Acta Sci. Pol.
Architectura 23 (2024), 56–78
aspa.sggw.edu.pl ISSN 1644-0633 (suspended) eISSN 2544-1760 DOI: 10.22630/ASPA.2024.23.5

ORIGINAL PAPER

Received: 05.12.2023
Accepted: 29.12.2023

TRANSFORMATIONAL GREEN SUSTAINABLE CONCEPTS IN THE FIELD OF INFRASTRUCTURE

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ABSTRACT

In this comprehensive study, we explore the multifaceted world of green sustainable construction, highlighting innovative techniques and materials. This article presents an insightful exploration of green sustainable construction, focusing on the crucial aspects of architectural design, judicious material selection, and the adoption of optimal structural designs. Through comprehensive literature research supplemented by practical examples, it highlights several innovative construction methodologies that are at the forefront of green sustainable development. These include the use of lightweight framing, cladding systems, autoclaved aerated concrete (AAC), rammed earth, and straw bale construction, each contributing uniquely to environmental sustainability. The study brings to light the looming issue of raw material scarcity due to excessive exploitation, urging for sustainable material management in construction. It stresses the urgency of implementing effective pollution control measures within the construction sector, asserting that such practices are not just beneficial but essential for environmental conservation and sustainable development. This research contributes significantly to the field by providing a foundation for future exploration and advancements in sustainable construction practices.

Keywords: sustainable construction, eco-friendly, pollution, wall materials, housing environment

INTRODUCTION

In this modern era, protecting the environment is a major concern for both developed and developing countries, but due to the unremitting population rate, the demand for housing and its development plan increases day by day. It becomes a challenge for engineers and architects to protect resources and adopt environmental technology in buildings. Generally, the resources existing on the Earth are categorised as renewable and non--renewable materials. Due to the growth of modern technology, the construction industry has become the major exploiter of the Earth's resources – about 3,000 Mt annually – surpassing other sectors described in Figure 1; however, continuously extracting raw materials for construction activities poses future threats. Out of various environmental impact agents, the building sector is considered one of the major phenomena that have a serious effect on the environment (Pacheco-Torgal, 2011; Papanicolaou et al., 2016). The construction industry became not only the largest exploiter of raw materials but also the emerging source of generating pollution –

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it is strongly believed that construction activity damages our environment because of adverse impacts, including loss of biodiversity due to raw material extraction, landfill problems, poor productivity of workers, depletion of resources, acid rain, global warming, poor quality of air, and the production of smog during the manufacture of building products and their transportation.

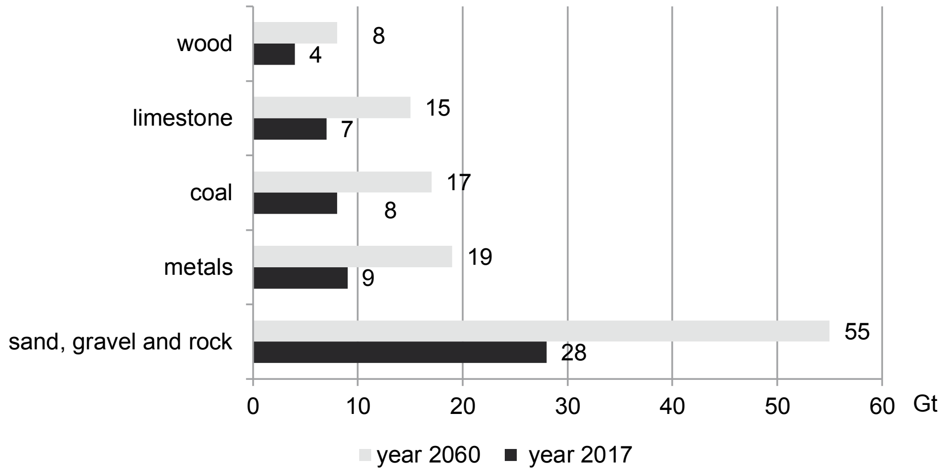

Fig. 1. Estimated consumption of material for construction from the year 2017 to 2060

Source: Organisation for Economic Cooperation and Development [OECD], (2019).

In modern construction, concrete and mortar are extensively used building materials due to their availability and cost; hence, the demand for cement increases day by day, and it directly leads to increasing production. Worldwide every year, it is estimated that cement production alone emits 7% of total carbon dioxide, along with other harmful greenhouse gases (Windapo, 2014). As per a recent study, the current proportion of carbon dioxide in the atmosphere was found to be 550 ppm, with an increment of 2.5 ppm annually and due to this, the mean air temperature has increased at an alarming rate. Additionally, the extraction of river sand through quarrying and mining will seriously impact the environment. In the past four decades, we have faced a lot of negative experiences through the excess extraction of resources, global warming, acid rain, depletion of the ozone, etc. Usually, the impacts during construction are broadly categorised into three types based on the ecosystem, natural resources, and human health. In the case of the ecosystem, fine pollutants are generated in the form of dust during large-scale construction and spread to a large extent. Usually, the dust generated during construction is classified as particulate matter PM_{10} (Song, 2018). Even after implementing several building by-laws and regulations to control those pollutants, health problems for labourers and occupants still exist. In the present method of construction, the materials are more prone to moisture along with the formation of mould, and the presence of toxic substances and particulates in the materials may affect the quality of indoor air, leading to the increase in the possibility of premature death and long-term respiratory ailments such as asthma, chronic pulmonary diseases, silicosis, etc. Additionally, inhaling fragments called respirable crystalline silica – which is commonly found in limestone and aggregates – can cause serious health defects in human beings. Those pollution problems are addressed by creating more environmental awareness and labelling through sustainable and green construction. The term sustainability in the construction field refers to adopting eco-friendly concepts in the case of planning and design to protect the environment at the stage of building construction (Aminu Umar, 2012). Traces of sustainability in our ecological system are found before the prehistoric period. It has been reported that in ancient times, most Chinese buildings used solar heaters to produce heat energy. In Egypt, for the construction of pyramids, they utilised wind power, and some of the tribes in America still use hot springs as a geothermal energy source in their day-to-day activities. In the year 1970, due to industrialisation, many construction companies began to increase their research and laboratory studies to find eco-friendly materials and practices by using renewable energy in their buildings to achieve sustainability in their constructions instead of using fossil fuels (Muthusamy, Subburaj, Shanmughan, Arunachalam & Raja, 2020). Heavy competition between construction companies leads to developing the methods and materials for sustainability issues.

In practice, the main purpose of using green materials and techniques is to achieve energy conservation and sustainable development, and to improve people's coordination with nature. Achieving sustainability in the field of construction mainly depends on the design and selection of suitable building materials. When selecting sustainable materials, it is more important to focus on their performance specification, the rate of greenhouse gas emission and possibilities to improve recycling and the reuse of materials (Li, Liu, You, Chen & Zeng, 2020). From various literature, it is known that implementing the concept of green sustainability in buildings creates possibilities for the development and productive utilisation of materials, equipment, and practices that preserve the green nature and resources. Through this implementation, it may improve the enactment of building in a positive way for the economy, people, and the environment. From most of the case studies, it was proved that the adoption of green technologies in construction can increase ventilation, control inner room temperatures, improve lighting control, and save energy and resources. As per the latest survey conducted in the USA, it was found that when compared to normal reinforced structures, buildings constructed with the green concept can save 30% of energy on average (Janssen & Hendriks, 2002). The main theme of the study is to describe how green buildings can decrease their environmental impact and degradation and create healthy buildings in the field of infrastructure development for occupants, as well as our natural environment. Since people spend most of their time in residential buildings, the focus was on the technologies and structures that are most often used there.

