LIVING CONCRETE AS A LOW CARBON DESIGNER : A FUTURE OF SUSTAINABLE CONSTRUCTION PRACTICES

Abstract

It is well known that the key component of the modern world is 'Cement'. But the Cement production and its composite 'Concrete' formation result into the emission of around 8% carbon dioxide to the environment. There is a need to invest in reducing the catastrophic effect of carbon emission and the best way is to develop sustainable construction practices. The present chapter deals with a concept of developing concrete that is live and grow to reduce the environmental effect of the construction sectors. This chapter suggests the need of 'Living Concrete' as a low carbon designer for developing sustainable construction practices in the near future.

Keywords: Living Concrete; Sustainability; Self-Healing; Low Carbon Designer.

Graphical Abstract: Schematic Representation of the Concept of 'Living

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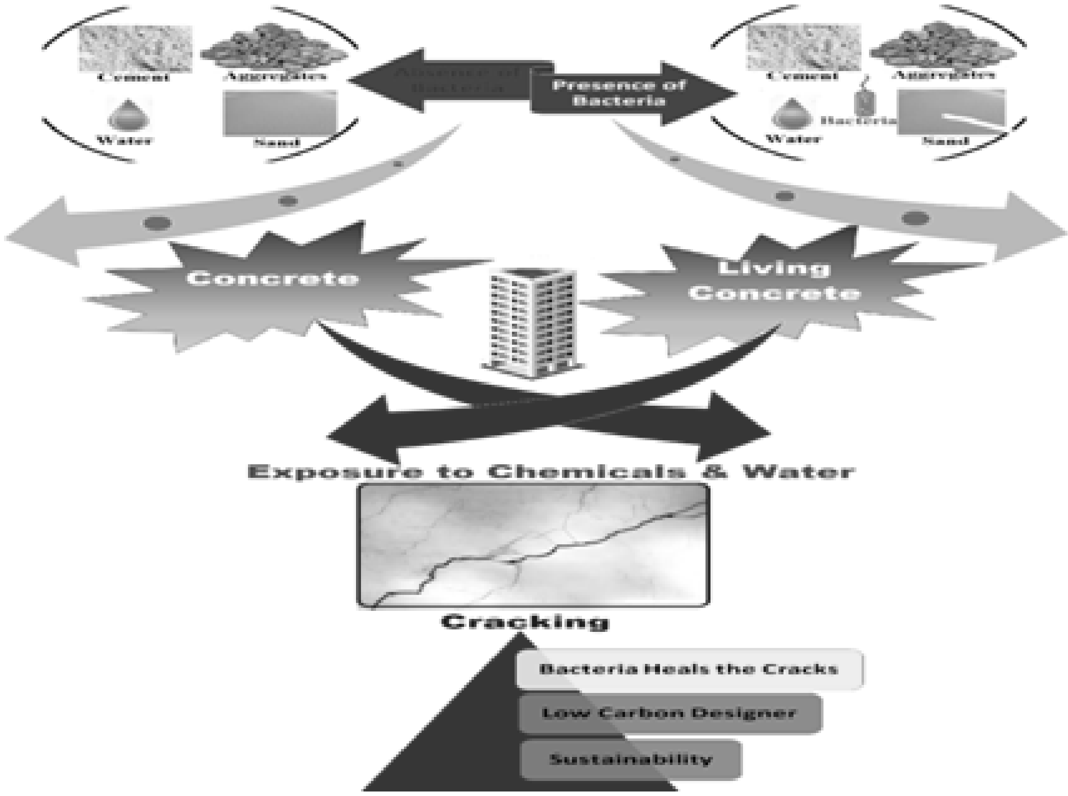

I. INTRODUCTION

1. **The Inevitable Components of Urban Infrastructure:** ‘Cement’ is the most common and a significant engineering material utilized worldwide [1]. Figure 1 highlights the significance of cement as an inevitable component of urban infrastructure. It is a chemical material used to set, hardens and bind other construction materials like sand, gravel etc together. The word cement derived from ‘Opus Caementicium’ which represented ‘Roman Concrete’ [2]. As the name implies, cement consists of calcined lime and clay with the presence of principal constituents such as CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, SO_3 and alkalies [3]. The principal constituents and its proportions are responsible for the unique properties of cement and are discussed as follows:

