Current trends and biotechnology infused cleaner production of biomaterials for the construction industry: A critical review

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Abstract

Over the last few decades, there has been a significant awareness established to accept the idea of biotechnology in the field of construction. This growth in awareness has occurred tremendously. In today's world, the development of new building materials and processes that make use of biobased components, such as microorganisms and materials that are mediated by microbes, is an example of developing scientific technology. In general, building materials that are produced through the use of biotechnology, such as cement and grout, are seen as being environmentally benign, affordable, and sustainable. In contrast to traditional cementitious materials, bio-based cementitious materials has the potential to considerably contribute to a large role in reducing the negative impact that the building sector has on the surrounding environment. The purpose of this review work is to present a contemporary evaluation of biotechnology and biobased materials to assess existing developments and suggest new prospective routes for the advancement of construction biotechnology. Based on this study, it was observed that the inclusion of biotechnology can significantly increase the engineering behaviour of cement concrete and weak foundation soil. Hence, its was recommened to implement the idea of biotechnology as effectively in the building industry to obtain the major environmental and economic benefits it offers.

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1 Introduction

Biotechnologies have applications in the medical, pharmaceutical, agricultural, and environmental protection sectors. Building biotechnology has arisen as a totally new subfield of biotechnology in recent years. Building materials that are produced by microorganisms and that include live organisms with their enzymes directly into the process of construction are at the heart of construction biotechnology [1]. In the next few decades, the extraction of construction materials is projected to increase from 25 billion to 80 billion tonnes as a result of uncontrolled population growth and changes in people's lifestyles globally. According to a recent study conducted by the Global Construction Forum, the construction industry is projected to increase by 15.5 trillion dollars by 2030. Countries such as India, China, and the United States is controlling more than 60% of the global construction market [2]. In light of this, the use of biobased materials in construction has become a more effective means of mitigating the detrimental effects of conventional construction techniques. As structural members such as columns, piers, and purlins, etc., timber products have been used in the building industry for a very long time as an effective biobased material. However, they were unable to compete with steel's and reinforced concrete's superior performance in the last century while building ever-taller buildings [3]. But in recent years, the need for sustainable development has started to change this circumstance. The resurgence of biobased materials has also benefited from the efforts of the scientific community.

Ordinary Portland Cement (OPC) manufacture in traditional building uses chemical admixtures and agents to regulate the fresh and hardened phases of concrete, consuming 15% of all earth resources. "Super plasticizers," such as naphthalene and melamine condensates, are used to upsurge the workability, strength, and durability of conventional concrete. An enormous amount of petroleum resources are needed for the extraction of these synthetic polymers. The number of potential environmental concerns rises as a result of excessive oil exploration for synthetic polymers. This issue can be resolved by using biodegradable polymers, which should be made from renewable sources like plants and microorganisms [4]. Materials used in biobased technology are either produced from plants or from bacteria and fungi. The production rate of bacteria and fungi produces materials that are more efficient than plant-based ones [5]. Utilizing a specific biomass from agricultural feedstocks as an alternative construction material in plant-based technologies can improve the environmental performance of the end products [6]. In the past, many animal-based biomaterials including egg shell, blood, milk, and urine were added to plasters and mortars to improve their performance. The combination of Cowdung and straw has found been used as a composite polymer to enhance the physical characteristics of clay structures. Extracts from cactus and hyacinth juice are used in cement-based products as viscosity modifiers [7]. In the composite structure, some of the bioresins are utilized to get interesting results made from the polyfurfuryl alchol derived from agricultural wastes [8]. Similary, for thermal insulation and sealant in building, the substance called polyurethane was widely used which is made from the harmful substance called Isosyanates. To replace the susbstance, in last couple of years a biobased polyurethane was produced using rapseed oil [9] and coffee ground waste [10].

On the other hand, the growth of nanotechnology in the construction business will facilitate the creation of a unique biobased material. Among these, nanocellulose-based building materials have garnered considerable attention in recent research. Due to its carbon neutrality, biodegradability, and regenerative nature, cellulose, an organic polymer that has been identified as the most abundant material on earth, has become a prospective biotech resource for future construction [11]. For thermal insulation, high performance thermal insulators with low heat conductivity are required. Extruded polystyrene and expanded polystyrene are two extensively used petroleum-based polymers with greater than recommended thermal conductivities. These polymers have been replaced by organic cellulose aerogels, which are highly recognised for their benign and incendiary properties [12]. Utilizing bio-based goods and materials in construction can enhance the technical features of both building and ground components. In addition, civil engineers who want to implement the concept of biotechnology in construction should have a certain level of knowledge about the biological sciences and the roles of genetics, molecular biology, and microbiology in order to address the numerous engineering issues associated with civil engineering projects. The novelty of the study as we are compelled to create an alternate method for constructing materials, which must be sustainable and be the ideal replacement for existing conventional building materials. The objective of the study is to examined how the application of biotechnology protects the environment from pollution and restores an ecosystem damaged by the construction industry.

2 Fundamental of biobased organisms in construction material

Modern biotechnological techniques incorporate the most advanced techniques in biotechnology, civil and geotechnical engineering, soil sciences, environmental and medical microbiology, information processing, biogeochemistry, nanotechnology, defence science and technology, and environmental engineering