Green sustainable construction – what, why, and how?

The Greek word 'ecology' means the study of the habitats of various living beings in a scientific approach. In the law of nature, all living beings are related and dependent on one another. As per the principle of ecology, the management of a healthy environment is based on handling its resources effectively and efficiently. The term sustainability refers to the functioning of an ecosystem, society or any community through limited utilisation of resources existing in the ecosystem without harmfully disturbing the environment (Klemm & Wiggins, 2016). The concept of green sustainable development is achieved by developing the skill of living with the support of the environment; hence, the green sustainable concept in the field of infrastructure helps to accomplish a stable environment as well as an economically viable one. When an engineer needs to design a building within the concept of green sustainable construction, it is important to be aware of the goal of sustainability, its background, and its economic possibilities. Due to the growth of industrialisation, the theory of 'ecologically sustainable development' has been seriously embraced by many countries from the year 1970 onwards for the growth of economies and environmental sustainability (Petrovic, Vale & Pedersen Zari, 2017). The construction industry is one of the fastest-growing and longest-lasting fields compared to other industries. In this growing stage, usually, it needs an enormous quantity of raw materials to meet its demand. Construction processes have created many environmental impacts, such as the exhaustion of natural resources, emission of greenhouse gases, ozone depletion, and increases in global temperatures.

As per the U.S. Environmental Protection Agency definition from 2014, green buildings are usually defined as a method of creating structures by way of protecting the environment and its resources efficiently for the entire life cycle of a building by careful consideration of aspects such as design, construction, maintenance, operation, and repair. In the past few decades, the concept of a 'green building' has become popular and spread all over the world with special attention to addressing problems such as global warming, undefined change of monsoons, and controlling emissions from the construction industry (Yildirim et al., 2020). In normal construction methods, it is believed that greenhouse gases are emitted only by using fossil fuel directly as a source to produce electricity. However, in most cases, it was also found that greenhouse gases are also emitted through construction materials during manufacture, transport, construction, operation, and demolition. Generally, the materials utilised in the normal method of construction have several pollutants in the form of harmful chemicals, which may cause serious respiratory complications and headaches to both children and adults (Pacheco-Torgal, 2020). However, in sustainable buildings, naturally, the quality of indoor air is better, and the occupants feel more comfort and satisfaction, which has a good impact on their happiness and health.

In general, a green sustainable building has a positive influence over its lifetime by taking suitable actions for human well-being. These kinds of buildings not only contribute to the health of the environment, but also create many advantages and benefits for the owner and users, such as living comfort, lower capital and operational costs, durability enhancement, less maintenance, and a good indoor atmosphere. It is also important to note that the concept of green sustainable construction is not the same in all countries, because the diverse regions of countries are distinctive based on their culture, climatic condition, tradition, building types, economic status, social condition and environmental priorities, which are considered as the main factors of green sustainable construction (Dipasquale, Rovero & Fratini, 2020). Furthermore, green sustainable construction is defined as a kind of development that needs to meet today's requirements without affecting future generations. The concept of green sustainable construction possesses different strategies for the design, construction, operation, and maintenance of projects. The design of such buildings and the choice and usage of material which is suitable for this concept play a major role. As per the latest report, if the green sustainable concept was introduced in the urban areas of developing countries like India, it would be possible to save 8,500 MW of power every year. Building green and sustainable buildings is about constructing buildings that augment the local ecosystem using locally available materials (Correia, Santos, Tonoli & Savastano, 2020).

During the design of green sustainable construction, most engineers feel differently and create that in aesthetic, social, economic, and ecological ways. This construction method is believed to be a chance to swap the dominance of human beings over nature and create a fulfilled connection with the world of nature. For the successful implementation of the green sustainable concept, several guidelines are needed to implement it before execution to remove the problems which are obstructing the root of implementation (Zuo & Zhao, 2014). While implementing the concept of green sustainable construction, it is more important to use renewable energy in buildings for both the conservation of energy and the protection of the environment more efficiently than in non-sustainable buildings. During implementation, there is a need to deliberate on the green sustainable technologies, and utilisation of products, systems, and equipment that preserve natural resources and the environment. At the design stage, the cost of a green sustainable building may seem higher, but during the finishing stage of construction, the outcome proved that it was possible to save money in the form of saving energy, less maintenance, and effective utilisation of waste materials (Tiwari, 2001). It was significantly proved that the implementation of green sustainable technologies in construction meets a high level of performance and productivity in the buildings.

The idea of passive design in green sustainable construction

Passive design is an innovative approach to designing buildings with zero energy consumption. The ultimate aim of passive design in buildings is to eliminate the mechanical systems that consume a lot of energy and to provide comfortable facilities for the occupants (Spiegel & Meadows, 2012). Through this design, it is possible to save up to 40% of energy or eliminate the energy needed for heating and cooling. In the passive design of buildings, the source of heating and cooling is contributed to by natural sources such as solar heat and cold wind. This can be achieved through the proper design of elements such as walls, roofs, floors, and windows of the home, and with this, it also needs to follow the orientation of the buildings (Franzonia, 2011). In a good passive design, the occupants feel thermally comfortable with the minimum energy usage. When designing a passive structure, it is important to consider the following important parameters such as material selection, landscape, orientation, shading, location, massing, insulation, thermal mass, and the position of openings (Fabbri & Morel, 2020). The function of a passive house is described clearly in Figure 2.

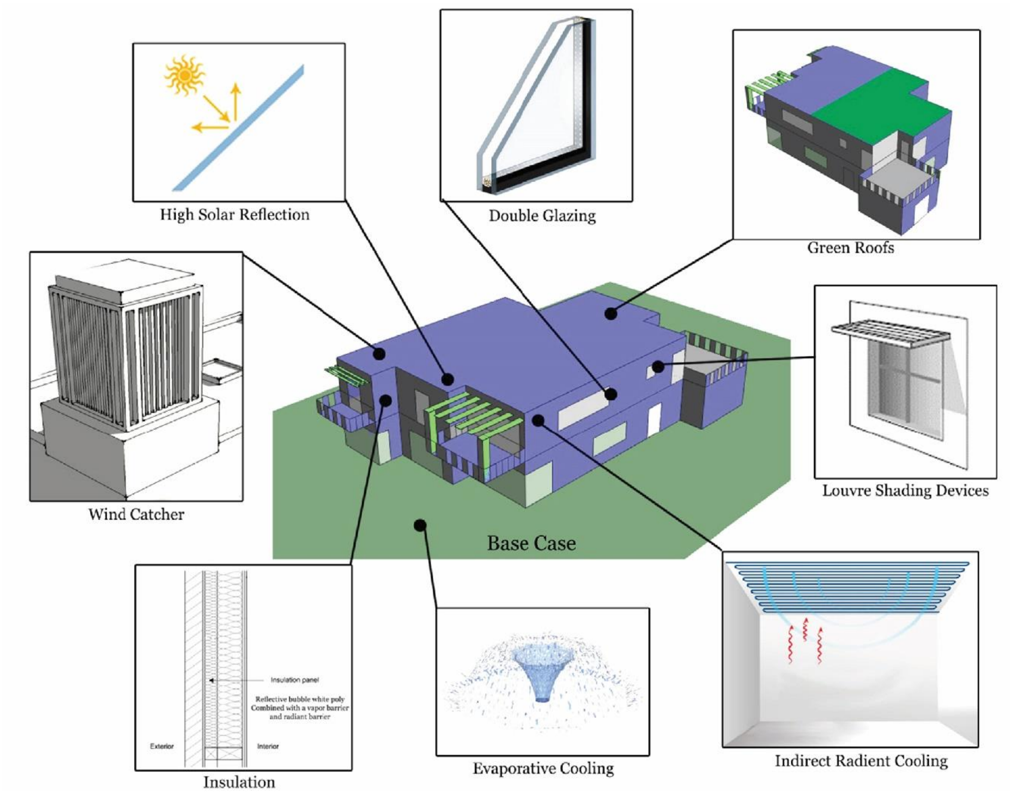

Fig. 2. Passive design model of a building

Source: Taleb (2014).