   - CaO (60-65%) majorly control strength and soundness of construction,
   - SiO_2 (17-25%) gives strength to cement and its excess presence results into slow setting of cement,
   - Al_2O_3 (3-8%) allows quick setting of construction materials,
   - Fe_2O_3 (0.5-6%) imparts the colour and the fusion of various constituents presents in the cement material,
   - MgO (1-3%) imparts hardness and if it exceeds, it causes cracks in concrete,

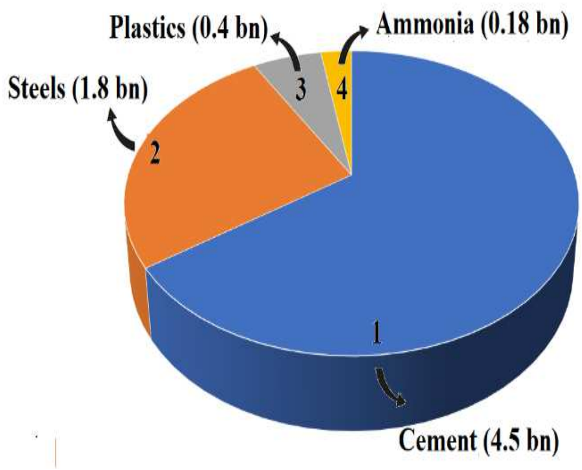

Figure 1: Schematic Representation on the Scale of Necessary Engineering Materials for The Modern World (Given in Billion Tonnes Per Year)

- SO_3 (1-2%) makes cement sound,
- Alkali residues (0.1-l%) and if it exceeds efflorescence and cracking of the concrete takes place.

The above said characteristics of the constituents present in cement lead to its extensive use and the major area covers Masonary work; Engineering formulation; Engineering fabrication; Acid-resistance; Water-proof structures; Supporting structure and Concrete [4] (Figure 2).

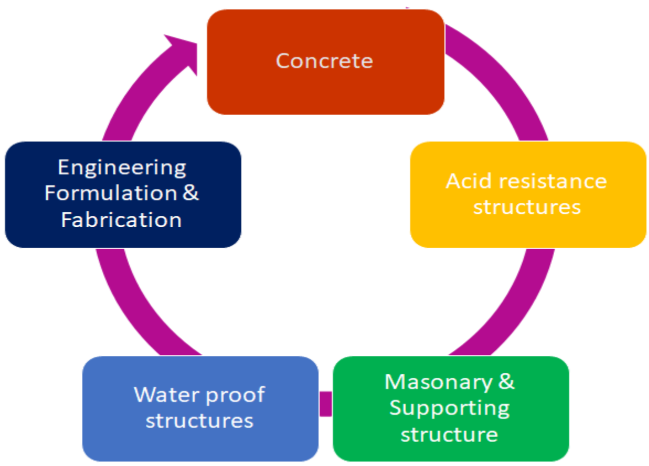

Figure 2: Schematic Representation on various uses of Cement

The weaker nature, difficulty to cure on its own, and its susceptibility to cracking makes less suitable for the cement applications by itself [5]. The versatile nature of cement makes it attractive as a binding substance to form its aggregate 'Concrete'. But there is a need to form concrete by mixing cement with crushed stones, gravel, sand and water. Cement hardens and cures over time to form concrete which is also act as an inevitable component of urban infrastructure. The variety of structures, surfaces and formulation can be formed with cement and its composite concrete as the engineering materials for constructing, developing and maintaining the urban infrastructure.

2. **Carbon Emission – A Catastrophic Effect:** It is known that the cement is the most widely used engineering material in the construction sector and its world production is about 4.5 billion tonnes per year (Figure 1). The cement industry is responsible for the third largest emitter of carbon dioxide in the world [6]. The cement industry emits up to 2.8 billion tonnes of carbon to the environment. The firing of coal or coke in the Kiln resulted into 8% global emission. During cement manufacturing, 900 kg of CO_2 per ton are released to the atmosphere (Figure 3). Between 4-8% of CO_2 emissions are produced by concrete worldwide. The cement production and its use as a concrete have complicated environment that is influenced by CO_2 emissions as well as the direct effects of infrastructure and its development [7].