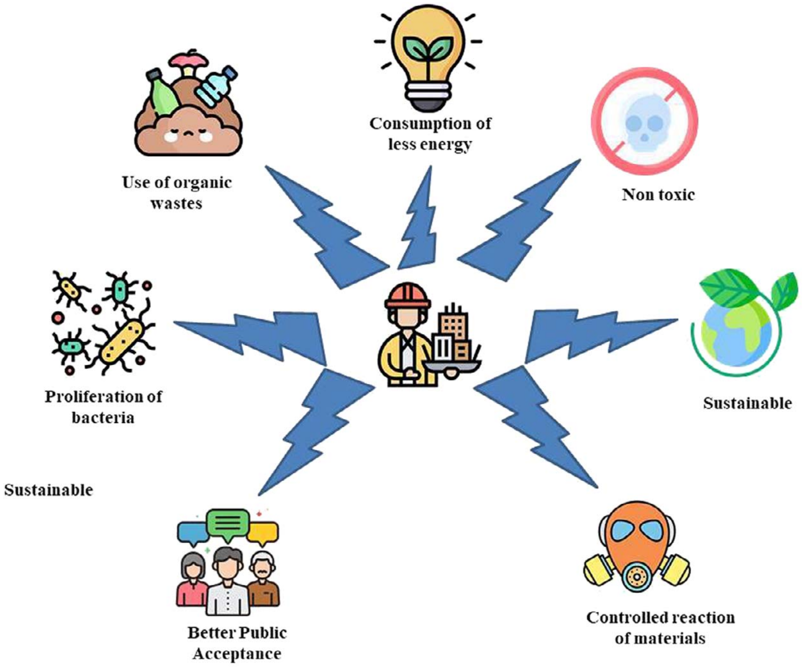


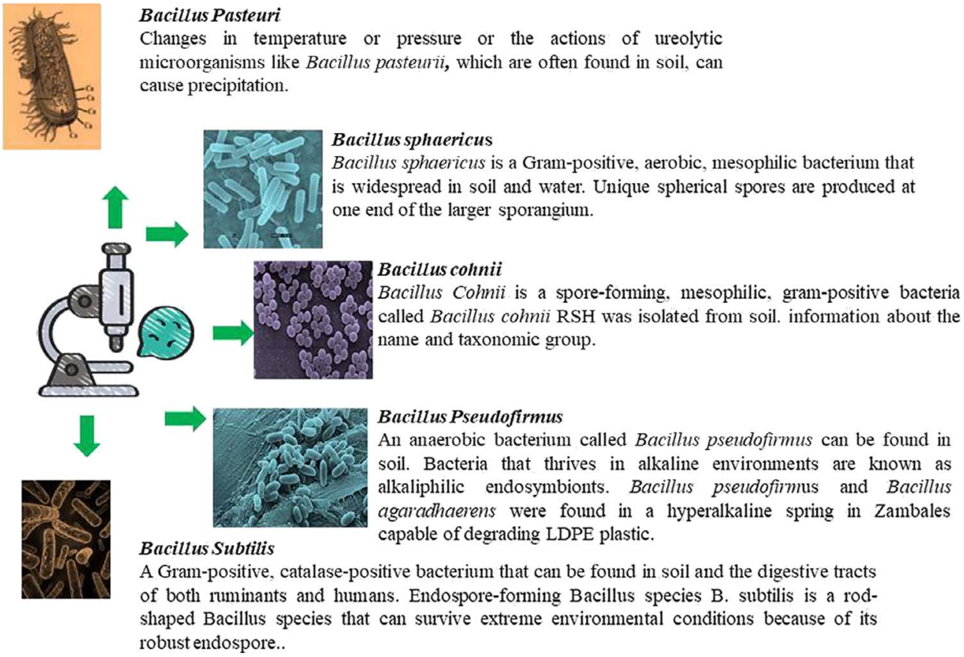
Figure 1. *Drives for biotechnology infusion in construction.*

[13]. The most effective technology in any subject is often the result of combining biological materials, technologies, and it was amendment as mechanically. In the evolution of biotechnology, there are few examples of application-only bioprocesses that do not involve chemical or mechanical processes [14]. In civil Engineering, particularly the biobased materails are suggested for the reasons as revealed in Fig. 1.

Like discuss in Introduction section, most of bio based construction materials are derived form bacteria or viruses and plant based substances. Before enter in to the deep discussion on the application of biobased materials, in construction its is prime important to understand the role of microorganism which are beneficial to the construction industry. Microorganisms are the vital of any biobased material. In general, the microorganism are classified in the size range of 70-100μm, they are invisible and studied with the aid of microscope only [15]. In most of the studies, the microorganism are classified based on its phenotype deeds such as the property and structure of organism and this can be typically done by collection of species strains [16]. Fig., 2 which depicts the category of different microorganism species which is widely utilized in construction field are epitomise with their species and genus name.

Majority group of microorganisms employed in construction biotechnology for in-situ biocementation, bioclogging, and the creation of building materials. Out of which, the bacterias are typically sized in the range of 1-2 μm and found usually in the shape of rodshaped, spherical and helix inshape [17]. While compared to bacteria, the Archeas are found in similar shape and size, but unlike bacterias they are survived in extreme conditions like high salinity, anaerobic environment and high temperature [18]. Likewise, the fungus is a microscopic creature, which are consider as active polymer degraders which leads to biofouling, biocorrosion and biodeterioration of construction materials. In construction biotechnology, algae can be used to cover the sun-exposed surfaces of ponds and canals and to immobilise particles on soil surfaces [19]. During changes in temperature or pressure or the actions of ureolytic the microorganisms like Bacillus pasteurii are exist, which are mostly found in soil, can cause precipitation.

Unlike bacteria, the fungi are identified by their diversity and morphology. The kingdom of fungi has been classified as *Oomocytes* a water mold organism, *Zygmocytes* usally found in air with spores, *Ascomycetes* a form of yeast usually found in single and multicellular with toxic spores, *Deuteromycetes* an active biodegrader and *Basidiomycetes* a wood degrader [20]. Similarly, the Algae which are defined based on their structure of its cell wall, morphology, reserve carbon and phytopigments. Some of the common algae belonging to *Chlorophyta*, *Euglenophyta, Rhodophyta* and *Chrysophyta* provide remarkable contribution in the field of construction especially in water purificiation and treatment [21]. In the construction industry, the biobased substances are added to induce biochemical reaction of construction materials/substances in rapid and diverse rate. The complete reaction caused by the microorganism in the constructions substances are simulated by its protein molecules, polysacchardies, nucleic acids called "bioenzymes" such as oxidoreductases, hydrolases, lyases, ligases and isomerases [22]. Many of these enzymes are introduced to stimulate the biochemical reaction to increase the performance and production of construction material and these enzymes are catalysed million times faster than the conventional chemical materials used in construction [23].



Bacillus Pasteuri
Changes in temperature or pressure or the actions of ureolytic microorganisms like *Bacillus pasteurii,* which are often found in soil, can cause precipitation.

Bacillus sphaericus
Bacillus sphaericus is a Gram-positive, aerobic, mesophilic bacterium that is widespread in soil and water. Unique spherical spores are produced at one end of the larger sporangium.

Bacillus cohnii
Bacillus Cohnii is a spore-forming, mesophilic, gram-positive bacteria called *Bacillus cohnii* RSH was isolated from soil. information about the name and taxonomic group.

Bacillus Pseudofirmus
An anaerobic bacterium called *Bacillus pseudofirmus* can be found in soil. Bacteria that thrives in alkaline environments are known as alkaliphilic endosymbionts. *Bacillus pseudofirmus* and *Bacillus agaradhaerens* were found in a hyperalkaline spring in Zambales capable of degrading LDPE plastic.

Bacillus Subtilis
A Gram-positive, catalase-positive bacterium that can be found in soil and the digestive tracts of both ruminants and humans. Endospore-forming Bacillus species B. subtilis is a rod-shaped Bacillus species that can survive extreme environmental conditions because of its robust endospore..

Figure 2. *Microorganisms benefical to construction industry.*

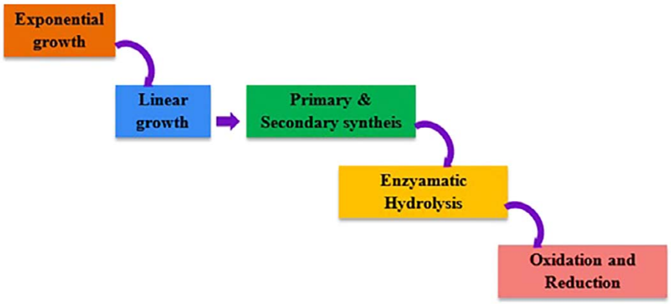


Figure 3. *Bioprocess in construction biotechnology.*

3 Synthesization of biobased construction materials

Bioenzymes synthesis for the devolpment of any construction materials are largely depends on the prime factors such as pH, optimal temperature, concentration of gases and osmotic pressure of microorganisms involved in biochemical reaction [24]. The stages involved in the synthesis of biobased construction materials has to follow the stages as shown in Fig. 3 below which helps to assess the bacterial growth at different stages.

While compared several microorganism, the role of bacteria in construction industry was very significant. In general, the bacterias are genetically classified in to two types such as aerobic bacteria, which can survive with the help of oxygen and Anerobic bacteria which can exit even in harsh environment without need of oxygen [25]. In construction, both the types of bacterias have played serious role in the devolpment of construction materials. In exponential growth, the bacterias are devolped in a cell medium which involves the growth of cell at double rate by consume nutrients from the feeded biomass [26]. In liner growth, the bacterial are multiplied in terms of division of cell per unit time and it is usually measured under the condition of growth and method of cell division of bacteria. During primary synthesis, the compounds which are essential for growth, devolpment and reproduction system of bacteria has been devolped. Similarly in secondary phase, the bacteria have gain a defence mechanism against certain foreign bodies and help to produce the bioenzymes depends on biomass feed. In the stage of enzymatic hydrolysis, the bacterial cell gets breakdown by the action of decaying oligomers present in the bacteria through the addition of water molecule between cell monomer units [27]. At final stage, due to oxidation and reduction of bacterial substances, the bioprocess has been intitated coupled with the growth of microbial. In any bioprocess work, it follows four stages like upstream, core, downstream and Control and monitor process [28]. The upstream process usually include steps like collection and preparation of raw materials, Medium preparation, devolpment of microbial strain and inoculum preparation. In core method, the bacterias are devolped under some controlled condition with specific reason. In the downstream process, the process extracted through the separation and dewatering of biomass in the bacterial medium [29].

