبيق تغيير في أي من متغيرات البناء أو مواد البناء لتحقيق انبعاثات كربونية أقل.

كلمات المفتاح: مواد منخفضة الكربون – قياس انبعاثات الكربون – صناعة البناء المصرية.

كلية الهندسة
قسم العمارة
قسم الهندسة المعمارية

تم تقديم هذه الرسالة للحصول على درجة ماجستير العلوم في الهندسة المعمارية، كلية الهندسة، جامعة عين شمس.

حيث إن ما تتضمنه هذه الرسالة من قِبَل المؤلِّف، ولم يتم تقديم أي جزء منها للحصول على درجة أو مؤهِّل في أي كيان علمي آخر.

الاسم: هدير عبد الرحمن المسلماني

التوقيع:

التاريخ:

كلية الهندسة
قسم العمارة
قسم الهندسة المعمارية

إطار عمل لدمج المواد منخفضة الكربون في صناعة البناء المصرية

أطروحة مقدمة كجزء من متطلبات الحصول على
درجة الماجستير في علوم الهندسة المعمارية

إعداد

هدير عبد الرحمن المسلماني
بكالوريوس هندسة العمارة
كلية الهندسة – جامعة عين شمس

تحت إشراف

أ.د/ مصطفى رفعت
أستاذ العمارة – قسم العمارة
كلية الهندسة – جامعة عين شمس

د/ وئام محمود
أستاذ مساعد – قسم الهندسة البيئية
كلية الدراسات البيئية والأبحاث – جامعة عين شمس

القاهرة - ٢٠٢٣