Review article: Prospects for creating building materials based on regolith

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Abtsract

The article discusses the prospects for using lunar regolith for space construction with a promising approach to ensuring a sustainable human presence on the Moon and beyond. The key concept involves the use of resources in place, where local materials such as regolith are used to reduce the need to transport materials from Earth. As a building material, regolith can be processed to create durable building materials using 3D printing and other methods such as melting or sintering. Regolith structures can protect astronauts from extreme temperatures, radiation, and micrometeorites. Regolith contains oxygen, which can be extracted for life support and fuel production. It also contains metals, such as iron, aluminum, and titanium, which can be used to create tools and infrastructure. Construction based on regolith will contribute to the creation of self-sufficient infrastructure on the Moon and Mars. The ability to use local resources to create living quarters, produce oxygen, and generate energy will minimize dependence on supplies from Earth. Current research focused on improving the methods of mining and processing regolith, as well as on the development of new composite materials for space construction, is analyzed. These innovations may also be applicable to Mars and other celestial bodies. The prospects for the development of regolith-based materials for extraterrestrial construction are extremely important for future space missions and the colonization of other planets. The use of regolith makes it possible to build infrastructure, provide energy and life support needs, making human settlements on the Moon and Mars a reality. The development of technologies for the use of this material will continue, creating new opportunities for space exploration.
Keywords: space engineering, silicate, chemical properties, modelling extraterrestrial construction
Kulcsszavak: űrmérnökség, szilikát, kémiai tulajdonságok, földön kívüli építkezés modellezése

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1. Introduction

Today, the study of extraterrestrial bodies is one of the main activities of the largest national space agencies and commercial aerospace companies. Over the past 100 years, humanity has reached the Moon and Mars. The Moon is currently the most explored extraterrestrial object. For a long time, the exploration of the Earth's satellite was limited by the high cost of missions and the lack of resources for a long stay of humans on the Moon.

The prospect of a multi-planetary future for humanity has become more attainable thanks to significant investments and innovations in the aerospace industry. The European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) have announced their commitment to provide opportunities for people to live permanently in special habitats on the Moon or Mars by 2040. NASA's Artemis program aims to land astronauts on the Moon to create a permanent human presence and support scientific research. In addition, these missions will serve as a testbed for technologies that will be used for future missions to Mars. Long-term human presence on the Moon to accelerate research requires the creation of a developed infrastructure using available resources, including lunar rocks.

The study of lunar rocks has shown that the most accessible local material is lunar soil, the composition of which varies slightly depending on the sampling site (*Fig. 1*). Lunar soil (regolith) is a layer of loose, heterogeneous material that covers the lunar surface and can reach a thickness of up to 15 meters. It consists of dust, rock fragments, micrometeorites, and the remains of other space bodies that have been bombarding the Moon for billions of years. Unlike the Earth, the Moon has no atmosphere, so all meteorite impacts do not dissipate but leave traces in the form of regolith [1].

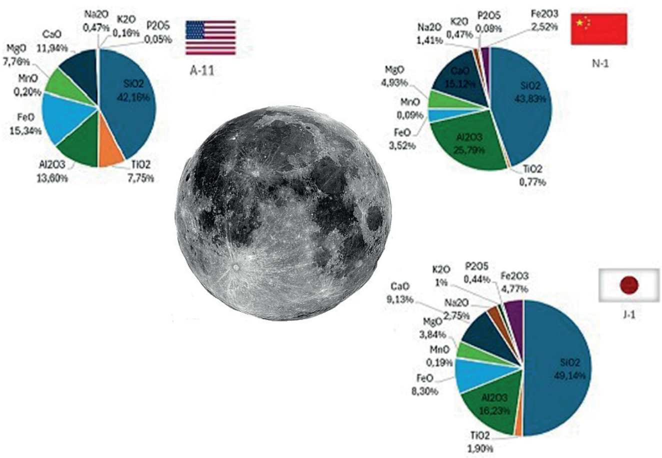

Fig. 1 *Illustration of the results of lunar soil studies by various space missions based on simulations according to [3,4,5]*
1. ábra *A Holdtalaj különböző űrmissziók általi vizsgálatainak eredményeinek illusztrációja [3,4,5] szerinti szimulációk alapján*

Modern terrestrial technologies allow for the creation of strong and durable building materials, but due to the high cost of transportation to the Moon, their production must be carried out directly on site from lunar rocks. According to the vast majority of researchers, regolith has great potential for use as a building material due to its availability and useful properties: resistance to high temperatures and extreme temperature changes, chemical inertness, and the ability to protect against radiation [2].