4 Wide application of biobased materials in construction industry

Biobased admixtures are used a construction material for over long periods. In the Roman Empire, it was found that the vegetable

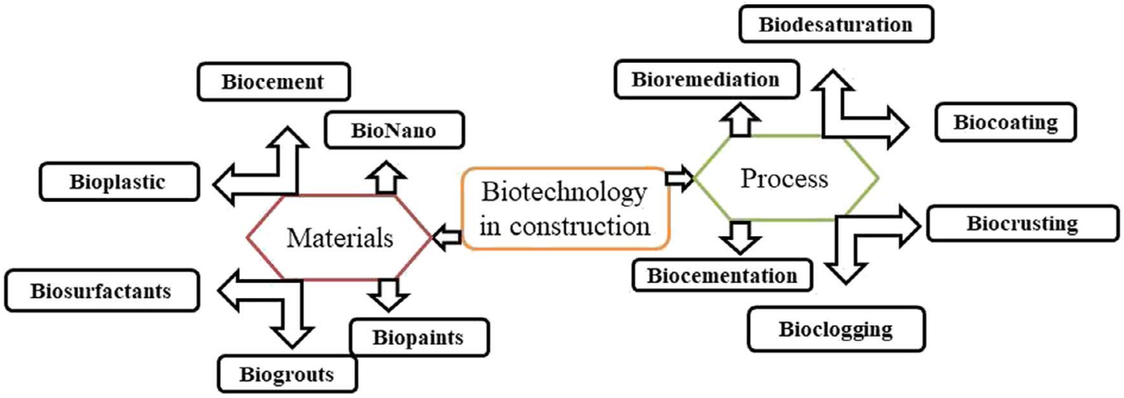


Figure 4. *Microorganism application in construction biotechnology.*

fat was used as additive material in the lime mortar and animal blood [30] as an air entraining agent to improve the performance of their building materials. Similarly, the Great wall of china was found constructed with fish oil, egg white and blood mixed mortar due to their imperviousness [31]. During 20th century at the beginning of using admixture in concrete, a biopolymer called "Lignosulfonate" has been introduced in the place of conventional Portland cement as a first functional polymer in construction at large scale [32]. In conventional cement concrete the properties such as strength, durability and workability are enhanced by adding synthetic super plasticizers such as naphthalene and melamine. But, now a days the synthetic polymers are widely replaced by the biopolymers include starch, pine root extract, lignosulfonate, chitosan, proteins and vegetable oils in the cement concrete [33]. Polyfurfuryl alchol an bioresin extract from the agricultural waste has been utilized extensively with promisable result in construction [34]. Biobased admixture made from fungi and bacterias via fermentation process has shown better performance due to their rate of biosynthesis when compared to plant based admixtures like xantham gum, gluconate, gellan gum [35]. The advancement of Nanotechnology in construction provide new direction to devolp eco efficient nano biopolymer based materials like cellulose nano crystals [36]. Typically, the cellulose was an abundant source, contribute 1.5 trillion tonnes in total biomass production as annualy. It was a carbon neutral, biodegradable and non renewable, likewise it was low cost and potential to use large quantities in construction industry as a perfect alternative to conventional carbon nano tubes used in concrete and polymers [37]. During the production of bioadmixtures for construction in the way of sustainable process by means of utilizing biotechnological and agricultural biomass as used as raw materials.

Role and function, of any biobased material in construction has been estimated and analyzed based on the two major broad division such as biotechnology in construction materials and construction process as shown in Fig., 4. Which helps to understand the complete role of material and process involved in construction biotechnology. It is crucial to comprehend the distinction in biobased construction technology. Before commencing the topic of application, it is necessary to address each and every division as specifically and concisely as possible. Both the bio-based materials and its process are hence inevitable. Several products that were developed and are being used in building can be found in the materials. A process known as microbially induced calcite precipitation follows, and it is this that the biocement employs to bond soil particles. It produces a sturdy and environmentally beneficial building material by using microorganisms [38]. Biocement uses less energy and produces fewer greenhouse gases during production than conventional cement. One of the chemical processes employed by bacteria to produce calcium carbonate precipitation is urea hydrolysis.

In terms of price and duration, this has emerged as one of the most popular procedures for generating biocement [39]. Additionally, biocement has been applied in self-healing situations. In this process, water is utilised to activate the bacteria so they may interact with the materials and produce calcium carbonate deposits that can be used to seal holes, bridge gaps, and connect surfaces [40]. It strengthens concrete constructions, halts leaks, and lengthens their useful lives. In order to create limestone, which fills the crack and helps prevent corrosion of the steel reinforcement caused by water penetration, calcium is broken down by bacteria utilising oxygen [41]. By using this technology, buildings made of porous materials might be preserved or conserved. Moisture, pollution, chemicals, and other impurities can harm the strength and beauty of monuments, structures, and other delicate artefacts [42]. Climate and pH levels are just two examples of environmental elements that may have an impact on how well the process works.

The issue of plastic trash, which is choking the earth and harming the ecology, can be reduced by using bioplastics, which are renewable and biodegradable. Additionally, the marine animals and birds that consume this waste, such as whales, sea turtles, albatrosses, and others, die. Additionally, it seriously endangers the ecology by forming waste islands and patches [43]. These polyesters are made by a number of bacterial strains that consume uncooked vegetable sources. PHAs can be utilised, among other techniques, to create automotive components during injection moulding. Polyhydroxyalkanoate is specifically derived from bacteria like pseudomonas [44]. In its natural state, it resembles clear kitchen film, with the exception that it is a true bioplastic. Innovative designs that catch the eye and lessen the carbon impact of home and city occupants, including multicoloured facades and shaded areas in buildings, incorporate bioplastics [45]. They can be included in a comprehensive sustainability strategy for the building.

Biosurfactants, which are surface-active chemicals with the ability to reduce interfacial and surface tension, have a variety of applications. These are amphiphilic chemicals produced on living surfaces, specifically microbial cell surfaces or ejected extracellularly. They can agglomerate between fluid phases, thereby decreasing surface and interfacial tension at the surface and interface, respectively [46]. Bio resins are made up entirely or mostly of monomers that come from biological sources. Since they use components made from plants instead of petrochemicals, these resins are environmentally benign. It is not a recent development to use bio-based components in coatings. A resin in which some or all of the monomers are sourced from biological sources is referred to as a bio-resin. Today's supplies are typically leftovers from the refinement of biodiesel fuel made from corn or soy [47]. Through a metabolic response, biological organisms are used in bioremediation to remove or neutralise an environmental contamination. Bioremediation is a branch of biotechnology that focuses on the use of microbes and other living things to remediate polluted water, soil, and groundwater as well as oil spills [48]. The blocking of soil pores by microbial biomass, such as their bodies and byproducts such as extracellular polymeric material, is known as biological clogging. The microbial biomass restricts the flow of water in the pore space, resulting in the production of a specified thickness impermeable soil layer and a significant decrease in the rate of water infiltration. Bioclogging has been documented in numerous field settings using continuous ponded infiltration, including percolation trenches, artificial recharge ponds, sewage treatment systems, irrigation channels, and landfill liners [49].

