An assumption of *in situ* resource utilization for "bio-bricks" in space exploration

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Microbially induced carbonate precipitation (MICP) mimics the natural cementation process that occurs in various geological settings by using the bicarbonate minerals resulting from various bacterial metabolic pathways as cementing agents. This bio-technique can be used to manufacture so-called "bio-bricks," which rival regular bricks in strength and durability. In the last two decades, MICP has been increasingly utilized for the maintenance and repair of infrastructure. More recently, this process has also been shown to have great potential as an energy-saving and cost-effective means of *in situ* resource utilization (ISUR) to produce construction materials; these can be utilized for extraterrestrial human settlements for space programs such as lunar exploration. We thus review the description of natural cementation, the anaerobic and aerobic bacterial metabolic activities leading to calcium carbonate precipitation, the properties of the lunar regolith, the production of bio-bricks, and potential research needs.
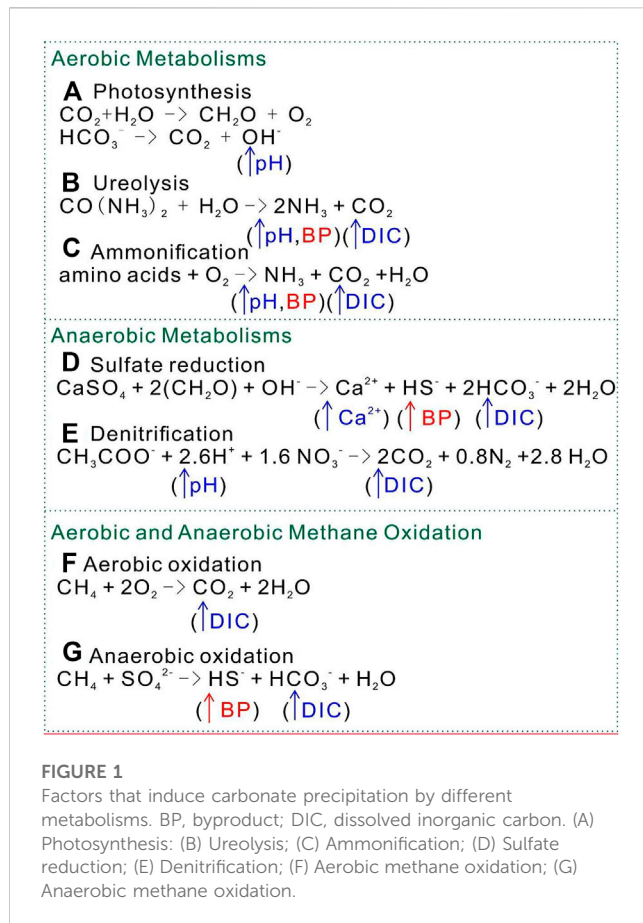
1 Introduction

Space exploration has been making great efforts to develop extraterrestrial human settlements. However, as estimated by the US National Aeronautics and Space Administration (NASA), it costs about $10,000 USD to put only one pound of material in Earth orbit. Thus, the *in situ* utilization of raw materials, also known as *in situ* resource utilization (ISRU), is an economic imperative. ISRU covers a wide range of production techniques, including the production of propellant, gases, and water for sustainable life support, and the production of construction materials for shelter (Pickett et al., 2020; Schlüter and Cowley, 2020). Scientists have considered and studied various techniques to transform ingredients (i.e., regolith/mined ores) to a construction phase on our Moon (Anand et al., 2012; Wilhelm and Curbach, 2014). Naser (2019) gave a detailed review of the main extraterrestrial processing methods, including melting/sintering, combustion, dry-mix/steam injection, and cold pressing.

The energy consumption of the aforementioned processing methods is daunting (Kara and Li, 2011; Qureshi et al., 2012). However, bio-cementation is being progressively recognized as a green solution for the application of bonding in construction materials. Bio-cementation uses microorganisms to induce the precipitation of carbonate minerals for construction. In the last

FIGURE 1
Factors that induce carbonate precipitation by different metabolisms. BP, byproduct; DIC, dissolved inorganic carbon. (A) Photosynthesis: (B) Ureolysis; (C) Ammonification; (D) Sulfate reduction; (E) Denitrification; (F) Aerobic methane oxidation; (G) Anaerobic methane oxidation.

two decades, microbially induced carbonate precipitation (MICP) has been increasingly utilized to maintain and repair infrastructures and has particularly been used to produce biological cement for sandstone bricks. More recently, numerous research articles have been published on the application of MICP to produce "bio-bricks" (Bernardi et al., 2014; Li et al., 2020b; Cheng et al., 2020; Nething et al., 2020; Zhao et al., 2020; Arab et al., 2021; Liu et al., 2021). This review focuses specifically on the metabolism of the MICP process, the properties of lunar regolith particles, and the characteristics of artificial bio-bricks.