The use of extraterrestrial resources, such as lunar regolith, to build infrastructure on the Moon is a key aspect to ensure the sustainable and affordable development of lunar bases. This will reduce the cost of missions, reduce dependence on transportation of materials from Earth, and make it possible for people to live on the Moon for a long time.

2. Analysis of research and publications

2.1 Chemical and mineral composition of lunar regolith

Real lunar regolith is complex in composition and usually contains large amounts of basalt fragments and their minerals such as pyroxene, olivine, and ilmenite, while those collected from the highlands contain numerous fragments of anorthosite rocks and plagioclase feldspar [6]. In addition, micrometeorite impacts create tiny glass beads that are often found in regolith.

It should be noted that mineral building materials produced on Earth require a large amount of water and significant energy consumption, which makes it impossible to use them on extraterrestrial objects [7]. Unlike terrestrial soil, lunar regolith does not contain organic materials or water. It is completely dry and lacks the biological activity that characterizes terrestrial soil.

It is quite clear that to prepare samples of building materials made from regolith, access to the appropriate amount of raw materials is very limited. Therefore, an important element of research is the creation of mixtures that imitate the mineral composition of lunar regolith. Preparation of simulants is a difficult task, firstly, because of the need to take into account a large number of characteristics, not only possible changes in the chemical composition of rocks sampled in different areas of the Moon, and secondly, because of the limited availability of relevant data.

The most important characteristics of any rock (apart from morphological features) are its chemical and mineralogical compositions, mechanical and physical properties.

The chemical composition of the lunar regolith samples and simulants according to [3-5, 8-10] is given in *Table 1*.

Sample code	Component content per calcined substance, wt. %										
	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Fe_2O_3
A-11	42.16	7.75	13.60	15.34	0.20	7.76	11.94	0.47	0.16	0.05	–
A-16	45.20	0.58	26.40	5.29	0.70	6.10	15.32	0.52	0.14	0.12	–
NU-LHT	46.60	0.12	21.55	5.08	0.09	9.50	12.60	0.97	0.12	0.07	–
C-1	49.24	1.910	15.80	11.47	0.14	8.72	7.25	3.08	1.03	0.30	–
J-1	49.14	1.9	16.23	8.3	0.19	3.84	9.13	2.75	1.00	0.44	4.77
N-1	43.83	0.77	25.79	3.52	0.09	4.93	15.12	1.41	0.47	0.08	2.52

Table 1. *Chemical composition of lunar regolith samples and simulants according to the results of works. [3-5,8-10]*
1. táblázat *A holdi regolit minták és szimulánsok kémiai összetétele az irodalmi eredmények alapján. [3–5,8–10]*

A similar feature can be found in the samples, namely, a large proportion of SiO_2, which indicates the potential of extraterrestrial regolith for the preparation of building materials. Silicon dioxide is the main component, which indicates the presence of silicates, the most common minerals in lunar regolith. The high content of titanium dioxide in some samples (A-11) indicates basaltic rocks from lunar seas that are rich in ilmenite. Aluminum oxide is often associated with plagioclases, such as anorthosite, which are characteristic of the lunar crust. A high content of iron oxide indicates the presence of iron-bearing minerals such as ilmenite, pyroxenes, and olivine. Low alkaline oxide content is typical for lunar rocks, as they are poor in volatile elements.

We should note that all samples of regoliths simultaneously contain oxides of CaO, FeO, Al_2O_3, and SiO_2 in large quantities (over 10 %). In addition, certain samples (A-11, NU-LHT) also contain a significant amount of MgO and TiO_2 oxides. The authors of [14] proposed the concept of creating new multicomponent systems for use as building materials.