4.1 Role of biobased materials in cement concrete

Decades of research have been devoted to enhancing the microstructure of hydrated cement in an effort to boost the material's strength, workability, and especially durability in order to make it more environmentally friendly. Polymers added to the mixture have made this possible. Currently, the construction materials industry has access to a variety of polymers used as admixtures [50]. Nowadays, no cement paste or concrete product can be found without at least one additive that was developed specifically to improve a specific feature. A polymer additive is a substance that is added into a cement mixture to improve its performance. Polymers can modify the hydration rate of cement paste; they can make the paste more fluid with a low water-to-cement ratio, or they can make it more viscous and cohesive, depending on the polymer introduced and how it interacts with the cement paste. The additives could be either synthetic or natural. Bio-admixtures compete with synthetic alternatives in many uses, but are essential in others, such as water retention and viscosity modification [51].

Natural or synthetic biopolymers, as well as biodegradable chemicals, make up bio-admixtures. Common polysaccharides include starch, guar gum, methyl hydroxypropyl cellulose, and countless others. Growth in the market for bio-admixtures, particularly microbial biopolymers, is anticipated as a result of both technological advancements and the growing trend toward using organically derived or biodegradable goods in the construction materials industry. The Aztecs fermented nopal cactus juice, which has been utilised for centuries to increase the pliability and water-absorbing capacities of lime mortar and clay plasters. This is due to the fermentation byproducts, cellulose fibres, and gel polysaccharides that are present. Nopal cactus and water hyacinth extracts are still used today to increase the viscosity of cement-based products [52]. Chinese cities were built with a composite substance called sticky rice-lime mortar, which had amylopectin as its primary organic component, dating back to antiquity. It was discovered that by adding amylopectin to lime mortar, calcium carbonate crystal development was inhibited, resulting in a more compact structure with enhanced performance compared to that of lime mortar made with just one component [53]. Chemical derivatives of plant biopolymers, like carboxymethylcellulose sulphate or carboxymethyl cellulose, or industrial precursors like lignosulfonates, are commonly employed in cement and mortar admixtures to speed up the setting time and increase the plasticity of self-consolidated concrete [54]. As illustrated in Table 1, the biotechnology procedure and function of various biobased admixtures in the building sector.

The use of biological admixtures like microbial extracellular polysaccharides in cement and gypsum-based products has been shown to increase their viscosity, dispersing/thickening effects, set acceleration, adhesion, air entrainment, hydrophobization, film formation, water retention, and retardation. The material benefits from increased flexibility, adhesion, water retention, reduced shrinkage, and flowability. Welan gum and protein hydrolysates find application in the building material. In the future, technological developments and the increasing need for eco-friendly and biodegradable construction materials are expected to increase microbial biopolymers' market share. High-viscosity admixtures, such as those produced by the biotechnology industry, considerably minimise the concrete's propensity to separate [77]. In this study, the effects of various cellulose ethers (CE) and starch ethers (SE) on mortars were analysed. Surface diffusion coefficient and admixture impact on transient water concentration at the solid-liquid interface were also determined. The results indicated that the water-retaining capacity of the hydrated cement in mortar samples adjacent to a solid support increased with increasing proportion [78]. To demonstrate how cement hydration degree influenced the capacity of hydration products, cement particles, and water to interact, microcrystalline cellulose was used to construct a waterproof barrier on the anhydrous cement particles. The adiabatic temperature maximum was reduced and the hydration reaction was retarded as a result of these interactions [79].

There are a wide variety of admixtures that can be used in mortars and concretes that use cement. This last decade has seen a rise in the use of self-compacting concretes and cement

Table 1. *Function of varied biobased admixtures in construction industry*

Process of biotechnology	Biobased admixture	Responsive microbes/source	Function of admixture	Reference
Biosynthesis	Xanthun gum	Xanthmonas campestris	Retarder and thickening agent for self compacting concrete	[55]
	Dextran	Lactic acid bacteria	Grouts, micro-fine cements that increase the flow resistance of Portland cement, self-leveling cement slurries for use in fresh or saltwater oil wells, etc.	[56]
	Pullulan	Aureobasidium pullulans	Retarder and thickening agent for self compacting concrete	[57]
	Welan gum	Alcaligenes sp.	Retarder and thickening agent for self compacting concrete	[58]
	Curdlan gum	Agrobacterium Spp.	Retarder and thickening agent for self compacting concrete	[59]
	Succinoglycan	Alcaligenes sp.	Thinner with temperature-induced viscosity that is high shear-thinner	[60]
Biosynthesis	Casein	Animal milk	Used as retarder, superplasticizer, and self-leveling agent in concrete	[61]
	Chitin/chitosan	Microorganisms/ animals	Retarder and thickening agent for self compacting concrete	[4]
Biooxidation	Sodium gluconate	Aureobasidium pullulans	Used as Set plasticizer, retarder, corrosion inhibitor used in concrete mix	[62]
Chemical synthesis	Polyaspartic acid	-	Concrete corrosion inhibitor, biodegradable dispersion, and air-entraining agent	[63]
	Air-entraining admixture	Biosurfactants	Help to improve performace of concrete in freeze thaw environment	[64]
	Coloring admixture	Iron ore microbes	Helps to control corrosion in steel structures	[65]
	Shrinkage reducers	Osmoprotectors	Helps to reduce drying shrinkage	[66]
	Lignosulfonate	Wood lignen	Used as thinner in painting agents	[67]
Extraction	Sodium alginate	Brown seaweeds	Used as thickener, Stabilizer, and emulsifier in concrete	[68]
	Modified guar	Plants	Water retention agent and viscosifier	[69]
	Alginates	Algae	Viscosifier, set retarder	[70]
	Rosin	Plants	Concrete Air-entraining agent	[71]
	Carrageenan	Red seaweeds	Foam used in highway construction to prevent premature drying of freshly poured concrete	[72]
Aerobic cultivation	Bacterial cell walls	Common bacteria	Used to fill micropores in concrete	[73]
Derived monomers	Polylactic acid	Bacteria	Inhibitor of pore formation; binder; suspension; coating; sticky; and foam in concrete	[74]
	Polyglycolic acid	Fossil fuel	Pore farming agent used during drilling of gas	[75]
	Polyaspartic acid	Fossil fuel	Used as disperant	[50]
	Polyvinyl alcohol	Fossil fuel	Used in binder coating	[76]

grouts for a wide range of building projects. Grouts and self-compacting concrete, which fills forms without being compacted, are examples of materials that can flow and consolidate. Soil stabilisation, radioactive waste containment, concrete repairs, anchor embedding, posttensioning, and ground treatment are just few of the many uses for grout [80]. By increasing yield stress and plastic viscosity, viscosity modifiers thicken mixes to improve cohesion and reduce segregation in cement-based products. To obtain the low yield stress necessary for excellent flowability, they are generally combined with superplasticizers. Diutan, welan, and xanthan gum are anionic compounds that modify viscosity and bind positively charged cement particles. Adding viscosity modifiers to cement causes the particles to clump together, making the mixture thicker [81]. Water reducers or plasticizers can improve the workability of cement-based materials in two ways: I by boosting the durability and mechanical strength of the material at a low water-to-cement ratio; and (ii) by improving the dispersion of the cement grains at a constant w/c ratio. Concrete typically has lignosulfonate-based admixtures added to it at a weight percentage of between 0.1% and 0.3% by weight of cement, as they are frequently used in the building sector [82].

Biodegradable and environmentally acceptable polysaccharides have been used to create an organic water-reducing agent. A lot of research has gone into anionic molecules derived from starch and cellulose. These polymers extend the time it takes for a material to both absorb water and set. They could be synthetic or naturally occurring biopolymers [83]. As an acid precipitate, casein is a biopolymer extracted from milk. This chemical has been used in cement consistently since the time of the Roman Empire. It's an excellent water-reducer that, at low concentrations, acts plasticizingly and plays well with other polymers, including retarders. Self-leveling underlayers, a subset of dry-mix cement mortar for flooring, are made with casein as a key ingredient in the formation of automated correction of unevenness [84]. Chitosan, a biopolymer, can be chemically modified into a powerful superplasticizer. The superplasticizer has a high water-reducing ratio and a stronger, more consistent dispersing force. Chitosan superplasticizer is superior to polycarbonate in terms of impact resistance. The combination of retardation effects and its unique structure of multifunctional groups and ring-shaped units is implicated as the cause of the enormous dispersive force and regulating capability of the chitosan superplasticizer [85].