During the summer season, the sun can generate a huge quantity of radiation in the form of heat directly in each area of the building. At this time, the provision of shading of the outdoor area can reduce the temperature, save daytime energy, and improve the liveability for the occupants. Shading devices such as shutters, eaves, pergolas, window awnings, and planting can block 90% of the heat generated by the sun. To maximise thermal comfort, it is necessary to calculate the different positions of the sun relative to the building's location and analyse the orientation of the building and climatic conditions (Siddique, 2020). The emission of carbon and the generation of high electricity bills can be reduced by up to 25% by providing sealing materials to control air leakage, especially in the winter season. If the gaps are not sealed properly, it can lead to loss of heat and causes problems like condensation and draught. In most passive design constructions, the insulation material acts as a barrier to heat flow, and it also maintains the temperature of a home as cooler in summer and warmer in winter. The choice of insulation materials is mostly influenced by climatic conditions (Walker, Thomson & Maskell, 2020). Most of the construction materials, such as hollow expanded polystyrene blocks, straw bales, and aerated concrete blocks have low insulating value, and may be used as zero insulation. Generally, insulation materials are broadly classified into two types, such as reflective and bulk. Reflective insulation can resist heat flow radiation due to low emissivity and high reflectivity of heat. In this type, based on the direction of heat flow, the rate of thermal resistance varies (Fenner & Kibert, 2017). In the case of bulk insulation, it can resist the heat which is stuck in the gaps of construction materials and act as a medium for heat conduction. In general, materials such as wool, polyester, cellulose fibre, glass wool, and polystyrene are extensively utilised in bulk insulation.

Before installing any type of insulating component, it is important to address issues such as the development of vapour barriers, air gaps, thermal bridging, and ventilation. Installing insulated components in an existing structure or a newly constructed one can always make significant variations in the energy and comfort demand of a building. Apart from this, it is also essential to discuss an important property called thermal mass in the passive design of the building. It is described as the property of a passive building material to store and absorb heat energy at any given time. If the temperature of high-density materials like bricks, tiles, and concrete needs to change, it requires a large amount of heat energy (Collingea, 2015). However, naturally lightweight materials like timber have low thermal mass. To achieve an effective thermal mass, it is recommended to integrate passive design techniques with the thermal mass of the material. In high-mass buildings, to maintain the ambient interior temperature, it needs to lose or gain a large amount of energy. However, in lightweight construction, the interior temperature of the structure is maintained through its natural properties. In passive buildings, during the daytime in the winter season, the thermal mass of materials absorbs heat directly through the waves or radiation of sunlight, and during nighttime, the absorbed radiation is released from the home (Khandve & Rathi, 2015). In the summer season, the cool breeze at nighttime is stored within the material and is utilised by the hot air during the daytime. Good passive design gives the building more thermal comfort with less usage of energy appliances and reduces the emission of greenhouse gases for the entire life span of the structure.

Main elements of green sustainable construction

The basic needs of all living beings are food, shelter, and clothing. Among all of these, our Earth directly acts as a shelter that protects us from natural calamities and provides constant life support. But now, our Earth is standing at the edge of destruction, and our actions are the primary reason for it. In our everyday lives, the activities and things that we use primarily increase the daily rate of the carbon footprint, which is the prime factor of climate change (Kalpana & Mohith, 2019). This also includes how we construct and maintain our homes. The unmetered usage of resources, energy, and water in our buildings majorly contributes to environmental problems; hence, the concept of green sustainability in the field of construction (Fig. 3) is encouraged to overcome all these issues (Costa, Penna, Magenes & Galasco, 2008).

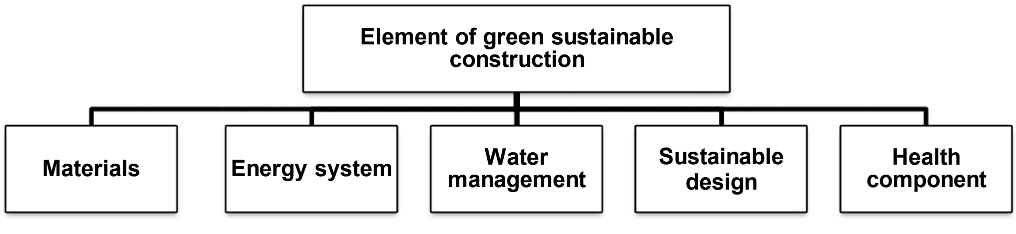

Fig. 3. Primary elements of a green sustainable construction

Source: own work.

Sustainable green construction in the field of infrastructure deals with adopting techniques and strategies to construct a building with the minimum usage of resources and that is environmentally friendly. During design, maintenance, and renovation, a green sustainable building should keep efficiency throughout its lifecycle. The five primary elements, which are shown in Figure 3, make buildings more efficient, effective, and successful (Windstorm & Schmidt, 2013).

Significance of selecting materials for green sustainable construction

Green sustainable construction is a way of utilising resources effectively to meet current demands as well as future demands, and to minimise the serial negative impacts on the environment. In the construction industry, protecting the environment is achieved through using eco-friendly building materials. A concept of green sustainable buildings is that living conditions are improved by giving more attention to the design of buildings and the selection of materials (Magar, 2020). The primary goal of this method is the controlled usage of non-renewable sources of raw materials, and prevention and reduction of waste during construction. In the process of construction, buildings require various materials in their different stages, and the life cycle of the building is determined by the choice of construction materials. In traditional construction methods, materials such as concrete, steel, glass, and aluminium are usually considered high-energy materials; therefore, using these materials in construction may consume enormous energy and increase the level of greenhouse gas emissions. The selection of materials for the construction of green sustainable buildings is considered a very important parameter for its life cycle assessment (Yin, Lawrence & Maskell, 2018). Hence, the process is thought of as a more difficult and challenging one.

The next step involves selecting sustainable building materials by creating an evaluation matrix. Each material used in the project should be evaluated individually to assess its environmental attributes. All the materials are addressed by separate weightage with a rating system to verify whether the material meets the specific goals and objectives of the project or not. Various materials are used in construction today, and each material is required to meet specific complex assembly and functional demands (Taleb, 2014). For example, the materials utilised in the construction of exterior walls generally act as a heat barrier from the temperature of the exterior to the interior, protect habitats from rain and wind, and provide structural stability with adequate exterior and interior finishes. The properties which are desired to meet the demand for green sustainable construction should satisfy the following requirements:

(i) Materials selected should possess the least amount of volatile/toxic compounds.
(ii) Use materials that can lower the water requirement of a building.
(iii) Materials selected should fulfil the quantity needed for a project without compromising durability.
(iv) Use a lesser quantity of PVC materials.
(v) During construction, operation, and maintenance, the materials should have the ability to control environmental impacts.
(vi) Materials selected should have a low maintenance cost, and maintenance should be easy.
(vii) Materials selected should save energy, resulting in reduced operational costs.
(viii) Materials selected should have long durability; hence, the necessity of replacing materials in the future is reduced.
(ix) Materials selected should be able to reduce the amount of waste generated and minimise the unnecessary extraction of resources.
(x) Materials selected should have low emissions and be able to control pollutants present in the air.

Mostly, the materials are selected during the design stage of the buildings. The evaluation of materials is completed at the manufacture, transport, and construction stages, and at the end of the life cycle of the buildings.