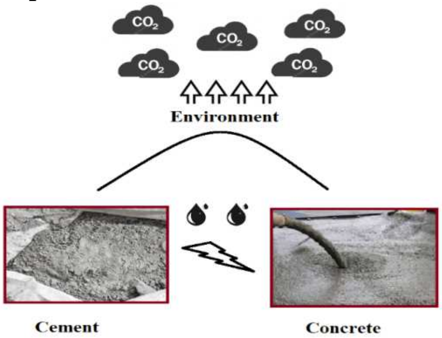

Figure 3: Schematic Representation on 'Carbon Emission' by Cement Production and its Composite Use

This potent greenhouse gas contributes to climate change which can result into global catastrophe. The research aimed at direct exploration of risk associated with climate change is discussed [8]. There is a continued increase in anthropogenic greenhouse gas emission despite the efforts taken by global communities [9]. This carbon emission leads to global warming, sea level rise, weather pattern changes, precipitation pattern changes, ocean acidification and so on. The carbon emission and its catastrophic effect already hit the world by causing disrupt in weather pattern, droughts, floods, hurricanes, heat waves, and wild fires, displacing the people, and triggering massive economic change. There is a threat not only to environment but also to human health is reported. There is a question for the future generation for living in a sustainable world. It is necessary to follow sustainable practices in order to lessen the carbon emission or reducing the carbon emission by switching over to sustainability from unsustainability (Figure 4) which safeguard both the human and the environmental health.

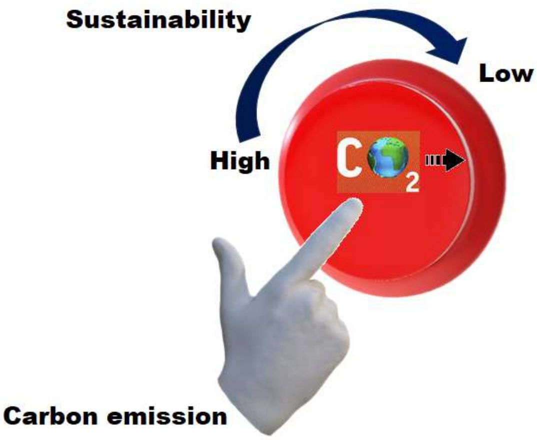

Figure 4: Schematic Representation on Switching Over to Low Carbon Emission to Reach Sustainability

3. **Environmental Problems:** In addition, the concrete itself faces some serious environmental problems as given below:

- May need reinforcement from steel structures to increase its tensile strength,
- Can experience salty deposits on top if the mixture contains soluble salts,
- Can require repairs over time,
- Can crack in cold temperatures,
- Restoration can be more labour-intensive,
- Requires professional installation to ensure structural integrity.

It is a time to monitor the above concrete related problems which causes environmental threatening and give a optimum sustainable solution.

II. SUSTAINABILITY AND ITS PRACTICES

1. **Sustainable Engineering:** It is the engineering process of applying scientific principles in order to design, create, build and use of machines and structures in a sustainable way. This engineering process emphasis particularly on a specified knowledge and its own problem-solving skills but at a rate that does not deplete natural resources. It is insisted that the implementation of sustainability is very important and it is much required at an early stage of engineering process [10]. Among the various discipline, sustainability in civil engineering insists to perform its engineering activities without harming the environmental resources. The sustainability in civil engineering acts as a backbone in project planning, management, and its execution which ensure that the particular assignment is performed in an environmentally friendly manner. The American Society for Civil Engineers (ASCE) defines the sustainability as a set of economic, environmental, and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality, or the availability of economic, environmental, and social resources [11]. Finding a constructive solution for global environmental challenges are associated to the civil engineering process such as smarter way of building innovative materials, intelligent urbanization, and effective designing etc., The commitment towards the above

challenges requires civil engineers to understand their accountability, the environmental problems and actively practices sustainability is inevitable and has always been at the forefront of innovation even in this modern era.