The multicomponent oxide system CaO-SiO_2-Al_2O_3-Fe_2O_3-MgO is very important for wide application in various technologies for the production of ceramic, composite, and glassy materials, as well as metallurgy. However, there is currently no data on the structure of multicomponent systems containing more than 3 phase-forming oxides, which requires appropriate research to determine their structure.

The figurative points of some regolith compositions reduced to the corresponding three-component systems with a 100% recalculation of the composition are shown in *Fig. 2* [11-13].

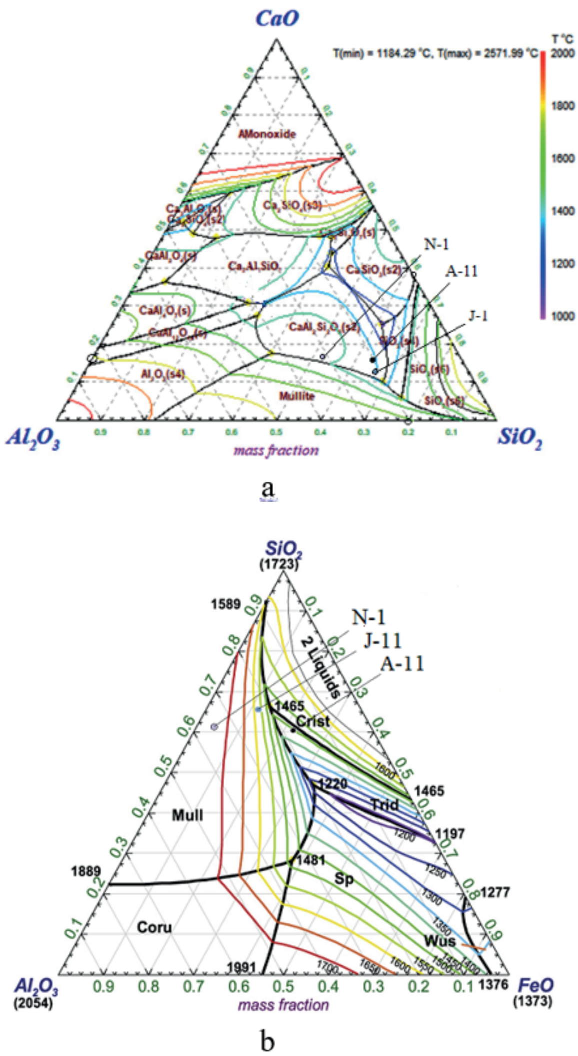

Fig. 2 Three-component oxide systems that are promising for obtaining materials based on regolith a - SiO_2-Al_2O_3-CaO system [11,12], b - SiO_2-Al_2O_3-FeO system [13]

2. ábra Háromkomponensű oxidrendszerek, amelyek ígéretesek regolit alapú anyagok előállítására a – SiO2–Al2O3–CaO rendszer [11,12], b – SiO_2–Al_2O_3–FeO rendszer [13]

A number of articles are planned on this topic related to the fundamental study of promising multicomponent systems for use as building materials in the space industry with the potential for 3D printing and the expansion of the areas of building materials production.

2.2 Properties of regolith

Lunar regolith has several unique physical and chemical properties that distinguish it from Earth's soil. These properties are important for understanding the lunar geology and planning future exploration missions, as well as utilizing its resources.

Regolith consists of very fine dust (often called lunar dust) with particle sizes ranging from submicron to several millimeters. Lunar dust is very abrasive because it is not subject to atmospheric or water weathering, which means that the particles retain sharp edges.

On the surface, regolith has a low bulk density (1.5 g/cm³), but at deeper levels it becomes denser. The upper layers of regolith are porous, with voids between the particles.

Due to the limited amount of real lunar material, the research was mainly conducted using regolith simulants. The simulants are formulated to mimic lunar soil samples obtained during the Apollo missions (the Apollo program made a manned landing on the Moon and conducted an on-site inspection; ~380 kg of lunar regolith samples, including basalt, breccia, plutonite, soil, core, and other materials, were delivered to Earth for further scientific research [15]).

