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Construction Biotechnology: The Promise of Sustainable Buildings

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The construction industry is one of the thriving industries in the world. There are various modern techniques implemented and latest construction materials are used to build an eco-friendly and sustainable building. Construction Biotechnology is a new scientific and engineering discipline that has been developing exponentially during the last decade. In this biotechnology-based construction, microbially treated construction materials are used. The bio-agents used in construction biotechnologies are pure or enriched with cultures of native microorganisms or microorganisms isolated and activated from the soil. Overall process of construction is also different due to involvement of biotechnology-derived processes and technologies. Biotechnology-based construction has shown potential of cost-effectiveness which renders such construction technologies promising in the current era. Architects, engineers, and people involved with construction are suggesting these biotechnology-based construction technologies for eco-friendliness and high sustainability of these novel construction materials. As a field, biotechnology offers countless solutions to common environmental problems well beyond the construction industry.

1. Introduction

Biological technologies are one of the main global directions of technological and scientific progress, providing a breakthrough in obtaining new materials with unique properties, through integrated use of diverse fields such as biochemistry, microbiology, and engineering sciences to provide the possibility of technological (industrial) application of microorganisms (Vasanthabharathi, 2017). Materials obtained through biotechnology have a high innovative potential and by now are already in demand in many industries, including construction. Biotechnology began to find application in many technological processes for obtaining building materials - preliminary processing of raw materials, production of adhesives, bio-surfactants for construction purposes, etc. (Plank, 2004; Achal, 2015; Salahudeen et al., 2018; Barberan et al., 2020).

The construction industry is a major contributor to the current model of unsustainable development due to its huge environmental impacts. The world produced 4.3 billion metric tons of cement in 2014, and this production will continue to increase due to construction demand in the world (Barberan et al., 2020). To help reduce those maintenance costs and make buildings and bridges safer, researchers are now offering concrete with the power to heal itself. In addition to economic constrains, cement and steel manufacturing are among the most environmentally harmful processes in the construction sector, accounting for 37.2 % of manufacturing primary energy demand and nearly 50 % of carbon dioxide emissions.

The field of biotechnology and also the field of biomimetics show a great potential in offering innovative

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solutions that can contribute to a greater eco-efficiency of the construction industry (Stabnikov et al., 2015). The use of microorganisms such as bacteria, fungi, or algae is studied to improve the properties of conventional materials such as concrete; in the creation of new construction materials with similar characteristics to existing materials (Barberan et al., 2020). Production process of novel construction materials are more sustainable and some of these microorganisms can be incorporated into newly developed construction systems as well (Pacheco-Torgal et al., 2013).

The use of construction biomaterials is one of these new, friendly, and sustainable alternatives since the raw material used is mostly from renewable biological resources, e.g. agricultural biomass residues and, recently, waste microorganisms which resulted from other industries have gained popularity for its production (Barberan et al., 2020).

2. Biotechnology

Biotechnology is a scientific discipline and an area of engineering on industrial manufacturing and practical applications of microorganisms and their products such as proteins, nucleic acids, polysaccharides, storage compounds, and low molecular weight metabolites (Ivanov et al., 2015). This area of study has already been successfully applied in sectors such as health, agriculture, and the industrial segment as well. Biotechnology is technology that uses living organisms, biological systems or their derivatives to create or modify products and processes (Erickson et al., 2012). Biotechnology can help to solve major global problems caused by the operations of the engineering and civil construction market - especially with regard to the reduction of environmental impacts caused by construction processes (Ivanov and Stabnikov, 2017).

After three centuries of industrialization, human beings see themselves in the overwhelming need to seek potential in natural systems. This potential in the area of construction currently translates into the creation of new bio-inspired materials, which mix biological and engineering processes within a research area called biotechnology (Barberan et al., 2020).