2 Microbial carbonate precipitation by different metabolic activities

Anaerobic microbes should surpass aerobic ones in respiration, given the fact that the moon lacks oxygen. In this review, the metabolic activities that induce carbonate precipitation are classified into aerobic and anaerobic groups. Microorganisms induce carbonate precipitation either by increasing pH, increasing dissolved inorganic carbon (DIC), or both. The process can be classified into several metabolic pathways—photosynthesis, ureolysis, ammonification, denitrification, sulfate reduction, denitrification, and methane oxidation (Jain, 2021). The major metabolism involved in microbial carbonate precipitation can be either aerobic (photosynthesis, ureolysis, and ammonification) or anerobic (sulfate reduction and denitrification). For anaerobic processes, the inorganic compounds sulfate (SO_4^{2-}) and nitrate (NO_3^-) serve as electron acceptors for bacteria (Ersan, 2019). Methane oxidation is a

metabolic process that can occur aerobically or anaerobically. Among these microbial metabolisms, ureolysis is the most studied MICP process due to its less complex and higher calcite precipitation (Wang et al., 2014; Castro-Alonso et al., 2019).

2.1 Aerobic processes: Photosynthesis, ureolysis, and ammonification

Photosynthesis is an autotrophic aerobic metabolic process that is reported to be feasible for MICP. Altermann et al. (2006) proposed that cyanobacteria can store Ca^{2+} and Mg^{2+} ions in organic envelopes and precipitate carbonate minerals within their sheaths, as well as extracellular polymeric substances. However, to satisfy the oversaturation status of Ca^{2+} and CO_3^{2-} in aquatic environments, heterotrophic bacteria such as sulfate reducers must help remove sulfate and raise carbonate alkalinity. The interplay of cyanobacteria and heterotrophic bacteria are believed to have contributed to the Earth's carbonate factory for the last 3 billion years. This mechanism has contributed to increased pH through photosynthesis by microalgae, resulting in the exchange of HCO_3^- and OH^- across the membrane (Figure 1A). With pH of up to 10.329 (Pedersen et al., 2013), CO_3^{2-} dominates the solution to reach supersaturation in the microenvironment around the cells. With calcium ions present in the microenvironment, carbonate minerals precipitate out of solution, inducing MICP. Photosynthesis utilizes HCO_3^- and decreases DIC but increases pH and CO_3^{2-} concentration to induce MICP.
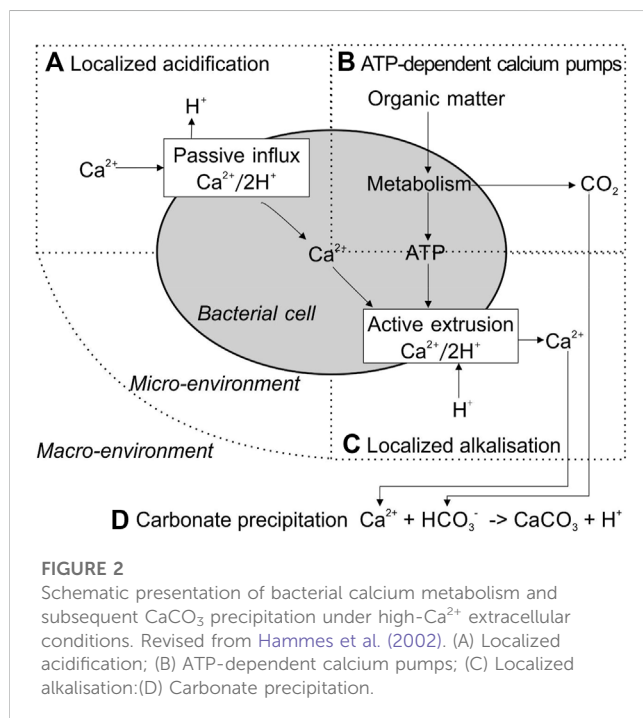
Ureolysis is the enzymatic degradation of urea by ureases, producing carbonic acids and ammonia. The carbonic acid produced increases the concentration of DIC. Ammonia increases the pH of the environment by ammonia hydrolysis. In this case, ureolysis simultaneously influences the concentration of DIC and the pH of the environment (Figure 1B), leading to the precipitation of carbonate minerals along with the presence of calcium ions in the environment. The genus *Bacillus* harbors the most species currently used in MICP biotechnology. A prime example of this is *Sporosarcina pasteurii*, formerly *Bacillus pasteurii*, which is one of many species highly efficient in ureolysis due to its high levels of secreted urease; it is used repeatedly as a study model for MICP. *Bacillus* is known to harbor many urea hydrolyzing species, so this factor is often exploited and manipulated for biotechnological application (Table 1). *B. sphaericus* appears in numerous papers in use as another model organism for MICP *via* urea hydrolysis (Table 1) (Hammes et al., 2003; Van Tittelboom et al., 2010; Achal et al., 2011; De Muynck et al., 2011; Cheng et al., 2013; Wang et al., 2014; Erşan et al., 2016; Kim et al., 2017; Sharma et al., 2021). Other species of this genus are applied in a variety of biotechnological applications, including *B. cereus* in soil stability (Oualha et al., 2020), *B. licheniformis* in the cementation of sand (Saricicek et al., 2019; Šovljanski et al., 2021) and *B. pseudofirmus* in self-healing concrete (Jonkers et al., 2010). The availability of whole-genome sequence data for several of the many species within this genus makes *Bacillus* ideal for future MICP genetic bioengineering.