Research into black liquor waste from the papermaking industry as a possible cement element has been shown [86]. As a result, black liquor waste strengthens and quickens the hydration of cement phases. When compared to cement pastes made with ordinary Portland cement, those made with black liquor waste set faster and remain workable for longer. For this reason, black liquor can function as a stimulant. Bulk density, combined water content, and apparent porosity all rise as a result of hydration curing, leading to an increase in compressive strength, particularly at the end of the curing process at ages 28 and 90. Various studies [87] have demonstrated the additive's potential usefulness in building. There are now many different admixtures used to change the properties of concrete, but microbial fermentation can have a far-reaching impact on the material. The price and environmental impact of concrete would change. Fly ash-based geopolymer with naturally occurring, low-cost kappa-carrageenan (KC) biopolymer has been investigated as a possible additive [88]. To improve the biopolymer geopolymer composite's mechanical qualities, more kappa-carrageenan was added to cover and join the geopolymerized fly ash particles. A biopolymer geopolymer paste's functionality was hindered and its density and porosity were enhanced when an excessive amount of KC was used to improve the viscosity of the biopolymer alkaline solution.

Eggshell powder, banana fibre, and water hyacinth fibre are only few of the options that have been investigated [89]. While both water hyacinth and banana fibres significantly lessen a composite material's permeability to water, eggshell powder has a less effect. High densification and improved water penetration resistance are also indicators of low water absorption. Including biomaterial fillers, such as eggshell powder, in concrete composites improved the material's physical, mechanical, and thermal qualities, making it more long-lasting, efficient, eco-friendly, and sustainable. Researchers [90] have experimented with miscanthus powders and steel slag cured with carbon dioxide to create cement-free bio-based cold-bonded lightweight aggregates (BCBLWAs). There's a chance that the miscanthus powders will allow more CO_2 to diffuse into the aggregate, hastening the carbonation of the steel slag particles. Despite this, BCBLWAs with a high miscanthus powder percentage may nevertheless be porous and weak. When compared to plain carbonated steel slag, the sample with 10% miscanthus powder is 20% more robust. Important new studies focus on how palm oil and its byproducts can be included into bio-asphalt and bio-concrete production processes. Mechanical problems could be solved, natural resources could be preserved by using less virgin material like bitumen, and emissions could be lowered by incorporating such biomaterials into materials like bio-asphalt and bio-concrete [91].

Self-repair mechanisms evolved in microorganisms to make structures more resilient. Fracture arrest in bacterial concrete is probably caused by the microbiological conversion of calcium lactate to calcium carbonate. The bacillus genus nonetheless managed to deliver outstanding results under a wide range of conditions. Calcite precipitation occurs in concrete when both a calcium source and microorganisms that promote urease are present [92]. To prevent further damage from developing in newly formed microcracks, the calcium supply is linked to ureolytic bacteria, which can produce urea to seal the precipitate. It's possible that the pH range and the bacteria's ability to live indefinitely in an alkaline environment play a role in the selection of bacteria and growth circumstances [93]. The precipitation of $CaCO_3$ from the degradation of urea by ureolytic bacteria is one such method. Microorganisms produce the urease enzyme needed to break down urea into ammonium and carbonate. Ammonia production raises the pH of the environment, making it possible for insoluble $CaCO_3$ to build in a very calcium-rich setting. Previous modifications have significantly improved the specimen's compressive strength and stiffness. Biomineralogical methods applied to concrete boost the creation of a one-of-a-kind material called bacterial concrete [94].

The *Bacillus subtilis* is rod-shaped, gram-positive, and its protective spore is robust. They occur naturally in soil and vegetation and are able to resist harsh environmental conditions. It can tolerate temperatures ranging from 25 to 37°C. When *Bacillus subtilis* is added to concrete, calcite precipitation increases the material's strength dramatically. The former can seal the crack and clog the pores, resulting in increased durability [95]. Additional research showed that the strength of M40 concrete increased when crushed stone dust was mixed with 5%, 10%, or 15% of calcium lactate and bacterial solution. When it rises above 10%, the ensuing mechanical strength is inadequate. Furthermore, adding 10% mix-friendly solution concentration improved the UPV result of bacterial concrete [96]. The real value is influenced by Bacillus pasteurii, an alkaliphilic soil bacteria that produces urease and may hydrolyze urea into NH_3 and CO_2. Calcite precipitation has been aided by an increase in environmental pH brought about by ammonia. In close proximity to the surface of the cracks, microbiological calcite precipitation was predominant. According to reports, *B. pasteurii* immobilised in polyurethane (PU) left a significant impact on the matrices [97]. After 28 days of testing with changing cell concentrations, fly ash with varying percentages added to cement displayed exceptional split tensile, compressive, and flexural strength. In addition to the required the porosity, strength, and permeability of the material have unexpectedly decreased [98].

Previous studies on the elements of bacterial infused concrete that may affect self-healing capacities have led to a variety of conclusions. Pilot specimens kept in water were more capable of self-repair. Complete repair is possible for any crack with a width of less than 0.3 mm. If the chasm is more than 0.3 mm wide, it may not heal itself. A crack that is only 0.1 mm wide can be completely repaired after around 200 hours. Additionally, cracks with a width of 0.20 to 0.30 mm often heal in 30 days [99]. Within 7 days, the fissures begin to noticeably narrow, going from 0.15 mm to 0.3 mm, and by day 33, the damage has been totally fixed. The ability to maintain hydration for longer periods of time has been linked to improved self-healing [100]. Cracks can heal more quickly if applied to the right amount of pressure. Because there are more unreacted cement particles available when the water-to-cement ratio is higher, the body can utilise this to increase its calcium carbonate production [101]. Bacteria should be used to effectively and permanently seal cracks in buildings, ideally for the entirety of the building's lifespan. We recommend using a bio-cement precursor chemical and microorganisms in material matrices. The acidic conditions of concrete are lethal to all but a select few bacteria, which are alkaliphilic [102]. To prevent bacterial cell death from concrete's harsh pH, they must be immobilised and protected.

During the dormant bacteria (of the bacillus variety) are incorporated into concrete mixes, Spores (very resistant for 200 years) must be formed in order to endure the strong alkaline environment that exists while concrete is being mixed. Calcite crystals can be formed when bacteria in suspension are fed a nutritional solution containing calcium lactate. Once the spores of the bacteria come into touch with water and nutrients, they can germinate and begin to multiply [103]. During the process of bacterial nutrition, oxygen is used up and soluble calcium lactate is transformed into insoluble limestone. Once the limestone hardens on the damaged surface, the cracks are effectively sealed. Every single test shows that the permeability of water and chloride is reduced by 88% in concrete that has bacteria implanted into it. Finally, the crystals grow to fill the entire void [104]. Utilized in Patchwork Evidence from prior research into bacterial concrete suggests that bacillus-based bacteria are safe for human consumption and can be utilised to patch small, shallow fissures. They find additional utility in surface treatments. As the bacteria of the genus Bacillus are aerobic, they are ineffective in environments where they have less contact with air, such as deep fissures. Curing the harm takes more time [105]. Many people are interested in using bacteria-induced self-healing as a concrete element (if mixed during casting) because of its potential for use in long-lasting structures, its low environmental impact, and its compatibility with conventional concrete. Researchers discovered that when bacteria were combined with Buffer solution, the outcomes were more favourable. Its pH value remains unchanged regardless of whether acid (or alkali) is added to it [106]. The results showed that the inclusion of bacteria increased the mechanical behaviour of concreter, with the increase being mostly attributable to the deposit of microbially induced calcium carbonate precipitation on the microorganism cell surfaces and within the pores of the mortar.