2. **Sustainability Practices:** The term sustainability in ‘Sustainability Practices’ denotes the ability to be developed by human society in order to maintain the ecological balance of the planet. The sustainability practices strongly recommend the environmental, economic and social aspects of human activities to be balanced in order to attain the goal. The sustainability practices can be achieved by each individual by adopting better evolution towards the environment and is referred as sustainable development. It is very essential to organise the principles that aims for sustainable development by sustainable practices and to keep the available natural resources for future generations. There are different ways by which the sustainable practices can be achieved and few of them are listed as: (1) Adopting renewable energy sources like solar, wind, tidal, hydro power etc., (2) Adopting 3R principle (Reduce, Recycle and Reuse) efficiently, (3) Preserving natural resources, (4) Protecting biodiversity and eco-system, and (5) Promoting social justice and human rights. Even though the above task is wide, the area of civil engineering has an undeniable responsibility to revolutionize them into chemical, biological and structural innovations [12]. There is a much skills needed in order to optimize performance and the efficiency of community systems such as the construction and maintenance of buildings, roads, railways, bridges, dams etc.

3. **Sustainable Construction Practices:** The construction sector which accounts for the 7% employability is the largest among the existing sectors in all over the world. The standard best practices to be followed in the construction sectors for the better outcome of the project are called as standard construction practices. The standard construction practices largely involve more waste generation and causes pollution to the environment. It is because of heavy consumption of oil, water, chemicals, electricity etc., It is to know that sustainable construction practices which are eco-friendly and resources efficient method of practices can be adopted to protect the ecosystem and biodiversity. There is a much need for sustainable construction practices to avoid the direct impact of standard construction practices to the environment. It can be any better materials, process and a system which can be implemented to improve the construction practices. Some of the best practices are: (1) Risk management, (2) Benchmarking, (3) Supply chain management, (4) Health and Safety, (5) Sustainable Construction. Among them, Sustainable construction helps counter major world environmental problems such as (i) Climate change and (ii) Global warming. The alterations to the Earth's climate, including variations in temperature, precipitation patterns, and extreme weather occurrences, are collectively referred to as "climate change." The term "global warming" refers specifically to the rise in the planet's average surface temperature due to the increase in atmospheric concentration of greenhouse gases. Both climate change and global warming majorly attributed to the carbon emission to the environment by direct and indirect unsustainable sources. The emitted carbon trap heat from sun and increases the atmospheric temperature. The emitted carbon also causes adverse effects like severe heat waves, droughts, floods, and storms. One of the most vital things we can do now is to slow down this catastrophic effect of carbon emission and safeguard the earth for future. There are several sustainable construction practices can be followed and main practices are (Figure 5): (1) Smart designing and (2) Sustainable materials. The smart designing

involves adopting latest technologies to estimate the required materials for construction to avoid excess wastage of materials, avoiding energy loss by thermal insulation to avoid energy demand, using smart materials to avoid further energy loss and designing integrated systems to reduce overall foot print. The sustainable materials involve using locally available materials and reducing transport cost to avoid its environmental impact, recycling used building materials to avoid the wastage, using renewable energy resources, and designing materials to reduce toxic carbon emissions. Environment friendly & biological standards are now maintained in sustainable construction & it is a new concept that emerged in the construction field in recent decade.

III. CRACKING AND THEIR HEALS

The major issue of concrete that affects construction is cracking and it typically brought by exposure to chemicals and water. It develops surface fractures because:

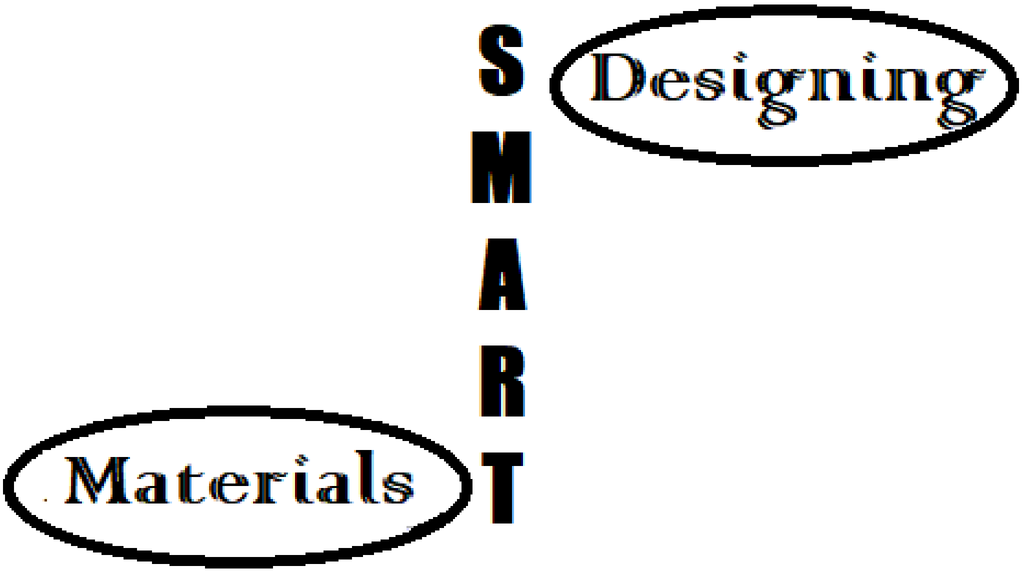

Figure 5: Schematic Representation on the Sustainable Construction Practices

In comparison to other building materials, concrete has a weak tensile strength [13]. Due to their ability to promote the movement of liquids and gases that could contain hazardous substances, these cracks lessen the concrete's durability. It is reported that concrete and the steel reinforcement bars will both be vulnerable to assault if microcracks deepen and spread to the reinforcement. Therefore, it's crucial to keep the fracture from getting any wider and to get it fixed as soon as possible. It was discovered that the Romans used a unique type of self-healing with lime mortar material [14]. Stratlingite crystals formed along the interfacial zones of Roman concrete, binding the aggregate and mortar together, and this process persisted even after 2000 years, the geologist Marie Jackson and her colleagues reported in 2014. Researchers have recently conducted a related long-term investigation on structural changes in calcium aluminate silicate hydrate [15]. The first self-healing technique was created by Carolyn M. Dry in the early 1990s using a design that permits the release of repair chemicals from fibers embedded in a cementitious matrix [5]. Since then, numerous techniques to incorporate self-healing properties in concrete have been developed by the research community. The two main types of self-healing are (1) Autogenous (2) Autonomous and are described in the following sections.

1. **Autogenous Self-Healing [16]:** The physico-mechanical performance of the composites is influenced by autogenous healing of cementitious materials, which also affects crack self-closure. It is regarded as one of the primary causes for the significant stability of historic structures and buildings. The French Academy of Science first observed autogenous self-healing in cement-based composites in 1836 when fissures in pipes, water-retaining structures, etc. self-healed. In the early 1900s, important theoretical and experimental studies showed that autogenous self-healing mechanisms are primarily related to physico-mechanical, processes occurring inside the cementitious matrix used. The carbonation of calcium hydroxide or the hydration of clinker minerals may cause cracks to finally fix. Numerous strategies have been investigated to improve autogenous healing using chemicals including crystalline admixtures, superabsorbent polymers, and mineral admixtures. It is difficult to manage autogenous healing because it can only fix small cracks and works best when there is water present. Due to this limitation, it is challenging to use this method of healing concrete.

2. **Autonomous Self-Healing [17]:** It depends on modifying the concrete mix to produce a self-healing process. The concrete might be altered to allow for self-healing the developed cracks. The autonomous self-healing that are most common are: (1) Microencapsulation, (2) Macroencapsulation, (3) Vascular Healing. Despite the fact that there is a wide variety of maximal crack widths observed are 10-100 m, occasionally up to 200 m, but fewer than 300 m, self-healing are only successful for small fractures. They are difficult to predict and regulate due to their frequently erratic results and reliance on numerous variables and causes. The most important factors are: 1) the concrete's age and composition, 2) whether water is present or not, and 3) the width and shape of the concrete fracture. The design of this self-healing system take into account a number of other factors, from system construction to integration, mechanical characterisation, triggering, and healing assessment.