In addition, through the development of advanced materials that offer more strength and durability and better value for money, biotechnology must also drive efficiency and financial results in our market. Food, Medical, Veterinary, Agricultural, and Environmental Biotechnologies differ in their areas of applications. A new biotechnological discipline, Construction Biotechnology, has appeared during the last decade (Ivanov et al., 2015; Ivanov and Stabnikov, 2017).

3. Construction biotechnology

By definition, construction Biotechnology refers to the newly emerged interdisciplinary field incorporating diverse applications of environmental microbiology, industrial microbiology, and biotechnology in civil engineering. Construction biotechnology designates the development of construction processes mediated by microorganisms and the use of biotechnological techniques for the production of construction materials (Barberan et al., 2020; Chen et al., 2020). The high potential to generate a positive impact on this market, both from an economic and sustainability point of view, makes research with construction biotechnology very promising. The main benefits of biotechnology in the engineering and construction market are related to the creation of more efficient, smart, sustainable, and cheaper materials (Kroll, 1990; Ghosh et al., 2006; Achal et al., 2011; Pilla, 2011; Jian et al., 2012).

New materials are already being developed using living organisms. The search for greater resistance, with greater efficiency and durability and lower cost, is the main objective. Some are in the experimental phase, such as mortars capable of regeneration and insulation that change shape according to humidity, controlling the internal climate of a building (Jonkers et al., 2016).

This modern science successfully combines the application of scientific knowledge about engineering methods for the production of construction biomaterials, as well as the use of bioprocesses in the construction industry (Barberan et al., 2020).

Construction Microbial Biotechnology is a new area of science and engineering that includes microbially-mediated construction processes and microbial production of construction materials. Low cost, sustainable, and environmentally-friendly microbial cements, grouts, polysaccharides, and bioplastics are useful in construction and geotechnical engineering. Construction-related biotechnologies are based on activity of different microorganisms: urease-producing, acidogenic, halophilic, alkaliphilic, denitrifying, iron- and sulfate-reducing bacteria, cyanobacteria, algae, and microscopic fungi. The bio-related materials and processes can be used for the bioaggregation, soil biogrouting and bioclogging, biocementation, biodesaturation of water-satured soil, bioencapsulation of soft clay, biocoating, and biorepair of the concrete surface (Table 1). Construction Microbial Biotechnology is progressing toward commercial products and large-scale applications. The biotechnologically produced materials and construction-related microbial biotechnologies have a lot of advantages over conventional construction materials and processes (Ivanov et al., 2015).

Researchers proposes three possible directions of application of biotechnologies to the construction industry: (1) work with 100 % organic material with thermal insulation functionality and structural qualities, (2) the use of micro luminescent micro-organisms for the design of devices with the ability to emit light without electricity consumption, and (3) cementation of granular structures mediating the use of environmentally friendly bacterial populations, without toxicity or corrosion (Barberan et al., 2020).

Development of materials and construction systems requires the study of microorganisms such as bacteria, fungi or algae, in the improvement of properties of conventional materials such as concrete; in the creation of new construction materials with similar characteristics to existing materials, with the advantage that their production processes are more sustainable; and in the incorporation of some of these microorganisms into new construction systems, which in addition to providing an aesthetic component, develop an energy task in the form of biomass (Barberan et al., 2020).

4. Applications of biotechnology in construction

Taking into account the process of gradual deterioration of our planet, alternatives that allow balancing this process produced mainly by the hand of man should be considered so, in this work we propose, as an alternative, to familiarize the scientific community with the application of biotechnological tools in the Cement industry that includes the use of microorganisms and their potential characteristics (Stabnikov and Ivanov, 2016; Barberan et al., 2020).

Different biotechnological products and biotechnologies applied to civil engineering are being developed in that direction (Figure 1). The reduction of the environmental impact of the conventional production of construction materials, together with a decrease in production costs, use of waste in secondary processes, increased quality and useful life of the materials obtained are considered in the process. These issues, among others, constitute the main advantages of this technology. In the following section, some novel applications of construction biotechnology has been highlighted (Figure 1) (Barberan et al., 2020).