4.2 Role of biobased materials in soil stabilization

When one or more of the soil's attributes are modified, either mechanically or chemically, stabilisation results in improved soil material with the necessary engineering features. Traditional soil stabilisation techniques involve products like lime and cement, both of which have significant embodied energies and negative effects on the environment [107]. Fortunately, the problem can be mitigated to a large extent by the use of biopolymers and related substitutes. The purpose of this part was to analyse bioenzyme-based soil stabilisation techniques by talking about how they are made, how they function, and what challenges and opportunities the sector may face in the future. The goal of soil stabilisation is to strengthen the soil so that it is less prone to erosion and dust [108]. Investment in efficient soil stabilisation technology is crucial for developing countries to support their construction sectors and national economies. Numerous construction projects have experienced setbacks due to the prohibitively high cost of soil stabilisation methods. More money is being spent on commonly used stabilisation techniques [109]. More and more individuals are searching for greener and more creative approaches to building that can help expand the reach of the road network. As a result, efforts to discover new materials and perfect ways for processing the indigenous materials have been ramped up. Soil stabilisation is an extremely inefficient procedure, but bioenzymes offer a fresh opportunity for developing countries to reap its benefits.

Due to their unique and often proprietary composition, bioenzymes have been used in a wide range of projects around the world for quite some time, but they still need significant field testing before they can be used on a large scale. The usage and production of bioenzymes are quickly becoming the most promising key for the development of a nation due to the potential savings in time, energy, and money [110]. Carbon emissions from traditional stabilisers are mitigated as a result. Therefore, it is critical to gain a deeper familiarity with this developing technology in order to take advantage of any potential boost it may provide to soil stability [111]. Soil stabilising bioenzymes can be made from readily available ingredients with just a little bit of study and experimentation. Research and academic institutions in any country should therefore be interested in developing economically viable, widely usable, and ecologically friendly enzymatic formulations from locally available raw ingredients [112]. Soil stabilisation using conventional methods, such as hydrated lime or cement, can increase final costs by as much as three times as much as using bio-enzymes. Traditional stabilisers are cumbersome and costly to carry because of their size and weight [113]. Enzyme soil stabilisers, on the other hand, may be transported more efficiently due to their concentrated liquid state [114]. For stability purposes, the enzymes are blended with water on the job site. Because of this, we may save money on shipping and delivery while also protecting our natural resources and reducing pollution.

Soil bio-enzymes play a catalytic role in surface-level chemical reactions, leading to increased soil density and decreased water retention. Road construction can then proceed once the soil has been stabilised. For bio-enzymes to do their jobs, there needs to be at least some clay present in the soil [115]. Chemical soil stabilisation transforms bio-enzyme-treated soil into a dense, compact layer that is impermeable to water; this makes it ideal for use in road paving, dust control, and the building of a variety of manmade roads and other transport infrastructure [116]. There are a number of ways to manufacture bio enzymes for use in soil stabilisation. The fermentation of vegetable matter, crop plant biomass and leftover molasses from the sugarcane industry are all sources that can be used to grow microorganisms that can then be extracted as bio enzymes [117]. Some examples of these microorganisms are the fungi that cause mould and spores, and the bacteria that contain both aerobic and urolytic species. Exoenzymes are produced by these microbes and can be harvested in large quantities. The resulting soil stabiliser enzymes are biodegradable and harmless, and they break down over time [111]. The ways by which bio-enzymes achieve this stabilisation by the process of hydrolysis was described in Figure 5 below. Adsorption of bio-enzymes by the clay grid diminishes the thickness of the diffuse double layer of clay because the process releases cations [108]. The introduction of bio-enzymes into the soil accelerates the breakdown of large organic molecules by the soil's naturally occurring clay particles. The hygroscopicity of clay is diminished and its negative charge is neutralised because organic molecules of large in size and have broad, and flat in shape that completely coat the surface of clay particles which are smaller in size [95]. Due to the covering effect, the soil is unable to lose density or take in any more moisture.

There are more different kinds of microbes in soil than in any other single environment. Maybe that's because it's very nutrient-dense and can keep some water inside its pores. Soil hosts numerous microorganisms, including bacteria, archaea, and eukaryotes [118]. Cell wall type, cell shape, nutritional requirements, metabolic pathways, and DNA and RNA sequences are commonly used for microbial identification, characterisation, and classification. Bacteria are the most common type of soil microorganism. Some bacteria produce spores in order to survive in harsh environments. Bacteria are able to thrive at extremes of pH and salt. They can also tolerate extremely high pressures and temperatures (from subfreezing to extremely hot ones) [119]. The bacteria are naturally found on Earth, thus they pose little threat to its ecosystem. The bacterial *genera Bacillus, Sploactobacilus, Sporosarcina, Clostridium,* and *Desulfotomaculum*, among others, are used in the bio-mediated soil improvement process because they can synthesise the urease enzyme. In response to an excess of ammonium, microorganisms that make urease fall into one of two categories [120]. For instance, microorganisms like *Bacillus megaterium, Klebsiella aerogenes, Alcaligenes eutrophus,* and *Pseudomonas aeruginosa* have their urease activity suppressed by high ammonium concentrations. Since hydrolyzing large amounts of urea is required for bio-mediated soil improvement, bacteria whose urease activity is not inhibited by the high levels of ammonium are selected for [121].

Bioenzyme formulations contain enzymes that catalyse the production of a reactant mediator from the soil's big organic molecules. Since large organic molecules have flat shapes comparable to the size of small clay particles, they can coat the clay minerals, preventing them from drawing moisture [122]. This coating helps to prevent the loss of density and the absorption of water. This reaction recycles the enzymes, ensuring that the process continues. Since soil contains chemical components such as clay minerals that might react with other chemicals, bioenzyme stabilisation of soil is optimal [114]. Enzymes should only be employed with water-loving clays, such as highly plastic clays with an organic component, according to research. Substances with a poor affinity for water, such as silts and granular soils, are ineligible for enzyme product stabilisation [123]. The treatment of soil with bioenzymes increases its stability by weakening the electric double layer between the clay and static water. This causes the static water layer surrounding the clay particles to evaporate, removing the charge from the clay [124]. Due to the fact that its particles divide and become so crystallographically bonded upon exposure to water, clay cannot expand or compress further. The possibility for soil organic cations created during plant and microbial development to switch places with other ions attracted to the clay particle was also evaluated. Organic cations, as opposed to metal cations, have wide, flat structures comparable in size to small clay particles, allowing them to effectively neutralise the clay particle's negative charge in a very short distance while substantially reducing the double layer thickness [120]. To separate water into its component hydroxyl (OH-) and hydrogen (+H+) ions, the enzyme decreases the dipole moment of the water molecule. Clay minerals drive water molecules out of their intermolecular spaces [125].