Based on the amount of gas emissions, the environmental performance of materials is examined, and the economic performance is examined by the cost of material and labour. Choosing natural, locally available, and durable materials provides benefits such as using less energy, improving the indoor condition of rooms, controlling air pollution during transport and construction, enabling easy installation, and reducing the overall cost of the project (Magar, 2020). Although several things have been discussed so far, further essential factors for selecting green sustainable materials are shown in Figure 4.

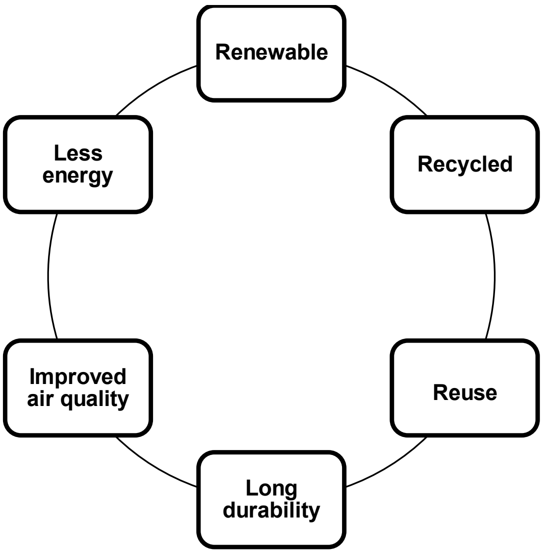

Fig. 4. Factors to consider for the selection of green sustainable materials

Source: own work.

Revolutional concepts in green sustainable construction

As per the previous discussion, it is clearly understood that, during the design of green sustainable buildings, the selection of products and materials should be deliberated as one of the major strategies. The primary objective of utilising green sustainable materials is to achieve better energy efficiency, and using these materials may offer several advantages to the occupants of buildings. In this chapter, it is planned to briefly discuss the properties and application of some modernised green sustainable materials that are revolutionising the field of construction.

Construction using lightweight framing

The method of lightweight framing construction is practised extensively in all developed countries. It consists of a variety of small and uniform components that are closely assembled using steel nailing. Lightweight steel and timber are the major elements that are utilised in this type of construction, and utilising these materials can bring comfortable environmental conditions to the buildings and occupants. Importantly, in areas with highly reactive soils and steep slopes, lightweight frame construction becomes flexible and cost-effective. In this system, the floor element can resist loads from the roof, exterior, and interior walls with the arrangement of suitable footings in the form of piles, piers, posts, or perimeter masonry walls. The appropriate design of openings such as doors, windows, and ventilators can ensure access to natural light, air circulation, and passive solar energy to meet energy demands. In different climatic conditions, a lightweight framing construction system supports a wide range of innovative glazing, lighting, and shading components to achieve thermal comfort. By using timber, this type of construction has low thermal bridging capacity; hence, it can be recommended mostly in areas like hot tropical countries and very cold regions.

When compared to existing construction materials, the lightweight frame materials perform well under both compression and tension. Through the engineering design of structural steel and timber, we can increase the structural stability of a lightweight frame structure and minimise the usage of materials. In this construction, the floor, which is made from wood, is erected initially and behaves as a working platform for the whole structure. The roof is constructed from the desired floor height using rafters or wooden trusses. The interior surface of the walls is created with gypsum boards in the form of sheathing, which provides smooth finishing, increased stability, and fire resistance, as shown in Figure 5. When selecting timber products, particleboard, fibreboard, and plywood are usually used extensively with jointing, glueing, and laminating techniques to ensure tensile and compressive strength. In the selection of steel components, hot-rolled or thin steel sections are mostly used to gain maximum structural stability from the minimum thickness of steel (Lawson, 1996). In general, this form of construction is considered to have low thermal mass and is unable to store passive heat. Due to their low thermal mass, these types of buildings will respond efficiently and rapidly to auxiliary cooling and heating. The insulation level of these structures entirely depends on the depth of the components adopted. It is known that steel is a good conductor of heat and efficient in thermal bridging, and timber is a natural insulator material, but it is inefficient in thermal bridging. Therefore, to maintain the temperature, an artificial insulation layer made from foam-based materials is applied externally, behaving as a barrier against the vapour, preventing condensation, and maintaining the interior temperature (Radhi & Sharples, 2014).

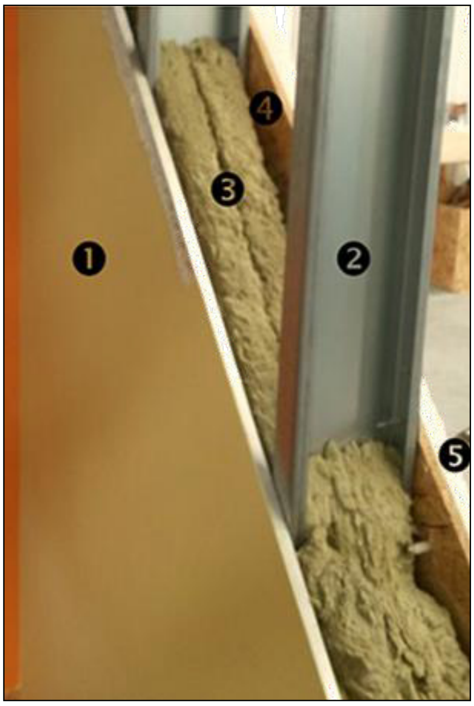

Fig. 5. Typical cross-sectional view of a wall in a lightweight frame construction: 1 – gypsum plasterboard; 2 – cold-formed steel profile; 3 – mineral wool; 4 – oriented strand board (OSB); 5 – external thermal insulation composite systems (ETICS) with thermoplastic expanded polystyrene (EPS)

Source: Santos, Simões da Silva and Ungureanu (2017).

In the case of sound insulation, the materials used in this construction are not efficient as sound travels along the surface of walls, floors, and roofs. Therefore, materials with a minimum level of sound insulation properties are chosen to minimise the transmission of sound. The openings provided for doors, windows, and ventilation are the major sources of sound transmission; hence, it is necessary to close the gaps between the openings with suitable sealants (Radhi & Sharples, 2014). Soundproofing sheets are available commercially as floor and wall elements to control the high emission of sound. During fires, timber rapidly loses its strength; therefore, to achieve better structural integrity while exposed to heat, plasterboard with high fireproof capability is used in this construction at different specifications and thicknesses. Light framing using steel and timber offers stylish design at a reasonable cost, and due to the advancement of technology, there are possibilities to extend the design with minimum resource consumption.

Construction using cladding systems

The exterior appearance of a building is a key element in deciding the quality of a building. Sometimes, due to adverse climatic conditions, the exterior wall surfaces are subject to large defects, and it directly affects the structural integrity and aesthetic appearance of the building. The exterior walls act as a barrier between the inner and outer environments, and the energy consumption of the building also depends on the thermal conductivity of the exterior walls. Therefore, to maintain efficient thermal conductivity, cladding is used. Cladding is like a non-load-bearing component attached to the exterior surface of the walls to protect the buildings from most rainwater and heat. This type of component usually has long durability and improves the aesthetic condition of buildings, as well as provides fire resistance, a smooth, non-dusty surface, and heat and sound insulation, mostly in polluted environments. For every type of project, varieties of cladding are available, and they are quite difficult to explain from one another. Materials such as bronze, stainless steel, copper, and rubber are utilised in the manufacturing of cladding. The system for installing cladding is different, and it's decided based on the type of material used. Sometimes, the claddings are prepared as a composite with a combination of materials such as wood, vinyl, plastic, metal, and masonry. To allow water vapour from the inside to the outside of a building and to maintain the humidity in the room interior, claddings are fixed or placed directly to the walls or in the frames.