IV. SELFHEALING BIO-CONCRETE

Limestone or Calcium carbonate ($CaCO_3$) can either be added to mix or chemically produced inside the concrete matrix as a result of the carbonation of calcium hydroxide minerals that already exist. This self-healing process found to be an effective, long-lasting repairing and eco-friendly method. A strategy which involves the formation of $CaCO_3$ as a consequence of microbial activity is reported. $CaCO_3$ chemically produced inside the concrete matrix undergo densification by pore filling. Thus, $CaCO_3$ aid in the self-healing of cracks, and reducing their water permeability and restoring their mechanical strength [18]. The added or in-situ produced $CaCO_3$ is compatible with the current concrete compositions. Most bacteria can precipitate $CaCO_3$ from the solution if the conditions are favourable. For the precipitation of bacterial $CaCO_3$, the carbonatogenesity of bacteria using different metabolic pathways differs. Furthermore, numerous external factors affect the effectiveness of precipitation and produce different amounts of $CaCO_3$ resulting in the closure of cracks. It is likely that healing proceeds more quickly in a wet-dry environment. Additionally, the fracture width plays a critical role in accelerating and improving biological activity-based healing.

V. LIVING CONCRETE

As the name indicates, the concrete heals or repairs its crack autonomously by living bacteria [19]. In general, there are two ingredients that makes a major difference between concrete and living concrete (Table 1). Concrete is mainly made up of cement, gravel, sand, and water, whereas living concrete contains bacteria and gelatin in addition to the cement ingredients. Living concrete seals its cracks and recover the mechanical structures of the elements with the help of live bacteria. This is otherwise called as self-healing or self-repairing concrete. The pros and cons of the particular concrete is as follows:

Table 1: Comparison on Cement with its Composites

Properties	Cement	Concrete	Living Concrete
Key components	Calcined lime and clay	Cement with crushed stones, gravel, sand & water.	Cement with crushed stones, gravel, sand, bacteria, gelatin and water.
Durability	Less on its own	High	Depends on humid conditions.
Maintenance	Not applicable	Required	Self-repair causes low maintenance
Affordability	Affordable and widely used	Affordable and widely used	Less affordable and not widely used
Usage	Not on its own	Used in roads, buildings and more	Basement, tunnel lining, highway bridges and more.
Sustainability	No	Somewhat Yes	Yes

1. **Bacteria Heals Cracks:** Researchers are working to create self-healing concrete using a mixture that contains bacteria in tiny capsules [20]. When water enters a concrete crack, this will germinate and seal the crack with limestone before water and oxygen have an opportunity to damage the steel reinforcement. Researchers developed a self – healing bacteria-based cement using a carrier material. Here, the carrier material support bacteria and preserve its activity over a long period of time. It was noted that this self – healing system helps in 417 µm sized crack closure in 28 days [21]. The bacteria which are used in the living concrete is called Synechococcus [22]. This bacterium comes under the criteria of Cyanobacteria. It gains its energy through the process of photosynthesis. In this process, it absorbs carbon dioxide, sunlight, and some other nutrients in the presence of chlorophyll and releases calcium carbonate and oxygen. Because of the chlorophyll, they are green in color and lack a membrane-bound nucleus. As a result, they are sometimes referred to as green algae. Cyanobacteria may survive without vitamins and are tolerant of severe environments. They divide by a process known as binary fission, in which one cell divides into two as the chromosomes separate. This concrete which heals or repairs the developed cracks is known for its sustainability, durability and long-lasting life time of

the concrete. Although bacteria based concrete is still in the early phases of development, its applications seem promising.