Numerous studies have utilised microbially induced calcite precipitation as a proxy for a soil's strength/stiffness and permeability. Multiple environmental and other parameters influence the microbiological reaction with the necessary reagents to cause calcite precipitates, which in turn govern the changes in treated soil's strength, stiffness, compressibility, and permeability. Thus, some physical qualities of soil always regulate the improvement of soil properties [116]. After a bio-mediated treatment process, the soil's strength and stiffness are significantly affected by the level of soil saturation. Therefore, Biocementation can be seen as the process of enhancing soil quality by creating particle-binding compounds through microbial processes. Its primary use is in geotechnical engineering for the purposes of soil reinforcement, void filling, and quality improvement [126]. Bioclogging is the process by which microbial activity generate pore-filling materials that reduce the hydraulic conductivity of soils and porous rocks. Microbially produced carbonate precipitate clogs soil pore spaces, reducing water flow and impairing the soil's permeability [126]. There are a number of bioenzyme formulations available for purchase and use in road construction projects. Although these medications are mass-produced on a global scale, their specific compositions remain secret due to commercial confidentiality concerns [127]. Furthermore, there is no written material available that specifies the necessary processes and recipe in the production process. Soil stabilisation using a fermented enzyme composition that comprised an enzyme expressed by microorganisms [117]. Different types of bacteria, fungus, and urolytic categories were all

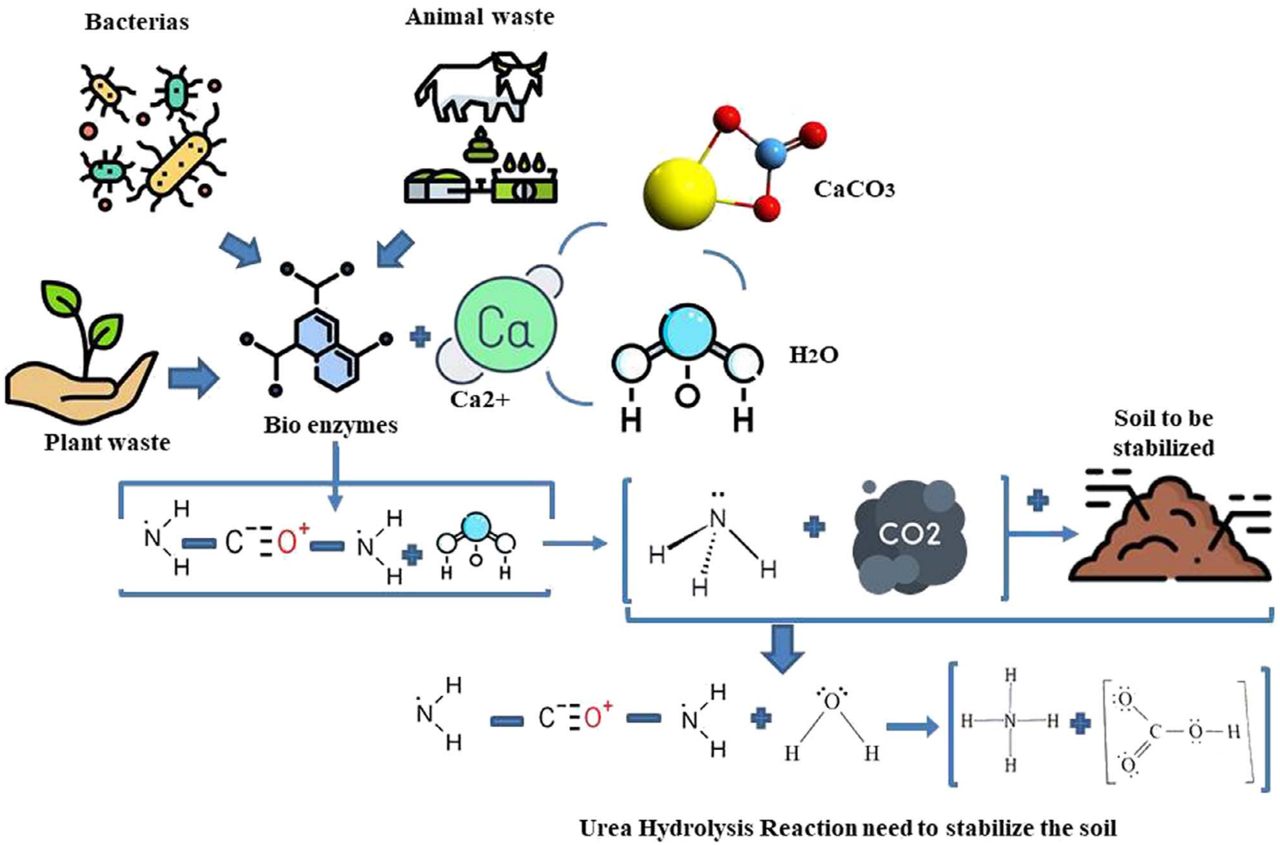


Figure 5. *Hydrolysis reactions in soil stabilization process.*

named. Sugar molasses, a byproduct of the sugar industry, could be used as a substrate for fermentation to produce enzyme formulations for soil stabilisation [128]. The bulk of bioenzymes used for soil stabilisation come from the fermentation of vegetables and sugar cane, making them organic, non-toxic compositions that biodegrade or dissolve in water over time [117]. The second theory arose from observations of the mechanisms used by insects to maintain their equilibrium, specifically termites and ants. Saliva, which is rich in enzymes, is used by ants and termites in the construction of underground masonry that is incredibly durable and can reach heights of many metres. It is common knowledge that these buildings can withstand even the most intense tropical downpours without sustaining any significant damage [129]. Several commercial solutions have been developed using variants of this fundamental idea in an effort to stabilise unstable soils, most often for use in road building. There are currently a plethora of commercially accessible enzymatic products to choose from [130]. Since the 19th century, numerous studies and projects have been conducted on the issue of these items. There's a lot of data out there, but that hasn't translated into widespread support for these stabilisation tools.

Lastly, it is believed that relevant inventions must be discovered and commercialised in order to satisfy soil stabilisation needs. Currently, bioenzymatic soil stabilisation is gaining considerable headway. The primary advantage of bioenzyme soil stabilisation is that no external stabilising ingredients are required. This is an excellent chance to enhance soil stabilisation at a relatively low cost. Due to its substantial economic impact and environmental safety, bioenzyme is the most promising key for developing nations. Bioenzyme technology is a blessing to any nation because it conserves enormous amounts of resources. It is crucial to obtain a deeper understanding of this advancing technology so that we can reap the health and environmental benefits it may bring.

5 Miscallenous application of biobased material in construction

Not only should materials have desirable properties like low thermal conductivity, sound insulation, moisture protection, mould and fire resistance, and thermal insulation, but they should also be environmentally sustainable. As a result, we require novel insulating materials that can match or exceed the performance of the current options [131]. However, agricultural and agro-based wastes are often burnt or dumped in landfills, making waste management an urgent issue for the protection of the environment and scarce resources. Wheat, barley, maize, sugar beet, triticale, rapeseed, and oats are the most prolific European cereal grains in terms of total residue [132]. Insulation made from renewable, recyclable materials with a low embodied energy in the building process has the same R-value as conventional insulation [133]. Reducing resource consumption, encouraging waste recycling, and decreasing reliance on harmful chemical kinds are all benefits of using thermal insulation materials created from such waste sources. Reusing agricultural wastes in construction materials not only helps to lower manufacturing costs, but also advances "green" building practises and offers a workable answer to environmental issues [134].

Biodegradable polymers could help bring down the cost of demolition and garbage disposal. The construction sector can become more environmentally and economically sustainable if biotechnologically produced and biodegradable plastics are used. These plastics can be composted to make soil fertiliser rather than being sent to a landfill or incinerated ([135]. The creation of biodegradable polymers would be beneficial for the environment, the building and biotechnology industries, and the economy as a whole. Raw materials, production biotechnologies, and end-use applications all play a role in how much energy and money are required to produce a certain quantity of bioplastics [136].