Technically speaking, cladding systems are broadly classified into two types: cladding layers and wall systems. In the cladding layer system, the proposed claddings are fixed on the outer finished layer to cover structural components and the outer walls. Through this, the environmental performance, appearance, and thermal condition of the building are enhanced and outdoor pollutants are also kept away. Due to the advancement of construction materials and building technologies, different cladding systems are available on the market. In-wall systems are classified into two types: barrier walls and cavity walls. At the time of constructing exterior walls, the barrier wall system is preferred; through this system, it is possible to integrate the construction joints with the outermost surfaces of the exterior walls. While using this system, the thermal mass effect becomes long-lasting, and the materials used in this method can be recycled and reused in the future. Cavity wall systems are preferred for pressure equalisation in altered climatic conditions. While comparing both systems, we can find a lot of diversifications in their type, thermal performance, fire safety, protection from moisture, durability of the material, acoustic performance, and maintenance. Because of the effect of this system on the environment, its energy performance is varied. Mostly, the structural components of mass wall systems are associated with masonry and plaster cladding systems. In the barrier wall system, polished solid metal plates with exterior insulation, precast spandrel panels, and composite cladding systems are widely used. For the proper functional requirement of a building, it is necessary to select a particular cladding. The poor design of cladding may affect the environmental and thermal condition of a building. The cladding system consists of vertical or horizontal boards, overlapping panels, or sheet materials in the form of tiles and shingles (Fig. 6). The effectiveness of those cladding systems varies based on the intensity of rainfall, the speed of the wind, and its direction. The exterior cladding should have the ability to absorb heat and reflect it, which is also based on the colour of the cladding. Therefore, choosing the colour is of utmost importance, and it's suggested to use a light colour with reflective finishes in hot climates, and for colder climates, dark-coloured cladding systems can be used, especially for roofing.

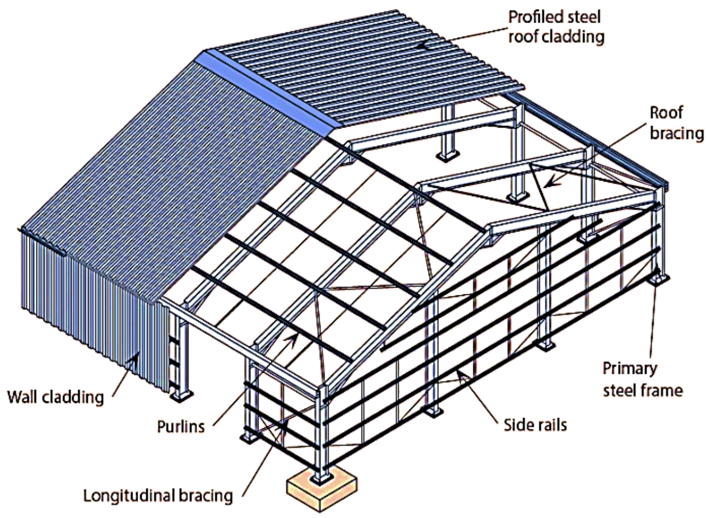

Fig. 6. Industrial building with wall and roof claddings

Source: SteelConstruction.info (2023).

The cladding systems are designed with variations in angles, both horizontal and vertical orientations, and shadow patterns. In a well-designed cladding material, it is noticed that a better appearance and perfect appearance occur in specific conditions. The risk of condensation during heat insulation can be eliminated through adequate design and fixing of vapour cavities in suitable places. The thermal performance of a lightweight framing system can increase using high-mass claddings. Apart from conventional materials, nowadays, claddings are also prepared with agro-based materials like paddy straw and waste paper in combination with bitumen. These products serve as good sound insulators and can be a thermal reflectance. The use of a cladding system can offer possible methods to reduce the environmental impact of the buildings by selecting the proper materials and systems.

Construction using autoclaved aerated concrete

Autoclaved aerated concrete (AAC) is a type of concrete that is made by combining expansion agents with cement and aggregate. It was developed in Sweden by an architect in 1924. At hardening, this type of concrete consists of nearly 80% closed air pockets in its total volume. Due to the presence of air pockets, this concrete is considered lightweight and highly energy efficient. This type of concrete is generally factory-made by placing concrete in a mould with a foaming agent and then cutting it into panels or wire-cut blocks to form the desired dimensions. The molecules in this type of concrete perform well in sound and thermal insulation. When compared to conventional cement blocks, the blocks prepared using autoclaved aerated concrete are lightweight, resist large structural loads, and are an excellent barrier against fire (Raj, Borsaikia & Dixit, 2020). During masonry work, these types of blocks are cut and shaped relatively easily using simple hand tools to the needed dimensions. Autoclaved aerated concrete-based components are extensively used for roofs, walls, and floors. The AAC blocks have equal dimensions; therefore, when used for wall construction, they require less mortar and provide a uniform finished surface. Generally, AAC is light in colour with the presence of visible perforated void particles. Hydrogen gas is used as a foaming agent to react with alkaline materials present in the cement to create small holes within the concrete. Through these holes, the insulation properties of the material are enhanced. To improve the durability of AAC products, some materials, such as natural stone and polymer-modified stucco, are added to the main ingredients (Ferretti, Michelini & Rosati, 2015). However, through these holes or air pockets, water may percolate; therefore, suitable damp-resistant solutions are needed over the surface to prevent the penetration of water.

AAC products are available in the form of blocks, and floor and roofing panels with reinforced lintels. Walls using AAC blocks are constructed using a thin bed of mortar similar to conventional brick masonry walls, and the panel components are erected vertically up to the full height of buildings. The wall panels used for the exterior are generally made as precast units and act as a load-bearing component for buildings with a maximum of two floors. In AAC panels and lintels, structural adequacy is ensured by integrating the steel reinforcement during design and installation, whereas the AAC floor panels are considered as non-load bearing members and heavier (Narayanan & Ramamurthy, 2000). During the erection of floor panels, special care should be taken, and skilled carpenters need to be employed. The thermal performance of AAC blocks is based on the type of climate in which it is used. Due to a combination of air pockets and concrete, the AAC blocks naturally have thermal mass performance, and it is fully achieved when used in flooring and interior works. Compared to the compressive strength of conventional concrete products, the AAC specimens have enough strength and also possess a one-fifth density value of normal concrete, and it is recommended that the AAC blocks are suitable for load-bearing structures. An eco-friendly building is constructed with AAC blocks, as shown in Figure 7.

Fig. 7. Eco-friendly building constructed with autoclaved aerated concrete (AAC) blocks

Source: Daphne Construction (2023).

In the case of thermal insulation, the AAC products meet the same requirements as other masonry; however, it is necessary to provide additional insulation in the form of plasterboard lining to enhance the insulation capacity further. The closed air pockets present in the AAC products act as acoustic materials, and they improve sound insulation effectively (Raj, 2020). For better improvement of sound insulation in AAC constructions, it is suggested to incorporate the asymmetric cavity system within the walls. The materials utilised in the AAC products are mostly non-combustible and inorganic; hence, damage due to fire occurs at a very low rate. Due to its porous nature, the AAC elements are more prone to moisture penetration, especially in harsh climatic conditions; this can be avoided by appropriate design. In terms of sustainable perception, AAC products offer both performance and material aspects. Because of its huge air gaps, AAC products use fewer raw materials than any other construction materials. During testing, it was understood that using AAC material in construction can save 10–20% of the energy required for the heating and cooling system of buildings (Narayanan & Ramamurthy, 2000). The AAC products are usually aerated; therefore, the air circulation within the buildings is greatly improved, and the material does not contain any harmful toxic substances. Hence, there is no chance of any breathing problems for the occupants. However, while manufacturing, the crystalline silica compounds present in the materials may cause some damage to the lungs while inhaling. It can be prevented by using suitable safety protection such as gloves, respiratory masks, and eyeglasses. Additionally, as a single material, AAC has major advantages in both construction and environmental issues, and the investment of material and energy utilised in these products proves that the buildings are intended to stand for a long period of time.