The ammonification of amino acids is a metabolic process similar to ureolysis, in which microbes increase the DIC concentration as well as the pH of an environment. Amino acids contain both nitrogen and carbon, which are oxidized by heterogenic microbes under aerobic conditions to form NH_3 and CO_3^{2-} (Figure 1C). The hydrolysis process of ammonia product generates OH^- around cells and creates a high

TABLE 1 Mechanism of precipitation induced by *Bacillus* species recorded in literature and capable of MICP.

Mechanism of precipitation	Microorganism	Nutrient	Reference
Ureolysis	*B. sphaericus*	Urea, calcium nitrate, and yeast extract	Wang et al. (2014)
	B. sphaericus	Urea and calcium chloride	Achal et al. (2011)
	B. sphaericus	Urea, calcium chloride, calcium nitrate, and yeast extract	Van Tittelboom et al. (2010)
	B. cereus	Urea, glucose, sodium chloride, potassium phosphate, peptone, and calcium chloride	Oualha et al. (2020)
	B. muralis, B. lentus, B. simplex, B. firmus, B. licheniformis	Urea and calcium chloride	Šovljanski et al. (2021)
	B. sphaericus	Urea, calcium chloride, sodium carbonate, ammonium chloride, and yeast extract	Kim et al. (2017)
	B. subtilis and *B. sphaericus*	Urea, calcium chloride dihydrate, ammonium chloride, sodium bicarbonate, and yeast extract	Sharma et al. (2021)
	B. pseudofirmus	Calcium lactate, calcium glutamate, yeast extract, and peptone	Jonkers et al. (2010)
	B. licheniformis	Urea, ammonium chloride, sodium bicarbonate, and nutrient broth	Saricicek et al. (2019)
	B. sphaericus	Urea, calcium chloride, nutrient broth, and sodium bicarbonate	Hammes et al. (2003)
	B. sphaericus	Urea and calcium chloride dihydrate	De Muynck et al. (2011)
	B. sphaericus	Urea and calcium chloride	Cheng et al. (2013)
Denitrification	*B. sphaericus*	Urea, calcium formate, calcium nitrate, and yeast extract	Ersan et al. (2016)
Bacterial metabolic conversion of organic acid	*B. pseudofirmus*	Calcium lactate, calcium glutamate, yeast extract, and peptone	Jonkers et al. (2010)

Note: *Sporosarcina pasteurii*, formerly known as *B. pasteurii*, is not included in this table.