2. **Bricks Alive:** The photosynthetic bacteria ‘Synechococcus’ need to maintain in humidity surroundings to live and to generate the bricks under the given condition. A recent study discovered that bacteria can be utilized to manufacture concrete in a more sustainable manner, leading to the creation of living concrete. Here to make bricks alive, the bacteria were mixed with sand, gelatin, and nutrients in a mixture by the researchers. The mixture was then put into a mold. The bacteria begin its biological activity and created calcium carbonate around the sand particles. After that, the fluid was cooled, which caused the gelatin to solidify into a gel. The gel was subsequently dried out, turning it into a sturdy polymer that could support weights. According to the researchers, if these live bricks are split in half and given additional sand and moisture, they will fuse together to form two full bricks. After three generations, an experiment revealed that they could produce eight bricks from a single parent brick. There is a need of photosynthetic bacteria to alive for the generation of new bricks. Research on the development, characterisation, and application of a biocomposite that may produce regenerative structures grown on feedstocks is reported [23].

3. **Low Carbon Designer:** There is a need to design urban projects in order to attain sustainability by reducing carbon emission in the construction sector. Low carbon designer is a particular construction method that incorporates eco-friendly and energy-efficient material and methods. This design includes being cautious while choosing a project, locations, designs, materials, methods and maintenance. Living concrete can act as a low-carbon designer in construction sectors [24]. Because, the concrete doesn't emit carbon dioxide; instead, it absorbs it and releases oxygen, making it a novel idea to protect the environment [Figure 6]. But concrete releases carbon to the environment. By replacing concrete by Living concrete, the construction sectors responsibility for the ozone hole can be transferred.

4. **The Challenges Behind Living Concrete:** The concrete must be properly dried in order to reach its maximal strength. As a result, bacteria's ability to survive must be put at risk. Since humid climates are not present everywhere in the world, this concrete's application is not universal.

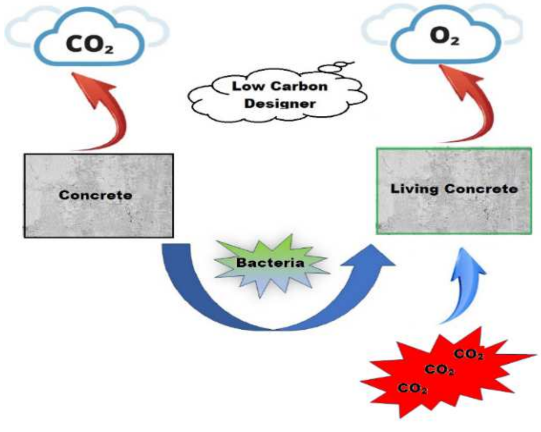

Figure 6: Schematic Representation on ‘Living Concrete’ as A Low Carbon Designer

Although the living substance has been compared to concrete, its qualities are more like those of mortar, which is not as durable as concrete. There is much studies required to overcome the challenges behind living concrete in order to use it widely. If the challenges overcome, the market will be expanded as a result of increased large-scale infrastructure investment and growing international cooperation on infrastructure projects for long-term objectives [25].

5. **Future of Construction in Mars:** The bricks made up of living concrete show advantages such as regeneration. The added bacteria can grow in the concrete mixture and resulted into doubled within seven days. The exponential production of bricks is possible from the original by living concrete methods. The above nature of concrete can be used to build in areas with a limited supply of resources, such as deserts or other places like Mars [25]. If the concrete is not completely dried out, the living concrete keeps growing. We can make more concrete from the present concrete by simply adding some sand and nutrients. Various research on concrete on Mars which shows the possibilities, and challenges is studied [26]. A study on construction material as a possible resource for extreme environment like 'Mars' is studied by researchers. It shows that the Living concrete can be a future structural material for Mars exploration for its living [27]. However, there is much studies and exploration needed to know the usage of living concrete in Mars.

VI. CONCLUSION

The chapter dealt with understanding the importance of developing a construction practice, which is the road map for attaining a sustainable future. It is understood that there is a need of redefining the inevitable components of urban infrastructure such as cement and its composite concrete by eco-friendly 'Living concrete'. It was found that a bacteria behind the concept of 'Living concrete' to make bricks to self-heal in a sustainable way. The bacteria might help in growing bricks and much more can be done with Living concrete in future. This concrete which heals the developed cracks by bacteria is known for its sustainability, durability and long-lasting life time of the concrete. It has been shown that Living concrete acts as a low carbon designer & it is a new concept that emerged as the future of sustainable construction practices. The challenges behind using the Living concrete must be addressed and will be helpful in construction and maintenance sector in near future.

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