Table 1
Applications of biotechnology in construction

Product	Microbial source	Function	Ref.
Sodium gluconate	*Gluconobacter oxydans* *Aspergillus niger* *Aureobasidium pullulans*	Set retarder; plasticizer; corrosion inhibitor used in concrete	Ma et al., 2015
Xanthan gum	*Xanthmonas campestris*	Thickener and set retarder for self-consolidated concrete	Plank, 2004
Welan gum	*Alcaligenes sp.*	Thickener, set retarder for self-consolidated concrete	Pacheco-Torgal and Jalali, 2011
Scleroglucan	*Sclerotium, Corticium, Sclerotinia, Stromatinia*	Thermostable thickener	Pacheco-Torgal et al., 2012
Succinoglycan	*Alcaligenes sp.*	High shear-thinner with temperature-induced viscosity	Ma et al., 2015
Curdlan gum	*Agrobacterium sp.; Alcaligenes sp.*	Thickener; self-consolidated concrete	Plank, 2003
Sodium alginate	*brown seaweeds*	Stabilizer, thickener, and emulsifier	Fytili and Zabaniotou, 2008
Bacterial cell walls	*Aerobic bacteria*	Microstructured filler for concrete	Pei et al., 2013
Carrageenan	*red seaweeds*	Foam for protecting freshly poured concrete from premature drying during highway construction	Mun, 2007
Dextran	*lactic acid bacteria*	Admixture to Portland cement, self-levelling grouts, fresh or saltwater oil well cement slurries, and micro-fine cements improving flow resistance	Pacheco-Torgal and Jalali, 2011
Pullulan	*Aureobasidium pullulans*	Thickener; self-consolidated concrete	Pacheco-Torgal and Labrincha, 2013
Self-healing concrete (ureolytic process)	*Bacillus megaterium* *Deleya halophila* *Halomonas euryhaline*	Re-inforced concrete; self-healing concrete; bio-cement	Talaiekhozan et al., 2014
Self-healing concrete (silica process)	*Leuconostoc mesenteroides*	Re-inforced concrete; self-healing concrete; bio-cement	Talaiekhozan et al., 2014
Microbe induced $CaCO_3$ precipitate (MICP)	*Bacillus pseudofirmus* *Sporosarcina pasteurii*	Re-inforced concrete; self-healing concrete; bio-cement	Barberan et al., 2020
Biobrick	*Synecococcus sp.*	Re-inforced eco-friendly brick	Khitab et al., 2016
Bioinsulator	*Ganoderma lucidum* *Pleurotus ostreatus*	Low cost insulator; foam sealing	Barberan et al., 2020