In addition, lunar regolith is also rich in glass fragments and their agglutinates formed by meteorite impacts. Therefore, basaltic lava or volcanic ash is commonly used as a raw material for lunar regolith simulants, such as JSC-1A and BP-1 in the United States, KLS-1 in Korea, UoM-B&M in the United Kingdom, and DNA-1 in Italy. Widely used simulators in China, such as CAS-1, CLRS-1 and 2, TJ-1, and NEU-1a and b, are also made on the basis of basaltic volcanic soriate [16].

When it comes to practical use in extraterrestrial environments, it is important to evaluate the properties of various building materials and select appropriate materials based on specific construction requirements. These requirements mainly stem from the extreme extraterrestrial conditions that can cause difficulties in both the preparation and application process. Specifically, extreme extraterrestrial conditions include space debris, hard vacuum, low gravity, temperature fluctuations, weak atmosphere, and extreme radiation. Extraterrestrial construction materials must provide a safe and stable environment for astronauts during the construction of extraterrestrial structures. Accordingly, the requirements for the properties of building materials can be divided into three categories: mechanical, thermal, optical, and radiation protection.

2.2.1 Mechanical properties

Almost all samples of extraterrestrial structures were tested for compressive strength. In addition, to determine impact resistance, Allende et al. conducted 19 experiments with high-speed impacts [17]. Analytical power-law relationships were obtained to predict transient crater dimensions such as volume and diameter based on projectile characteristics such as diameter, density, and velocity. The scaling exponents determined for the volume and diameter of transient craters in BSC are comparable to those in quartzite, sandstone, and basalt, indicating that cratering in BSC is largely driven by projectile kinetic energy, as expected for cohesive low-porosity materials.

The nanohardness of samples of molten regolith was investigated by Zheng et al. [18], in which a nanoindenter applied a force of 0.1 N to the sample. The coefficient of thermal expansion ranges from 6.42×10^{-6} 1/°C to 9.82 °C $\times 10^{-6}$ 1/°C between the initial temperature (30 °C) and the softening temperature (919 °C), and the thermal conductivity and specific heat capacity are close to concrete. At room temperature, the compressive strength and flexural strength are 67.1 ± 31.9 MPa and 100.7 ± 31.3 MPa, respectively, which are much higher than those of traditional cement on Earth. The microhardness of the SPS, DLP, and laser-sintered samples was tested by other researchers using Vivtorinox hardness testers. The fatigue curve of the "lunar cement" was obtained by Su et al. The fatigue resistance of JSC-1a-based IOH is higher than that of typical steel-reinforced concrete under the same loading conditions, especially when the stress amplitude is relatively high.

Thermal and optical properties of building materials also have a significant impact on determining their suitability for building and life safety.

2.2.2 Thermal properties

The low values of the coefficient of thermal expansion (CTE) of the material obtained by using regolith will make the stresses in the structure arising from the thermal load on it acceptable. Accordingly, Kim et al. studied the coefficient of thermal expansion of regolith samples sintered in a microwave oven [20]. With an increase in sintering temperature, linear shrinkage and density increased, while porosity decreased. Structural changes in the sintered samples were characterized by scanning electron microscopy and X-ray diffraction. Unconfined compression strength tests showed that the mechanical strength increased significantly with increasing sintering temperature, with the highest strength of 37.0 ± 4.8 MPa being achieved at 1120 °C. The sintered samples had a coefficient of thermal expansion of approximately 5×10^{-6} °C-1, which was well preserved even after cyclic temperature loads from -100 to 200 °C.

In addition, good thermal insulation properties and adequate light absorption will allow creating habitable conditions in the room. The diffusive heat capacity and thermal conductivity of various sintered samples were investigated by Fateri et al. [21]. Thermal conductivity measurements showed that the thermal conductivity increases for each individual sample (regardless of the sintering method) by about 10% in the temperature range from 25°C to 150 °C. The laser sintering of JSC-2A showed the highest thermal conductivity of approximately 1.1 Wt/m × K at room temperature compared to the other sintered samples.