In most of special type of advanced concrete, to achieve the appropriate fresh-state qualities, the addition of chemical admixtures, such as viscosity admixtures (VAs) are recommended. Nearly all VAs rely on polymers with high molecular weights that are both water-soluble and stable in the alkaline conditions of cement paste [137]. Other VAs are mostly composed of mineral admixtures, such as microsilica. VA, which alters the cement paste's rheological characteristics, is essential to concrete's stability and cohesiveness under flow and static loads [138]. Modern cement-based products frequently use biopolysaccharides as VAs; examples include welan gum, cellulose ether derivatives, and diutan gum. However, xanthan gum, guar gum, and starch ether have also been the subject of some research [139]. Compared to cellulose-based VAs, microbial anionic polysaccharides make SCC more resilient to changes in sand moisture content. Current VAs have a high production cost, which limits the widespread application of specialty concretes like SCC. Accordingly, as will be mentioned in due time, there is room for exploration in the pursuit of new VAs based on biopolymers. In addition, VAs should boost the cement-based materials' viscosity and cohesiveness without diminishing their mechanical and durability capabilities at either the young or old ages [140].

Employing fungal mycelium (fine filamentous strands) as insulation in construction the Toxic substances and waste items can be safely degraded by it. Biohm's mycelium-based insulation has the potential to both restore damaged ecosystems and provide a greener option for residential insulation. Insulation made from mycelium has the potential to outperform existing synthetic solutions and decrease plastic waste [141]. The production of construction reinforcement materials now includes the use of agro-waste products [142]. Because of their inferior compressive strength, concrete panels made with groundnut shells as an aggregate couldn't be used in substantial structural applications [143]. Wheat and barley straw fibres were used to create lightweight composites for use as building insulation. As an alternative to steel bars, fibre proved to be an efficient reinforcement material for concrete [144]. Based on the findings of various durability tests, including freeze–thaw resistance, carbonation depth, and permeability, the researchers hypothesised that incorporating fibres in concrete materials increased their longevity. production of hybrid polypropylene (PP) biocomposites using unprocessed rice husk and groundnut shell for application in environmentally friendly construction [145].

6 Advancement of biotechnology in construction

Most biotechnological materials used in construction to replace cement admixtures are still in the research and development phase. Therefore, building biotechnology as a field of science and engineering is still in its early stages of research and exponential growth, with only a limited number of commercial applications. Two broad categories characterise the benefits of incorporating agro-waste into the production of building supplies. There are two main benefits to employing agro-waste materials in construction: the first is the reduction of waste sent to landfills, and the second is the creation of new construction materials from a resource that would otherwise be discarded. An important benefit of the first group is that it helps address the environmental problem caused by traditional disposal methods such dumping in landfills, incineration, and composting [146]. The creation of large quantities of trash throughout various agricultural activities has been shown to present unique disposal and management issues. Over 600 tonnes of residues from agricultural products was reported in India alone. As a result, less time and energy are spent on administration of agro-waste programmes when the waste is recycled instead of discarded [147].

Another direct advantage is the use of rare nonrenewable resources in industrial operations when agro-waste products are used in place of traditional building materials like cement or sand aggregates. Because less power is required to manufacture necessary construction materials, the planet benefits. The review article reached a similar conclusion, stating that the improvements made in the newer edition were welcome. First, high-quality, lightweight bricks that met or surpassed industry standards were generated when agro-waste was utilised in brick or masonry building [148]. Bricks with the right modulus of rupture and compressive strength for green building were made by mixing clay with ash from rice husks and baggase at a weight percentage of 5%. Biocomposites made from agricultural waste products like hemp have superior insulating and mechanical properties, and this has been demonstrated in numerous studies. This suggested that those who insulated their homes with products derived from agro-waste could enjoy similar levels of comfort at a reduced cost. This is why insulating the economy and the entire society is so important [142]. The utilisation of agro-waste in the production of reinforcing materials, however, has been shown to significantly enhance durability and performance. It has been shown that the durability performance and characteristics of cementitious materials can be improved by using vegetable fibres as reinforcement. Tests showed that the composites' tensile strength, compressive strength, and tensile modulus were all improved by the addition of carbonised maize stalk ash particles [149]. It follows that the benefits of using specific types of agrowaste in building materials enhancement are linked to those benefits.

All things considered, the numerous construction materials made from agro-waste contributed to three main types of sustainability: financial, ecological, and social. The lower energy needs meant less money and materials were needed to make them. In a similar vein, energy savings from better insulation would benefit the environment. Residents of the various structures would enjoy a high standard of living because to the well-designed, high-quality spaces available to them.

7 Prospectives and recommendations

This investigation also reveals a number of open research avenues. The recommendations were given for futuristic studies as follows.

- It became obvious that agro-waste components, even in minute amounts, were necessary as additives in the production of various construction materials.
- Green concrete must be promoted further, but only through coordinated standardisation efforts and cross-industry cooperation.
- Additional demonstration projects and R&D are required to generate alternative binders from sustainable resources in order to further minimise the demand for oil-based polycarbonate (OPC). The widespread usage of green concrete is due to the multiple advantages it provides in terms of the environment, technology, and the bottom line.
- Using a concentration of between 4 and 10% agrowaste, high-quality materials for the production of bricks and green concrete can be obtained.
- Additional research is required to determine why the use of different types of agro-waste produced higher-quality building materials.
- Despite substantial evidence demonstrating the conformity of agro-waste-based materials to existing construction quality standards, additional research is required to identify the numerous difficulties that arise after deployment.
- The only way to evaluate the long-term performance of materials and how they respond to environmental and anthropogenic influences is through rigorous empirical analysis.

8 Conclusions

According to the findings of this literature study, biotechnology as a new field of research and engineering involves both the microbial synthesis of construction materials and the mediation of construction processes. Utilizing microbial materials and processes can be beneficial for a variety of construction-related tasks, including soil aggregation, cementation, clogging, desaturation, coating, and encapsulation. Improved environmental sustainability and safety, lower costs, reduced or controlled viscosity of admixtures and grouts, increased use of renewable resources, recycling of municipal, agricultural, and food processing wastes, recycling of calcium carbonate and iron ore mining waste, and the use of soft microbial aggregate are just some of the advantages of biotechnologically produced materials and construction biotechnologies over conventional building materials and techniques. Consequently, there may be significant economical and ecological benefits associated with the use of construction biotechnologies. Certain of these technologies are already in the first stages of development at university laboratories. From the nanoscale modification of genetic information to the fabrication of functional models, bringing a prototype home to life needs the collaboration of researchers from a variety of fields, including biology, engineering, and architecture. Future structures that are self-sufficient, durable, and healthy will require the parallel development of all of these technologies with the idea that the building and its materials, processes, and occupants are a symbiotic system, with "waste" from one process serving as "food" for another. In addition to enhancing our understanding of the properties of these biobased materials in the building industry, additional large-scale experiments will reduce their production costs. This strategy appears to provide a long-term solution to the challenges that have recently plagued the concrete industry. Both the industrial sector and the general public have high aspirations for the development of low-energy, low-carbon dioxide-emitting materials that can be manufactured and decomposed in nature with minimal environmental impact. If the guideline is adhered to, buildings and its components should endure at least 50 years with minimal repair costs and minimal to no maintenance. As previously stated, the aforementioned composite was designed to fulfil the needs of both industrial and consumer industries.

Author contributions

D. S. Vijayan (Conceptualization [Equal], Data curation [Equal]), D. Parthiban (Formal analysis [Equal], Investigation [Equal]), Balachandar Ramalingam (Resources [Equal], Software [Equal]), Manzoore Elahi M. Soudagar (Project administration [Equal], Supervision [Equal]), V. Mohanavel (Conceptualization [Equal], Supervision [Equal]), T. M. Yunus Khan (Visualization [Equal], Writing – original draft [Equal]), Kiran Shahapurkar (Investigation [Equal], Methodology [Equal], Writing – original draft [Equal]), and Erdem Cuce (Investigation [Equal], Supervision [Equal], Writing – original draft [Equal], Writing – review & editing [Equal])

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