FIGURE 2
Schematic presentation of bacterial calcium metabolism and subsequent CaCO$_3$ precipitation under high-Ca^{2+} extracellular conditions. Revised from Hammes et al. (2002). (A) Localized acidification; (B) ATP-dependent calcium pumps; (C) Localized alkalisation; (D) Carbonate precipitation.

local supersaturated environment of calcium carbonate. Rodriguez-Navarro et al. (2003) reported that the metabolic activity of *Myxococcus*

xanthus involves the production of NH$_3$ and CO$_2$ by means of the oxidative deamination of amino acids. Apart from the modification of physical chemistry, both live and dead *M. xanthus* play a passive role in calcium carbonate precipitation by acting as a template for heterogeneous nucleation (Chekroun et al., 2004).

2.2 Anaerobic process: Sulfate reduction and denitrification

Sulfate reduction refers to reducing sulfate to sulfide coupled with anaerobic oxidizing organic carbon to bicarbonate, during which DIC and calcium concentrations increase Figure 1D). Specifically, the oxidation of organic acids increases the DIC concentration. More importantly, the release of calcium ions from gypsum (CaSO$_4$) increases local Ca^{2+} concentration (Figure 2). Sulfate-reducing bacteria (SRB) have been reported to produce a copious amount of exopolymeric substances (EPSs) with buffering and Mg–Ca binding capacity, which controls the precipitation of the carbonate minerals by acting as templates for different carbonate minerals (Braissant et al., 2007; Bontognali et al., 2014; Qian et al., 2019). In addition, the nucleation of carbonate minerals occurs on the cell surface, as well as bacterial nanoglobules (Van Lith et al., 2003; Aloisi et al., 2006). Both their cell surface and EPS carry a net negative electric charge and have the capacity to bind Mg^{2+} and Ca^{2+} ions. Thus, SRB have been recognized as key to the
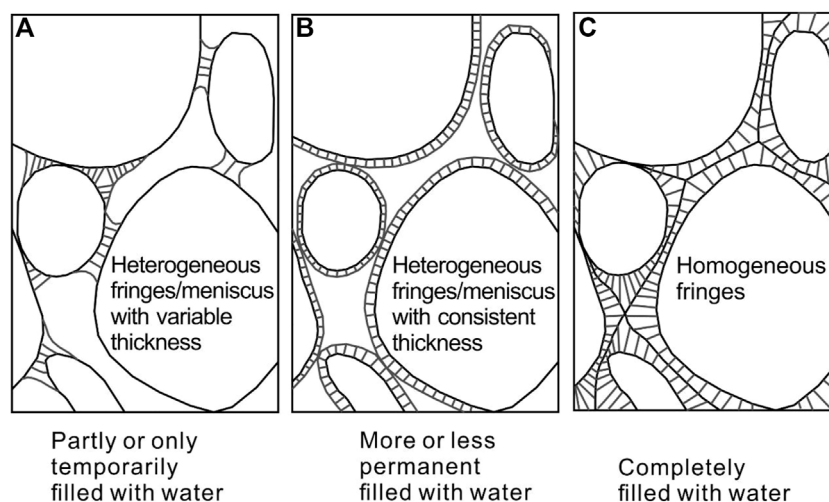
FIGURE 3
Distribution of cement under various environments. Revised from Scholle and Ulmer-Scholle, 1978.

precipitation of calcium carbonate, resulting in lithifying microbial communities (Baumgartner et al., 2006; Braissant et al., 2007). However, the application of sulfate reduction by SRB in concrete restoration has the problem of side-product H_2S, which could cause corrosion of the concrete structure by its reaction with oxygen (Mori et al., 1991; Li et al., 2019). Many efforts have been made to control H_2S production in anaerobic environments, such as using iron salts ($Fe^{2+} + S_2^- \rightarrow FeS$) (Muñoz et al., 2015). More economically, the magnetite-assisted *in situ* microbial oxidation of H_2S to S^0 has been recently reported (Jung et al., 2020). Furthermore, elemental sulfur S^0 can reduce CO_2 into formic acid under ultraviolet light below 280 nm (Li et al., 2020a). Thus, state-of-the-art of physical/chemical and biological technology requires more research on the application of sulfate reduction in bioconcrete.