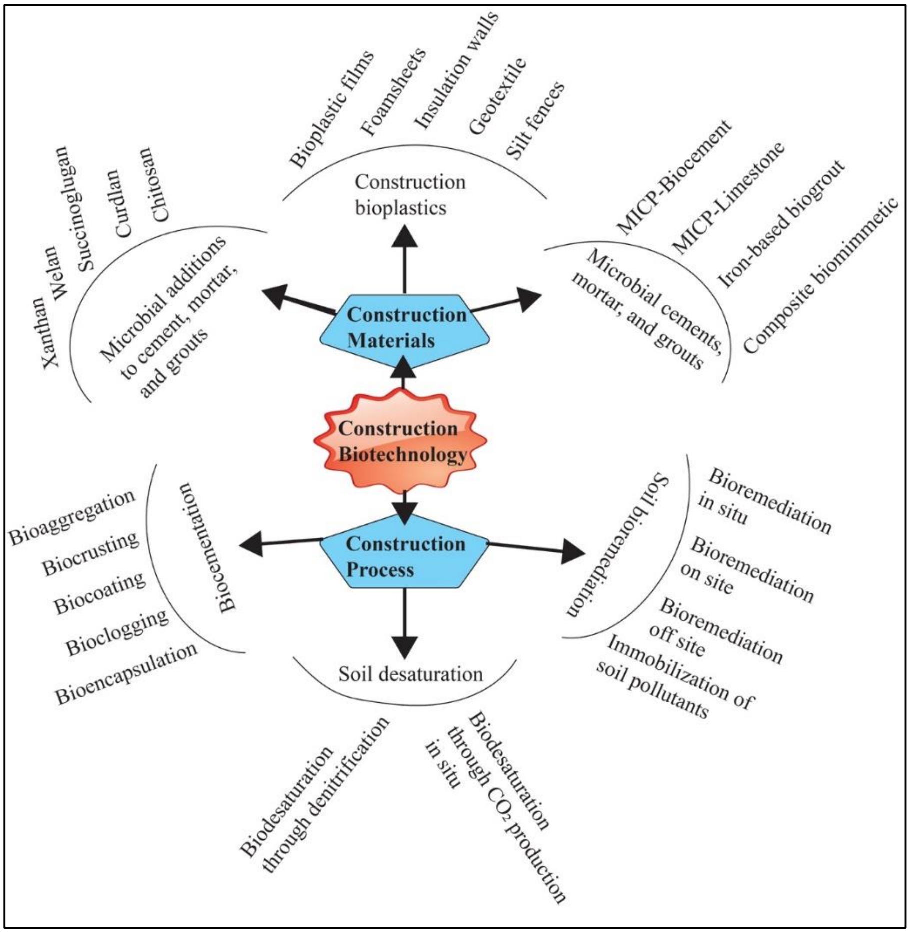

Figure 1. Potential applications of construction biotechnology

4.1. Bio-Brick

Brick is an essential component of any construction. About 40 % of the cost of a masonry brick is in the fuel used to burn the kiln. In addition to costing money, the burning necessary for the production of traditional bricks also contributes to the increase in the emission of polluting gases. Bio-crick was developed from a by-product generated by microorganisms, which binds sand particles together, creating a material similar to corals and strong enough to be used in homes (Dhami et al., 2012). In this biotechnology process, bacteria creates natural cement in just five days, without using fossil fuels (Brown et al., 2004; Bernard et al., 2014).

New bricks, according to their developers, are highly stable and have a long service life, durability. This building material, in accordance with the technology of its production, can be made, or more precisely, “grown” from ordinary sand, using calcium chloride, common bacteria and carbamide, that is, urea. This, according to the developers, is an optimal, affordable and practically complete modern alternative to the technology of firing building bricks, which is currently practiced by many enterprises, and requires the use of a significant amount of energy resources.

4.2. Bio-Insulator

Currently, civil construction mainly uses materials of petrochemical origin to insulate homes and buildings. The most used materials are derived from plastics, and such plastic materials can take hundreds of years to decompose. Bio-insulator has emerged as a sustainable alternative of such plastic based insulators (Binici et al., 2016). Bio-insulator has been developed from materials made from fungi, as well as from agricultural waste such as plant stems and seed husks. The fungus grows in a mold or inside a cavity in walls, providing rigid structural insulation for homes. The resulting insulation is fire resistant and fully compostable material (Chang et al., 2015).

Fungal mycelium is light and resistant, and since it can be produced on different substrates, the properties are highly variable and manageable. Its density is in a range of 0.05 to 0.59 g/cm, and although wood is more resistant, its tensile strength value is very high (it varies between 20 and 240 MPa) when compared with triplex, whose tensile strength is 0.55 g/cm^3 and polystyrene is 34 MPa (Girometta et al., 2019). The mycelium has also been studied for its high capacity for thermal and acoustic insulation. Other characteristics are: it floats, it is fire retardant, a dielectric insulator, and highly moldable. The material has very low thermal conductivity, which makes it an ideal thermal insulator. This characteristics, added to its fire retardant, resistance and low density properties, allow it to become a perfect candidate to replace plastic packaging foams as insulator (Latif et al., 2014; Velasco et al., 2014).