2.2.3 Optical properties

The optical properties of regolith powders and corresponding SPS samples were tested by Licheri et al. They compared the optical properties of sintered samples and the original regolith powders, taking into account spectral absorption/emission, integrated solar absorption, and integrated thermal radiation, evaluated in the temperature range representative of ISRU applications, i.e. from 100 to 1300 K. It was found that sintering changes the optical properties of regolith depending on the process, with sintered pellets exhibiting increased solar absorption and thermal emission compared to the original powders [22].

2.2.4 Radiation properties

Radiation protection properties play an important role when considering extreme radiation in outer space. Building materials with good radiation protection properties can support the long-term stay of astronauts in space. Montes et al. [23] conducted a simulation to study the protective properties of geopolymer concrete against proton radiation. Comparison of the modeling results made it possible to independently assess the required level of regolith protection to cope with primary and secondary radiation. For galactic cosmic rays, a value of > 200 g/cm^2 is estimated to result in a >50% reduction in throughput. For solar radiation, several tens of g/cm^2 can reduce the dose by more than an order of magnitude. To protect against neutron radiation, lunar regolith simulator samples were tested by Meurisse [24]. Neutrons were produced in the process of proton splitting with an energy of 800 MeV. The modeling results showed that the mechanical and chemical properties allow for sufficient radiation protection of the crew inside the lunar living quarters without additional requirements. To protect against heavy ions, both lunar regolith and regolith simulators were tested [25]. Measurements and model calculations show that a small amount of lunar soil provides significant protection against primary proton nuclei with solar particle energy, with a small residual dose from surviving charged fragments of heavy rays.

The data from the above studies are a valuable source for determining the preferred types of building materials when they are made from regolith.

2.3 Promising areas for the use of building materials from regolith

Regolith is considered a potential resource for future lunar bases. Extraterrestrial regoliths can serve as primary raw materials for the production of building materials. Through the use of remote sensing and experiments on real samples, a certain understanding of lunar regoliths has been accumulated.

Due to its accessibility, regolith as the main raw material is promising for the construction of extraterrestrial structures. With chemical components similar to those of terrestrial rocks, regolith can be used to make concrete or other composite materials, as well as to produce brick building blocks. In addition, useful chemical components of modified admixtures, such as S and Mg, can be extracted in situ from regolith to reduce the burden of extraterrestrial transportation, and can be directly used as radiation and heat shielding layers in structures, which helps reduce the cost of transporting materials from the Earth [2].

Concrete-like materials have the highest potential for use in extraterrestrial construction due to their natural mechanical properties, stability, and durability. Therefore, building materials that use few resources such as geopolymers while providing sufficient protection against harsh lunar conditions are of interest.

The production of glass from lunar regolith also has a wide range of applications, including substrates for semiconductors, windows, pipes, and other molded objects. Such glass can be used for thermal insulation foams and heat shields, which contributes to the development of lunar infrastructure, including habitat modules and scientific laboratories.

Glass production involves three steps: melting sand, forming hot glass, and heat treatment to prevent cracks. On the Moon, raw materials are limited to basalt sand, so the properties of glass depend on its composition. Basalt glass is formed by melting basalt material and occurs naturally both on Earth (e.g. obsidian) and on the Moon. The content of basalt glass in regolith can affect the production process by reducing the temperature and energy required for melting.

Mirror production on the Moon requires high-quality glass and the application of a reflective material such as aluminum, which is highly reflective (~90%) in the visible spectrum. Silver is less reflective below 400 nm. To achieve optimal reflective characteristics, an aluminum layer thickness of ~100 nm is required. To produce a mirror surface with an area of 100 m^2 and a density of 2700 kg/m^3, 27 g of aluminum with a purity of 99.999% is required. Taking into account losses, less than 1 kg of high-quality aluminum needs to be purified on Earth and sent to the Moon, which is a viable approach for a lunar mission [26].