Construction using rammed earth

In many older civilisations, certain types of soils are used as building materials. In traditional practice, materials such as sand, gravel, clay, and silt are compacted at high pressure until the materials attain homogeneity, and often, they need to be compacted repeatedly with the help of wooden poles. To increase the durability and strength, cementitious materials may be added to the compacted soil at a rate of 5–10%. Under different environmental circumstances, the life period of rammed earth material increased through the provision of air sealants with added protection. Around the world, many rammed earth constructions have remained in good condition for many centuries. For example, the Hakka roundhouse shown in Figure 8 was constructed in China 1,000 years ago (Kebao & Kagi, 2012). In rammed earth construction, most of the energy is utilised for quarrying and transporting the raw materials to the site. However, in modern times, stabilising the rammed earth requires difficult labour work, powerful arms, and large mechanical support. Most of the rammed earth materials have less insulation but have good thermal mass. The stable compacted earth material can be used directly in the form of blocks or placed layer by layer in between formworks. Based on the mineral constituent of earth material, the colour of rammed earth material is different. To improve or show the variance in colours, the aggregates should be dipped in different coloured pigments and incorporated into the construction. To get different shapes in this type of construction, the frameworks should be selected with unequal finishes that can be utilised and removed after the wall has been constructed (Easton & Easton, 2012). Generally, the construction materials derived from rammed earth are considered stronger under compression; hence, they are recommended as load-bearing components in the construction of multistorey buildings.

Like reinforced concrete, rammed earth materials can achieve high strength within a short duration. If the reinforcement provided in any form can cause serious issues, it is not recommended. This method of construction is based on onsite activities, so it is important to select the perfect earth material and formwork to minimise the difficulties arising in the construction by planning the services well in advance. When selecting the raw materials, it is important to follow the method of control during batching and sourcing of materials. The thermal mass of rammed earth materials is quite high, and sometimes, the thermal mass of materials is reduced by the passage of heat that travels through the walls (Lindsay, 2020). To limit the energy consumption in these types of walls, they should be properly insulated based on the requirement of cooling or heating. In alternative climatic conditions or variations of daily temperature, the rate of heat flow is reduced by the thermal mass of rammed earth material within the building envelope for nearly 10–12 hours. In heavy cold seasons, the rammed earth walls become a battery of thermal storage, and they provide sufficient heat for occupants whenever needed. In most tropical countries, rammed earth construction is not recommended due to exhaustion from overheating, and the occupants can feel more thermal discomfort. If the insulation properties of rammed earth walls need to increase, the wall thickness also needs to increase, and the insulation is introduced by the provision of a lining within the rammed earth wall. Increasing the thickness of walls during insulation may change the structural behaviour of the walls and increase the project costs (Dipasquale et al., 2020). Meanwhile, the provision of insulation in rammed earth buildings can offer advantages such as texture, acoustics, feel, aesthetics, and low maintenance. The insulation materials must attach to the exterior portion of the wall, and only then does the insulation meet the construction requirements.

Fig. 8. Hakka roundhouses using rammed earth construction, China

Source: Wallis (2012).

The noise transmission and reduction are based on the density and thickness of the wall. Rammed earth interior walls have a high ability to control the sound insulation between different rooms due to their monolithic nature. The materials that are used in the earth walls have good sound reverberation properties and do not generate unwanted echoes like conventional walls. No flammable materials are present in the earth materials; hence, the fire resistance property is good. High durability is the main advantage of these types of construction, but most earth walls are subject to long-term moisture damage due to the porosity of earth particles (Tiwari, 2001). During prolonged moisture exposure, the internal surface of the material may become degraded. Therefore, it is advisable to protect the bottom and top portions of the walls with the proper sealants. On the market, waterproof additive materials are available, and these kinds of materials keep the rammed earth in a breathable condition for a long period. The walls constructed with rammed earth need extremely low maintenance. Once the construction is over, no further attention is needed, at least for 10–20 years. Due to the natural aesthetic appearance of exterior walls, there is no need to spend money and time on painting. Walls constructed with 300-millimetre thickness are load-bearing, and no further structural components are needed. The rammed earth utilises a low energy impact, and the onsite material is enough to meet the demand for construction and reduce the impact of pollution on the environment.

Construction using straw bale

Utilising straw bale for construction is an innovative and sustainable method that uses blocks of straw derived from rice, oats, wheat, or rye and can be used in the form of building insulation and as a structural element. Bales are usually available in the form of two strings and three strings with a typical size of 90 cm long, 45 cm wide, and 35–40 cm high and weigh about 15–20 kg. In green sustainable construction, a building constructed using straw bales is considered a natural building and is otherwise known as brown construction. Straw bales were used over many centuries in the form of thatched roofs and also used with the earth walls in the form of wattle and daub. Straw is a byproduct of grass, which consumes the sun's energy while growing, until it is harvested (Jenkins Swan, Rtiel & Lovegrove, 2011). Straw bales were first used for construction by the people of Nebraska, USA, over a century ago. The major compounds present in the straw are cellulose, silica, hemicellulose, and lignin; therefore, the straw can easily be mixed with soil and form a material called mulch. Walls constructed using straw bales usually have a smooth finish, and earth and cement materials are applied over the finished surface as a rendering to cover the straw bales. The appearance of the finished wall surface is more textural and aesthetic. A load-bearing wall constructed using straw bales is shown in Figure 9.

Fig. 9. Load-bearing wall constructed using straw bales

Source: Walker (2016).

In straw bale construction, the stacked materials are kept in the form of rows over a raised foundation. With this, the straw bales and the supporting platform are constructed like a set of lateral arrangements and the moisture barrier is inserted in between. For longitudinal support, stacks made up of timber or bamboo are provided in the form of pins to hold the bale walls in position, and sometimes, along with these stacks, mild steel mesh also provides lateral support to increase structural efficiency. Later, the finished wall surfaces are plastered using lime or earth-based materials, and the selection of plastering materials is decided based on climatic conditions (Li & Yeung, 2014). Generally, walls constructed using straw bales act as load-bearing for a building. However, they can also protect buildings from seismic and wind loads. Based on research, it was found that straw bale construction has remarkable qualities, and it also suggested that it can be used to construct up to three storeys. Straw bales are usually composed of mostly air; hence, they have low thermal mass. However, plastering materials such as earth and cement have moderate thermal mass, and there is a chance to apply that thermal mass on the exterior and interior portions of the insulated straw core. It is recommended to maintain the 75-millimetre thickness of the plastering material to provide significant thermal mass. In the case of insulation, straw bales have perfect insulation properties compared to other green materials (Correia et al., 2020). When designing any type of building, a special requirement is to arrange and integrate the insulation performance with the overall performance of the building. Likewise, in the design of straw bale buildings, it is also important to provide insulation in the windows and roofs to maintain their overall performance. When compared to conventional buildings, straw bales provide better resistance against sound. Because it is lightweight, the materials provide significant quietness and contribute to the liveability.