4.3. Bio-Concrete

Concrete is one of the most widely used materials in the world in the construction industry that uses 1.6 billion tons of cement, and each ton of cement emits 1 ton of CO_2 into the atmosphere in its manufacture (Wu et al., 2012; Wang et al., 2012; Barberan et al., 2020). It is considered to be the mostly used building material on Earth. The annual production of Portland cement concrete reaches about 10 km^3/year, most of which is used in the execution of reinforced concrete structures (Stocks-Fischer et al., 1999; Jonkers et al., 2010; Pacheco-Torgal and Labrincha, 2013). With the help of biotechnology, Bio-Concrete has been developed with bacteria (such as *Bacillus pseudofirmus*) that, in contact with water, generates calcium carbonate which fills cracks and holes in the structure. Thus, it makes possible to build a building capable of repairing itself each time it suffers damage such as a crack that occurs in the concrete structure (Reddy et al., 2010; Van Tittelboom et al., 2010). How it works is simple: the contact of water with the cracks in concrete activates the spores so that they begin to feed on another aggregated substance, calcium lactate, producing calcite crystals. In this way, when the cracks are still microscopic, they can be filled with repair material, avoiding wear and tear and pathologies (Reddy et al., 2012; Kalhori and Bagherpour, 2017). Precipitation of polymorphic iron-aluminium-silicate ((Fe_5AI_3) $(SiAl)O_{l0}(OH)_5$) and calcium carbonate ($CaCO_3$) are the most important processes used for designing the biological self-healing concretes. *Bacillus pasteurii* and *Bacillus sphaericus* family are the most common microorganisms used in designing self-healing concrete through ureolytic processes (Toohey et al., 2007; Wang et al., 2012; Wu et al., 2012). The bacteria *Leuconostoc mesenteroides* plays an important role in precipitating the silica for development of self-healing concrete (Talaiekhozan et al., 2014).

4.4. Bio-Cement

Cement is widely used as a construction material (Stabnikov et al. 2013). However, its production generates environmental impacts during all manufacturing stages. Added to this fact, world cement production is responsible for consuming about 10-15 % of total industrial energy and 5-8 % of anthropogenic CO_2 emissions (Uson et al., 2013; González-Kunz et al., 2017). Bio-cement is an alternative to cement (De Muynck et al., 2010) that can produce binder materials through MICP treatment to improve the strength and durability of cementitious materials (Phillips et al., 2013; Dhami et al., 2014). “Biocement” is a MICP product that aims to reduce or eliminate spaces between particles of a granular material (sand as an aggregate, for example). As cement production is largely responsible for the high carbon emissions in the civil construction segment, the use of any alternative such as Bio-Cement will help to make buildings more sustainable. Scientists have found that carrot and beet fibers can make cement stronger, more economical and more sustainable (Ariyanti et al., 2012). The “nanoplatelets” extracted from vegetables increase the amount of calcium silicate hydrate, responsible for the structural performance in concrete. As a result, stronger concrete that uses less cement is generated. In addition, vegetables also improve the quality of the final product by reducing the number of cracks that appear in the concrete (Wu et al., 2012; Sarayu et al., 2014). Microorganisms most commonly associated with bio-cement production through MICP process include *Bacillus pseudofirmus*, *Sporosarcina pasteurii* and *Shewanella* sp. (Dhami et al. 2014; González-Kunz et al. 2017). Additional research is needed to improve production technology and reduce undesirable by-products to allow the use of MICP on a commercial scale.

5. Future perspective

The commercial and residential construction sector represents 39 % of the CO_2 emitted into the atmosphere, generating 30 % of solid waste and 20 % of water pollution. Based on the previous data, it can be concluded that half of the CO_2 expelled into the atmosphere is related to the construction of buildings throughout all its phases: construction, use, and subsequent demolition. Therefore, the construction sector and its CO_2 emission, as a threat of climate change, must be considered. Therefore, to reduce the environmental impact on the construction sector, it is essential to use materials that do not require the use of fossil fuels and cause high carbon emissions (Barberan et al., 2020).