Denitrification, like sulfate reduction, utilizes a highly oxidized-phase nitrate as the electron acceptor under anaerobic conditions, coupled with the oxidization of organic compounds. The denitrification process increases the pH in the microenvironment by consuming H^+ and producing CO_2 by oxidizing organic compounds, favoring carbonate precipitation (Figure 1E) (Lin et al., 2021). Recent research has demonstrated the potential of denitrification for improving the mechanical and hydraulic properties of soils (Pham et al., 2016; Hamdan et al., 2017; Keykha et al., 2018; Cheng and Shahin, 2019; Lin et al., 2021). The reduction of nitrate should produce the harmless terminal side-product N_2. However, producing N_2 requires four different enzymes involved in the denitrification process, or toxic nitrite and nitrous oxide might accumulate (Van Paassen et al., 2010). Denitrification has been evaluated as the most suitable MICP method for soil reinforcement by defeating ureolysis and sulfate reduction, based on four factors: substrate solubility, precipitation rate, carbonate yield, and the amount and type of by-product (Van Paassen et al., 2010).

Given the lack of oxygen on the moon or in space, anaerobic metabolic microbes should surpass aerobic ones when applied to MICP in space. Microbes that can use *in situ* minerals directly as the energy source to grow should generate considerable savings.

2.3 Aerobic and anaerobic methane oxidation process

Methane oxidation drives the concentration of carbon dioxide in marine and freshwater sediments due to its aerobic and anaerobic oxidation. Methane serves as the electron donor; for methane oxidation, the type of electron acceptor determines its aerobic or anaerobic process. In aerobic conditions, methane mono-oxygenase converts methane to methanol, which is further converted into formate by another cell enzymatic activity (Jain, 2021). Oxygen seems to be the electron acceptor in this process. Formate must then be further oxidized to CO_2. The increase of DIC concentration favors the precipitation of carbonate mineral around the microbial cell in the alkaline environment (Figure 1F). However, the aerobic oxidation of methane may lead to the dissolution of carbonates if the environment is not alkaline due to consequent increasing acidity from this process (Reeburgh, 2007). The anaerobic oxidation of methane can use sulfate as the final electron acceptor. This process increases DIC concentration and the byproduct HS^- (Figure 1G). Caesar et al. (2019) proposed that the MICP has potential application in the mitigation of methane release into the atmosphere due to anaerobic methane oxidation.

3 Properties of sand-sized material on the moon

Microbes may form minerals authigenically or diagenetically. Microbial-induced carbonate mineral formation is passive in the environment to "cement" sand-sized material. Geologically, the distribution of cement varies with the degree of water filled in the pore spaces between the material particles (Figure 3). When completely filled with water, cements present as homogeneous fringes around material particles. The properties of sand-sized material on the moon should be considered because it determines the characteristic of pore spaces.

On the lunar surface, regolith refers to fragmental and unconsolidated rock material—also known as lunar soil. The

TABLE 2 From sand to artificially "bio-bricks" and comparable unconfined compressive strength.

Material	D_{50} (mm)	C_u	C_c	G_s	Mineralogy	Microbe/organic/ inorganic	Unconfined compressive strength (MPa)	Reference
Masonry sand, Chico, California	0.42	2.60	1.20	2.60	Quartz	Sporosarcina pasteurii (ATCC 11859), 0.2 M urea and 0.1 M CaCl$_2$	1.0–2.2, Ave.1.6 ± 26.4% @28 days	Bernardi et al. (2014)
Graded silica sand, Cook Industrial Mineral Pty Ltd., Western Australia	0.42					S. pasteurii, 1 M urea and 1 M CaCl$_2$	~9	Cheng et al. (2020)
Poorly graded Ottawa silica sand	0.51				99.0% quartz	S. pasteurii, 30 g/L urea and 73.6 g/L CaCl$_2$•H$_2$O, 0.3% fiber, triple treatment	~3.5	Li et al. (2020a)
Silica sand, Holcim Kies und Beton GmbH, Germany						S. pasteurii (DSM 33), 0.4 M urea and 0.4 M CaCl$_2$, 3D printing	5–23 Mpa	Nething et al. (2020)
Poorly graded sand, China standard sand	0.73	5.19	1.73		98.0% Silica	S. pasteurii (CGMCC 1.3687), 1 M urea, 1 M Ca(CH$_3$COO)$_2$, various fibers	1.08-7	Zhao et al. (2020)
Graded silica sand, Société Nouvelle du Littoral, France	0.36	2.00	1.28	2.65		Urea 2 mol, CaCl2, urease enzyme. Non-fat powdered milk, sodium alginate 1.5%	~1.8@7″ title = "mailto:~1.8@ 7">~1.8@7 days	Arab et al. (2021)

thickness of this layered regolith is estimated at about 2–15 m thick with a specific gravity ranging 2.9–3.5 g/cm³ (Shkuratov and Bondarenko, 2001; Taylor et al., 2003; Lin et al., 2020). Contributing to the formation of the lunar regolith are meteoroid impacts on the moon for over 4 billion years; furthermore, the lunar regolith may be recycled by unceasing impacts of large and small meteoroids (Lucey et al., 2006; Lin et al., 2020).