Thus, using the material basis provided by extraterrestrial regolith simulators, dozens of methods for preparing regolith-based building materials have been proposed by various researchers. According to the molding principle, building materials can be produced in three main ways: concrete curing, additive manufacturing, and regolith sintering/melting. Concrete materials for extraterrestrial construction mainly include sulfur, biopolymer, geopolymer, polymer, and silicate [27-31].

Compositions of this system are the basis of high alumina and Portland cement, ceramic bricks and tiles, mullite, forsterite, and cordierite refractories, foam glass, and steel production wastes. Understanding the thermodynamics of this system and the complex interactions between these oxides is crucial for its application. Traditionally, this has been done using the well-known binary or ternary diagrams, where the interactions between two or three components are considered simultaneously. However, modern methods of theoretical research allow obtaining information on the susceptibility state of systems that include four components [32].

2.4 Application of additive technologies

With the rise of additive manufacturing (3D printing), complex geometries can be created directly from a computer design file. This process is defined both on Earth (e.g. obsidian) and on the Moon. The content of basalt glass in regolith can affect the production process by reducing the required temperature and energy for melting.

Analysis of research shows that the main extraterrestrial construction processes are carried out by two methods, namely additive manufacturing (3D printing) or prefabrication using sintered regolith bricks. From the perspective of extraterrestrial construction, 3D construction methods have become the most promising because of their environmental friendliness, given the huge economic costs of extraterrestrial transportation. Accordingly, extraterrestrial regolith is the main raw material available. The value of lunar regolith samples prevents the use of destructive experiments for construction research.

3D printing parts for space exploration is not just an Earth-based activity. For years, NASA and other space agencies have been printing polymer parts on the International Space Station.

Initial studies have shown the feasibility of processing lunar simulant powders using various bulk ceramic sintering methods, including traditional sintering, microwave sintering, solar sintering, 3D printing, direct laser production, selective laser melting, and glass formation techniques [2].

The abundance of regolith makes it a promising material for the production of building materials, such as lunar concrete or 3D printed structures for housing.

Several ISRU ("In-Situ Resource Utilization") methods have been proposed in the research, which translates to "in-situ resource utilization". In particular, several techniques involve the creation of concrete and cement materials. The authors of [33] proposed a 3D printing process with Sorel cement (magnesia cement) for construction on the Moon, but this technology required significant amounts of chemicals and water. Researchers [34] have developed a stone-like material using phosphoric acid that is promising for Mars, but not for the Moon, due to the need to transport water and acid.

In [35], the researchers focused on analyzing the properties of NU-LHT-2M that could be most critical for the selective laser melting process. The main focus was on the granulometry and the presence of water in the powder, due to the influence of an uncontrolled atmosphere during previous tests.

To avoid contamination due to the presence of water as much as possible, it was decided to place the batch in a thermal vacuum chamber for 24 hours, after which it was stored in sealed silicone containers. The presence of water proved difficult to completely avoid, but the experiments were not spoiled by the small residues left in the used powder. The second main problem was the grain size present in the batch, which should have been on average 100 μm with maximum values of about 1 mm, while the results obtained with the Malvern Mastersizer 2000 (particle size distribution analysis instrument) showed a slightly offset size of up to 250 μm.

The use of a 250Wt fiber laser at 1070 nm in previous work has shown that it is capable of effectively melting the JSC-1A simulant and producing strong 3D printed objects while operating at approximately 20% of its maximum power. The reflectivity values at the desired wavelength are not sufficiently different to justify the choice of a different laser type, so it was not changed in this work. The chemical composition of the two simulants should be different since they are designed to be similar to the soil of different regions of the Moon, but knowing some of the main components of the powder provides clues to fine-tune the process to improve it [36].

One of the missing information about 3D printing with lunar regolith simulant is the compressive strength of the material, which is introduced in this paper but needs further development to obtain accurate results suitable for the actual construction process with 3D printed lunar dust. In this study, the strength was measured using a strain gauge connected to a hydraulic press that imposed displacement values on a moving head. The material showed brittle behavior, as expected for ceramics, and strength comparable to concrete, reaching medium ultimate stresses.

One of the main advantages of this technology is the ability to print high-quality parts very quickly and without the need for tools. Given the high resolution and relative density of the samples, the ability to produce extremely precise, small and complex porous regolith parts such as catalysts and filters will allow for a significant breakthrough in the long-term space development of mankind.