The use of biologically based products has increased at a steady pace in the last decade. It is estimated that by 2020 the global market based on bioproducts will reach $ 250 billion and that by 2030 a third of the produced materials will come from biological resources. This study raises the possibility of implementing bio-cements and bio-concrete and its possible application in several areas where there is a higher demand for construction (Barberan et al., 2020).

The planet faces environmental challenges that require an urgent response to assure a sustainable development and the needs of future generations. Researchers around the world have been working in recent years on developing biotechnological solutions to problems in different areas, including construction. Living organisms are already being applied in the creation of more resistant materials, mortars capable of regeneration and insulation that changes shape according to humidity, controlling the building's internal climate. These are applications that can help solve major problems caused by processes in this segment, such as the large generation of waste. Better economic results for the sector with less environmental impact will be the main benefits of construction biotechnology to the market. The application of bacteria, fungi and plants in the manufacturing process of building materials will not only generate differentiated physical elements, but will also bring buildings closer to the dynamics of biology.

Novel biomaterials offer several advantages over the traditional construction materials: (1) biomaterials give us the opportunity to capture properties from nature and exploit them for more sustainable construction; (2) the advantage of the microstructure of construction biomaterials is its simplicity and ease of manufacture; (3) the new biomaterials could contribute to the drastic reduction of the environmental impact in construction; (4) bio-construction materials are equivalent to a reduction in waste and optimal recycling and waste from other sectors is reused for the manufacture of construction biomaterials; and (5) its cost is low and its ecological impact of its use is also low.

Most of this research is still in the experimental phase. But some studies have already achieved promising results. A part of these possibilities has been commercially exploited by companies in the construction industry. In a few years, therefore, the use of biotechnological solutions in the sector will be an increasingly significant reality throughout the world. Keeping up with the great global movements will help you be more prepared for the changes that should revolutionize processes in the engineering and construction market in the coming years.

The gathering of these contributions and cutting-edge research in the targeted areas, specifies the needs for significant changes related to education, research and public policy, in order to plan a sustainable future of the construction industry with the associated benefits related to the eco-efficiency.

6. Conclusion

We are living in the fourth industrial revolution. This new era is marked by the fusion of different technologies and the union of digital, physical, and biological spheres. Because of all this, biotechnology is gaining more and more importance and space. And this area of science can generate a great sustainable and economic impact on the civil construction market. After all, new materials and processes arise precisely because of biotechnology. Microbe-derived construction related applications are limitless and useful in applications that aim to generate safe and environmentally stable products. Even though construction biotechnology has its advantages, further studies are needed to overcome its limitations before commercialization on an industrial scale.

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Biotehnologija u građevinskoj industriji: budućnost održivih zgrada

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I Z V O D

Građevinska industrija je jedna od naprednijih industrija u svetu. U njoj se primenjuju različite moderne tehnike i najnoviji građevinski materijali koji se koriste za izgradnju ekološki prihvatljivih i održivih zgrada. Biotehnologija u građevinskoj industriji je nova naučna i inženjerska disciplina koja se postepeno razvijala tokom poslednje decenije. U ovoj biotehnološkoj disciplini koriste se građevinski materijali tretirani mikrobima. Bioagensi koji se koriste u građevinskim biotehnologijama su čisti ili obogaćeni kulturama izvornih mikroorganizama ili mikroorganizmima koji su izolovani iz tla i aktivirani. Celokupni proces izgradnje je takođe drugačiji zbog upotrebe postupaka i tehnologija zasnovanih na biotehnologiji. Ovakav način izgradnje se pokazao kao potencijalno isplativ, što biotehnologije čini obećavajućim. Arhitekte, inženjeri i ljudi uključeni u izgradnju predlažu ove biotehnologije kao ekološki prihvatljive i visoko održive. Biotehnologija kao oblast nudi bezbroj rešenja za česte probleme u vezi sa ekologijom, ne samo u okviru građevinske industrije.