The chemistry of the lunar soil shows Si, Al, Fe, Mg, Ca, Ti, Na, K, Mn, and Cr as the major and minor abundant elements in bulk and size fractions (Papike et al., 1982). The chemical composition varies with grain size. In most cases, the smallest fraction (<10 um) is enriched in Al, Ca, Na, K, light rare earth elements, and Th and is depleted in Mg, Fe, Mn, and Sc. Moreover, the soils of the lunar *maria* are chemically distinct from highland soils.

The particle size of the lunar soil is consistently and broadly distributed (Morrison et al., 1970; Mitchell et al., 1972; Graf, 1993; Jolliff et al., 2000; Carrier, 2003; McCubbin et al., 2010). The size of 143 different lunar samples collected during the Apollo and Luna missions are cataloged by Graf (1993) and vary from 0.002 to 4 mm. Carrier (2003), the director of the Lunar Geotechnical Institute, describes the particle size of lunar soil to be sandy silt/silty sand, well-graded in geotechnical terms. The geotechnical particle size parameters are published with average mean particle size D_{50} = 72 μm, average coefficient of uniformity C_u = 16, and average coefficient of curvature C_c = 1.2 (Carrier, 2003). These parameters indicate that the Moon's soil may be internally erodible and susceptible to "segregation piping" (Carrier, 2003). On the other hand, the lunar soil is characterized as very fine sand, very poorly sorted, nearly symmetrical, and geologically mesokurtic. These geological terms describe not merely particle size but also reflect the depositional environment. Obviously, meteorite impact is a very dynamic process, producing poorly sorted particles. Duke et al. (1970) proposed that it is caused by melting and consequent consolidation into clumps of finer particles on the Moon so that material finer than 15 um is less abundant. In this review, we tend to include both terms

since the cementation process relates to geotechnical application and geological properties.

The mineralogy of the lunar soil is not very complicated and includes plagioclase (typical formula Ca$_2$Al$_2$Si$_2$O$_8$), pyroxene ((Ca,Mg,Fe)$_2$Si$_2$O$_6$), ilmenite (FeTiO$_3$), olivine ((Mg,Fe)$_2$SiO$_4$), and impact glass as major phases (Smith and Steele, 1976; Taylor et al., 2003). The simple mineralogy is produced in a very reducing environment. The remarkably distinct grain boundaries indicate no real alteration. Impact glass is apparently a product of frequent meteorite impacts on the lunar surface and can fuse minerals and rock fragments together (Taylor and Liu, 2010). Notably, all agglutinitic glasses contain myriads of nanophase Fe particles distributed in glass without touching each other, resulting in a relatively high magnetic susceptibility to agglutinitic glass (Taylor and Liu, 2010). Troilite is the only sulfide in the lunar regolith.

4 Characteristics of artificial bio-bricks

The grain-size property of the starting materials is the main factor to consider in laboratory experiments of artificially forming bio-bricks. Previous studies of the properties of artificial bio-bricks have tested their unconfined compressive strength to better establish the validity and feasibility of MICP biotechnology (Table 2). The grain sizes used to produce bio-bricks are normally with D_{50} in the range of 0.42–0.73 mm (Table 2). However, it is difficult to report a relationship between the grain size and the compressive strength of the correspondingly produced bio-bricks since the same grain size might result in a different unconfined compressive strength under different saturation conditions (Bernardi et al., 2014; Cheng et al., 2020). *Sporosarcina pasteurii*—known as *Bacillus pasteurii* under older taxonomies (Yoon et al., 2001)—is a widely used model organism for making bio-bricks *via* MICP because it is highly productive in its secretion of extracellular urease. Arab et al. (2021) reported a hybrid technique to produce bio-bricks using

enzyme-induced carbonate precipitation and sodium alginate biopolymer. This shows that carbonate precipitation without microorganisms can also produce bio-bricks.