In case of a fire, a tightly packed dense wall constructed with straw bales is an airless environment; hence, the chance of a fire is impossible. However, any loose opening may increase the possibility of fire affecting the inner core of the bale construction. To prevent this, suitable air-sealing materials should be introduced during construction. Strict monitoring is needed to ensure the absence of sawdust and loose straw materials during construction. The straw bale walls have excellent resistance against termites; however, traps and bait near the finished surface can prevent the infestation of termites and mice in the future. During prolonged exposure to water, the cellulose present in the straw bales tends to grow fungus that leads to the development of rot, and is considered a major drawback in straw bale construction. It can be prevented by constructing the straw bale wall in a more waterproof way (Berndtsson, Bengtsson & Jinno, 2009). In terms of air pollution, the straw bales can store carbon in vast quantities and thus control the level of pollutants present in the air. The emission of greenhouse gases in straw bale construction is 50% less than in any other concrete construction. The rate of renewable compounds is higher in straw bales, and for long-term applications, the straw bales must have good soil conditions with ecological integrity. Using straw in construction has vast advantages for the environment, and it enables buildings to use less energy and cost less throughout the building's life.

Life cycle assessment of green sustainable materials in construction

Selecting materials in green sustainable construction plays a major role in the evaluation of the environmental impact of a building during its entire life cycle at various stages. Life cycle assessment (LCA) is the tool used to evaluate the impact of the environment in an effective way. The method of life cycle assessment of green sustainable building material is clearly stated in Figure 10 for future investigation. Since 1990, LCA has been used as an important tool for assessing the impact of buildings. In the field of green sustainable construction, LCA has helped building code officials and consumers make clear decisions during the design and construction stages. Also, it explores opportunities for manufacturers to find innovative products with quality and efficiency. A number of tools are available to assess the building environment, energy labelling, selection of construction materials, and indoor air quality. LCA was initially used in the USA and Europe for product comparison, but today, it is widely applied in product design, strategic planning, and government policy (Bribián, 2011). Through LCA, it is possible to assess the environmental impact of buildings on other structures, and additionally, it provides a way to reduce environmental impact through the implementation of trade-off analysis. Generally, the concept of LCA has complex structures that focus on energy and pollutants, and the flow of material both internally and externally within the life cycle perspective. The complexity in LCA means making enhanced decisions, creating eco-friendly designs, and reducing the environmental impact. In the construction industry, the impacts occur at different stages, such as manufacturing, processing, functional use, and disposal of building materials at the end of their life cycle. When using steel, concrete, and wood structural components in any form of construction, LCA introduced an assessment of the GHG emissions and the consumption of embodied energy during the initial stage (Samad & Yahya, 2016).

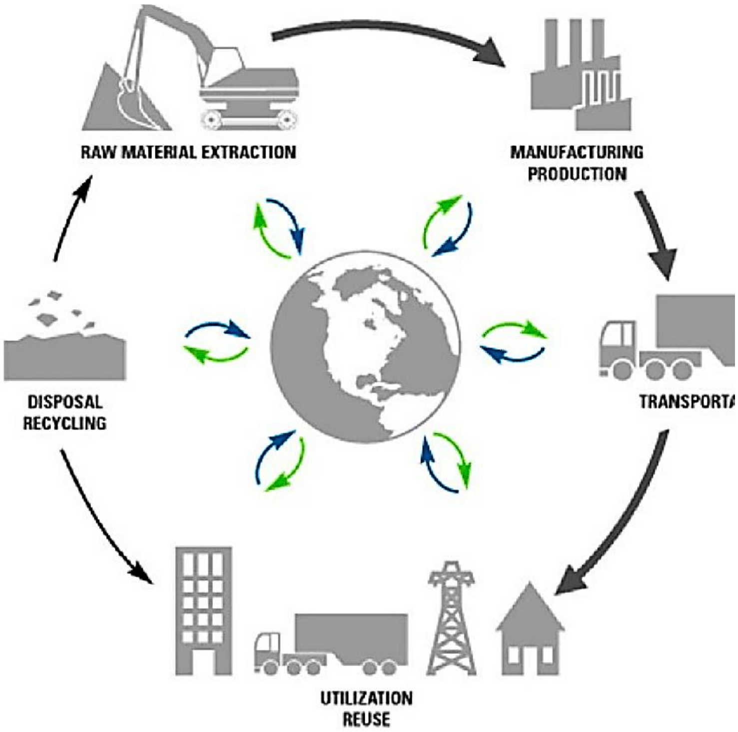

Fig. 10. Life cycle assessment of building materials

Source: Fenner and Kibert (2017).

DISCUSSION

The success of the green sustainable concept depends not only on its materials but also on the methods of construction. In this section, the method of adoption and growth of green vegetative matter over the roofs and walls of buildings are discussed. Growing vegetation along with the buildings provides many essential benefits such as cooling and insulation, production of clean air, reduction of rainwater runoff, energy savings, as well as a joyful and stress-reducing environment for the occupants. A green roof is an innovative type of roof surface that is flat or pitched in nature with vegetation over a waterproof membrane. These green roofs are created in a simple and basic way by using vegetative matter a few inches deep and can establish a mini park-like setup with trees, plants, and recreation facilities for people to use (Cantor, 2008). The green walls are constructed on vertical building elements on the interior and exterior, which provides the support of vegetation root growth in stacked pots. These walls are constructed with green vegetation and are becoming popular due to their design, including benefits such as sound insulation and circulation of clean air. The walls may be designed in the form of outdoor courtyards and indoor lobbies. A hotel building was constructed with a green roof and walls. In terms of economic benefits, green roofs save energy required for heating and cooling and extend the life cycle of the roofs by two to three times (Fig. 11). It also provides opportunities to urban citizens in terms of food production and enhances the biodiversity with the physiological benefits of nature. The latest research conducted by Michigan University reveals that a 21,000 square feet area of a green roof can save around \$200,000 in energy costs during its whole service period. Typically, green roof construction can save between 15% and 25% of energy during summertime in two to three-storey buildings.

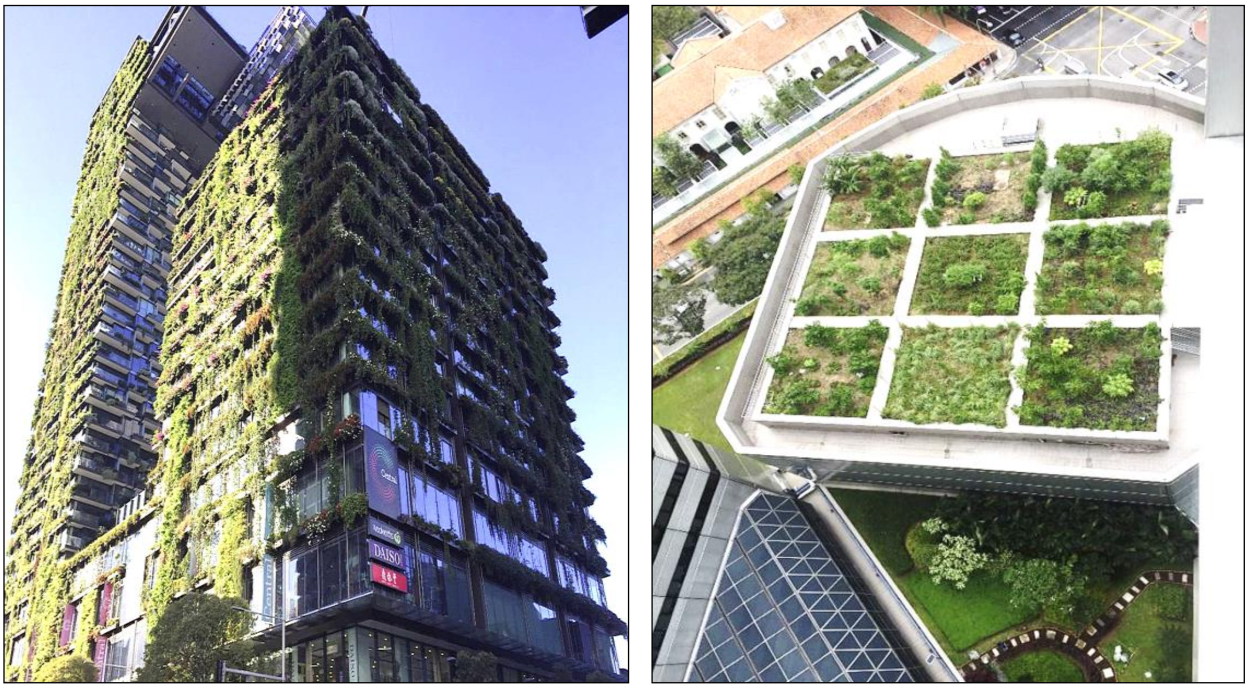

Fig. 11. Hotel buildings constructed with green walls and roofs in Singapore

Source: Beecham and Razzaghmanesh (2019).