Building 3D printing has significant potential for building in such harsh environments due to its robotic and autonomous capabilities. NASA is considering this technology for construction outside the world, and in 2015-2019 organized the "3D Printed Environments Competition", which awarded a total of $5 million to teams with construction solutions. In 2020, NASA's Johnson Space Center 3D printed a 1,700-square-foot environment (Mars Dune Alpha) to simulate the habitat of Mars. To realize an efficient planetary construction process, resources on the Moon and Mars must be used as printing materials. For example, sulfur concrete is an anhydrous alternative material that is well suited for planet construction. Elemental sulfur can be extracted from sulfate-sulfide mineral deposits on the Martian or lunar surface using ISRU technologies.

2.5 Further experiments and research on this topic

Within the framework of this research topic, a series of scientific publications is planned. In the subsequent stages of the study, attention will be focused on the in-depth investigation of multicomponent systems, particularly ternary and quaternary oxide systems such as SiO_2–Al_2O_3–FeO and SiO_2–Al_2O_3–CaO. The primary objective is to explore phase interactions within these systems, conduct thermodynamic modeling, calculate equilibrium phase diagrams, and provide a thermodynamic rationale for the formation of target crystalline phases with desired properties.

Theoretical results obtained from this study will serve as a foundation for the rational selection of material compositions, which will subsequently be synthesized under laboratory experimental conditions. For each selected composition, melting diagrams will be constructed to determine the temperature ranges of phase formation, as well as to establish optimal technological parameters for their synthesis, including heat treatment regimes and cooling conditions.

In addition to traditional ceramic processing methods such as forming and sintering, the developed compositions will be evaluated for their suitability in modern additive manufacturing techniques, particularly 3D prototyping. This approach will enable the assessment of the materials' potential for producing components with complex geometries and their integration into space and advanced construction technologies, taking into account structural integrity, thermal resistance, and functional performance requirements.

These investigations are aimed at establishing a scientific foundation for the development of efficient and energy-viable technologies for the in-situ fabrication of construction elements—directly on the surface of celestial bodies—by utilizing locally available resources.

The expected outcomes are anticipated to hold fundamental significance for materials science, ceramic chemistry, and the engineering of future space infrastructure.

3. Conclusions

The research analysis suggests a construction concept based on the use of in situ resources, given the high cost of extraterrestrial transportation.

In the future, with the development of technology and increased experience in the use of lunar resources, the opportunities for creating sustainable and long-term lunar bases will only increase. This opens up prospects for further exploration of the Moon and other space bodies, as well as for the development of new technologies that can be applied both on Earth and in other space missions.

A critical aspect for space applications is the appropriate technology, especially 3D printing technology, which has advantages such as energy efficiency, automation, design freedom, and reduced production time. This is an ideal solution for the production of lunar and Martian bases, but more efficient production methods from local resources need to be developed and the 3D printing process needs to be optimized.

Thus, extraterrestrial construction based on regolithic materials is quite achievable and promises to open up new horizons for humanity. NASA's program and other missions demonstrate the possibility of creating a permanent human presence on the Moon and Mars. The use of local resources, such as lunar regolith, to produce building materials on site, as well as 3D printing and ISRU technologies, make the construction of lunar and Martian bases a reality.

Geopolymers obtained from local lunar materials are a promising building material for the construction of lunar bases. They have high strength, resistance to extreme lunar conditions, and minimal water requirements, making them an ideal choice for extraterrestrial construction. Geopolymers can be used for direct construction with minimal human involvement, which is critical to eliminate the costly transportation of construction materials and astronaut activities.

Prospects for further development in this area include the development and improvement of technologies for using local resources, such as lunar regolith, to build infrastructure on the Moon. This will reduce the cost of missions, reduce dependence on the transportation of materials from the Earth, and make it possible for people to live on the Moon for a long time. In addition, the development of new technologies, such as additive manufacturing and generative design, opens up new opportunities for creating sustainable and long-term lunar bases.

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