The unconfined compressive strength of bio-bricks shows that they can have strengths of 1 MPa to 23 MPa (Table 2). The variation in unconfined compressive strength in different studies may be due to different reaction conditions. However, Nething et al. (2020) found a variation in strength between samples produced with the same parameters, which still requires further investigation of the cementation process. Regardless, bio-bricks have stress comparable to bricks prepared with more conventional cement and hydraulic lime additives (Bernardi et al., 2014). Previous studies have shown that the bio-bricks produced are comparable to cement-treated beams in terms of their mechanical properties and can also be considered an eco-friendly alternative to conventional bricks (Bernardi et al., 2014; Li et al., 2020b; Cheng et al., 2020; Nething et al., 2020; Zhao et al., 2020; Arab et al., 2021).

5 Research needs and future directions

The recent surge in lunar exploration by several nations and continuing research on lunar samples have encouraged scientists to think more about ISRU. Regolith generated by meteoroid impacts is the most accessible resource on the Moon's surface. By reviewing its properties, lunar regolith is the most suitable material with applicable grain size and mineralogy. Inspired by the natural geological cementation process by carbonate minerals, the artificial production of bricks on the Moon using *in situ* sand-sized regolith and mimicking MICP process shows promise. The mineralogy of material used in the artificial bio-brick experiments was mostly quartz or silica, and 0.4–1.0 M $CaCl_2$ was added to serve as a Ca^{2+} source for the precipitation of carbonate minerals (Table 2). Minerals such as plagioclase and pyroxene in regolith on the Moon happen to contain Ca, which can be used as a Ca^{2+} source. Artificially cemented bio-bricks made out of sands closely resemble their natural counterparts with respect to the failure mechanism at micro-scale (Table 2). Few studies, in fact, have tested the idea of consolidating lunar simulant soil in the form of a brick with non-trivial strength properties (Dikshit et al., 2020; Kumar et al., 2020; Dikshit et al., 2022). However, the average mean particle size for regolith (D_{50} = 72 μm) is approximately one order smaller than those sands (0.36–0.73 mm) used to produce artificially cemented bio-bricks in Table 2. Sizing down the particles in laboratory conditions might help future field application.

Although MICP has been successfully demonstrated in the laboratory for many cases, its real application in the field of ISRU faces huge challenges. Since the conditions on the Moon cannot be controlled as in a laboratory, microorganisms are likely to suffer from harsh environments. Therefore, it is essential to establish a qualitative and quantitative simulation to manufacture bio-bricks by selecting a suitable and effective microbial species for the Moon's extreme conditions. Microbes must overcome various stresses that suppress their ability to grow or their basic survival. Microbes have developed strategies such as the formation of cysts and spores, expression of repair enzymes for damage, changes in cellular membranes, and synthesis of molecules for relieving stresses for better survivability (Haruta and Kanno, 2015). The same species might present different microbial survivability under different conditions. Survival strategies can change from normal to micro-gravity, which may change microbial survivability. We must consider the fact that most microbial cells that provide nucleation sites for carbonate formation on Earth might change on the Moon, affecting dynamic cementation. In order to test the promise of MICP enabled bio-consolidation in extra-terrestrial conditions, it is essential to conduct low-gravity tests. Moreover, the generation of undesired by-products must be avoided. The upscaling of MICP from the laboratory to lunar application might present technical difficulties in obtaining homogeneous treatment. Finally, a substantial amount of water is needed for the bio-cementation process. Interestingly, water ice (H_2O) and hydroxyl radicals (OH-) have been recently identified on the lunar surface (Li et al., 2018; Rubanenko et al., 2019). Although the source of water ice accumulating in permanently shaded regions on airless bodies in the inner Solar System still remains undetermined, the existence of water on the lunar surface would save *in situ* bio-cementation considerable costs. Urea is another indispensable component of ureolysis-based MICP, and is the primary choice of bio-brick production. Lambert and Randall (2019) have successfully used human urine as a sole source of urea for manufacturing bio-bricks. This could thus provide a potentially critical solution for obtaining urea *in situ*. Alternative cell-free systems should also be considered to completely avoid these technical challenges associated with culturing microbes for cell-based MICP. The cell-free urease system reported by Arab et al. (2021) serves as a good starting point in this direction. If successful, such catalysts with active enzymes could even be manufactured on Earth and cost-effectively shipped to the field of ISRU.

Author contributions

HZ designed this review due to her geology and geomicrobiology background as well as other published works in this area. HZ reviewed the literature, organized the structure of the manuscript, and wrote the manuscript. SN wrote and revised the manuscript. MX revised the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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