Constructing green roofs may substantially increase the weight of the roof, and the roof can hold lots of precipitation, including rain, ice, and snow. The factors that affect the appearance and performance of a green roof are the amount of sunshade, climate, and the reflection of glass from other buildings. A green roof has the possibility to capture 40–60% of stormwater during rainfall, and it considerably decreases the flow rate into storm sewers. The green roofs lead to a 65% reduction in peak flows and a 55% reduction in runoff volumes during monsoon season. Quality water is needed to enable green walls to flourish for a long period via irrigation. Drainage is another important key to prevent clogging and to ensure the gardens do not become saturated. In terms of air pollution, a green roof is capable of reducing particulate matter of 10×10^{-3} μm in diameter and can save 8,300 kWh of energy annually (Yildirim et al., 2020). In extreme climates, a green roof environment provides facilities for agriculture in the form of rock gardens. Green roof technology is mostly adopted in areas which have a denser population and in productive landscapes due to the development of urban environments. In suburban areas, the green wall technique is used in homes as a part of aesthetic enhancement to treat domestic wastewater and improve the response of nature in individual dwellings (Kalpana & Mohith, 2019). Green roofs are generally categorised into two categories: intrusive and extrusive. In the intrusive type of construction, the depth of the green profile ranges from 20 cm to 100 cm in depth. Due to this, the volume of area for holding water and root development is increased, and it leads to the growth of a variety of plants.

This type of roof wall requires less maintenance than ordinary flower gardens. In the extrusive type, the depth of soil contains a lean profile and has environmental benefits such as deeper and intensive green roofs. These types of roof constructions are suggested mostly in areas with desiccating winds and drought conditions.

In certain conditions, green walls may behave as a freestanding structure or as a building's main structure able to support cables, trellises, and frames. Due to the cover of vegetation, green roofs have low thermal mass; hence, the rate of thermal conductivity between the interior and exterior is greatly controlled. In green roofs, the soil and vegetation cover acts as an insulating layer and provides significant shading and thermal insulation to the building (Klemm & Wiggins, 2016). The amount of insulation is dependent on the type and extent of vegetation and the thickness of the growing medium. The soil used in green walls and roofs has the ability to absorb noise emitted from trams, trains, trucks, and buses. Compared to conventional concrete roofs, a 100-millimetre-thick green roof can reduce the transmission of noise by up to 5 dB. The durability of roofs and walls is based on the integrity of waterproof membranes, and the membrane can be protected by less exposure to direct sunlight, which protects against ultraviolet radiation and helps maintain constant heating and cooling of the membrane (Spiegel & Meadows, 2012). Due to the continuous presence of moisture, green roofs and walls offer good fire resistance. Plant selection and long-term maintenance of vegetation are essential to enhance the lifespan of the structure.

FUTURE SCOPE AND RECOMMENDATIONS

The future scope and recommendations for green sustainable construction, as explored in the article, emphasise advancing the field while addressing current challenges. Here are five key points:

- There's a growing need for advanced research in eco-friendly building materials. Future studies should focus on innovating and testing new sustainable materials, emphasising their durability and cost-effectiveness.
- Integrating cutting-edge technology like AI and IoT in green construction can optimise resource usage, enhance building efficiency, and monitor environmental impact.
- Developing and implementing comprehensive policies and regulations that encourage green construction practices is crucial. This includes incentives for using sustainable materials and constructing energy-efficient buildings.
- Increasing public awareness and education about the benefits of green construction can drive market demand. Educational programs and campaigns can play a vital role in changing perceptions and encouraging sustainable practices.
- Encouraging collaboration between government bodies, construction companies, material suppliers, and academic institutions can foster innovation and spread best practices in green construction.

CONCLUSIONS

In addressing green sustainability in construction, this conclusion emphasises the importance of zero energy consumption, the use of low carbon footprint materials, and reducing the overall impact on the environment. Key takeaways include:

- Zero energy consumption is pivotal in green construction, necessitating a balance between reducing greenhouse gas emissions and managing embodied energy in building materials.
- Emphasis on materials with low carbon footprints, such as earthen and wood-based products, is crucial for minimising environmental impact.
- A comprehensive framework incorporating social, environmental, and economic aspects is essential for achieving true green sustainability in construction.

– Life cycle assessment (LCA) plays a critical role in evaluating material impacts on the environment, offering a quantitative approach to sustainable material selection.
– Innovation, research, and development are key drivers in the field of green-sustainable construction, with LCA effectively meeting these challenges.
– Selecting construction materials not only affects environmental sustainability but also impacts the health and comfort of building occupants.
– Active involvement of both government and private sectors is necessary to implement and promote green sustainable construction practices.
– Educational initiatives and certifications in green sustainable materials are important for fostering awareness and advancement in environmental sustainability.

Authors' contributions

Conceptualisation: P.D., D.S.V. and A.S.; methodology: P.D. and D.S.V.; validation: A.K. and W.S.; formal analysis: A.S. and S.K.; data curation: P.D.; writing – original draft preparation: P.D.; writing – review and editing: D.S.V., A.K. and W.S.; supervision: D.S.V.

All authors have read and agreed to the published version of the manuscript.

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IMPLEMENTACJA ZIELONYCH ZRÓWNOWAŻONYCH ROZWIĄZAŃ W INFRASTRUKTURZE

STRESZCZENIE

Celem artykułu jest przedstawienie zagadnień budownictwa zrównoważonego. W artykule wskazano, jakie jest znaczenie samego projektu architektonicznego, doboru materiałów i wyboru optymalnej konstrukcji budynku. W pracy wykorzystano badania literaturowe, wzbogacone przykładami zrealizowanych budynków. W badaniach wykazano istnienie głównych typów konstrukcji, które zrewolucjonizowały koncepcje zrównoważonej infrastruktury zielonej: konstrukcję z wykorzystaniem lekkiego szkieletu, konstrukcję z wykorzystaniem systemów okładzinowych, konstrukcję z autoklawizowanego betonu komórkowego (AAC), konstrukcję z ubijanej ziemi, konstrukcję z beli słomy. Autorzy zwrócili również uwagę na konieczność zrównoważonego zarządzania materiałami w budownictwie z uwagi na ograniczone zasoby surowców naturalnych. Głównym wnioskiem z przeprowadzonych badań jest konieczność kontrolowania zanieczyszczeń pochodzących z sektora budowlanego, co jest niezbędne dla ochrony środowiska naturalnego i zachowania zasady zrównoważonej gospodarki.

Słowa kluczowe: budownictwo zrównoważone, przyjazny dla środowiska, zanieczyszczenie, materiały ścienne, środowisko mieszkaniowe